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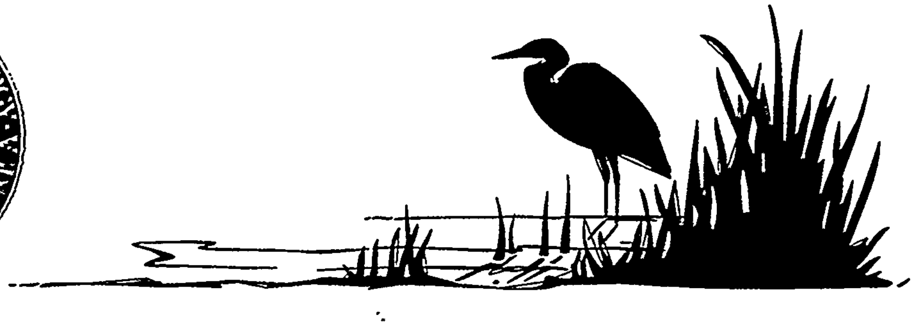

DOCUMENTING COST AND PERFORMANCE FOR ENVIRONMENTAL REMEDIATION PROJECTS

Department of Energy
Office of Environmental Management

August 8, 1996

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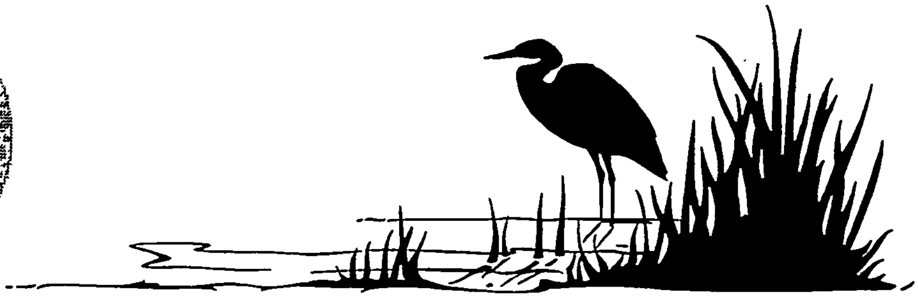

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FOREWORD

The purpose of this DOE guide is to facilitate the use of consistent procedures to document cost and performance information for projects involving the remediation of media contaminated with hazardous and radioactive waste. It provides remedial action project managers with a standardized set of data to document completed remediation projects. Standardized reporting of data will broaden the utility of the information, increase confidence in the effectiveness of future remedial technologies, and enhance the organization, storage, and retrieval of relevant information for future cleanup projects.

The foundation for this guide was laid down by the Federal Remediation Technologies Roundtable (FRTR) in their publication, *Guide to Documenting Cost and Performance for Remediation Projects*, EPA-542-B-95-002. Member agencies of the FRTR include the U.S. EPA, the U.S. DoD, the U.S. DOE, and the U.S. DOI. All the member agencies are involved in site remediation projects and anticipate following the guidance provided in the above reference. Therefore, there is much to be gained for DOE to be consistent with the other member agencies as it will be easier to compare projects across different agencies and also to learn from the experiences of a wider spectrum of prior completed projects.

Over the last several months, we have been discussing performance specification contracts, which outline what we want the contractor to accomplish and when we want it, while challenging the contractor to decide on how it is accomplished. The advantage of these performance specification contracts is the recognition that the commercial sector will find the most efficient and least expensive way to perform cleanup. We also want to see more design/build/operate contracts used where applicable in which we pay the contractor for the quantity of waste processed. In order to achieve these goals, it is important that we work together with the regulators on developing "technology neutral" Records of Decisions (ROD). In these RODs, instead of specifying a specific technology solution, a list of viable technologies would be provided from which the contractor could choose from to accomplish the remediation goal stated. We need to work with the regulators in identifying those technologies that are viable, those in which we have confidence in their performance. I believe that this guidance on Documenting Cost and Performance for Environmental Remediation Projects is the tool we can use to provide the documentation on remediation projects that will give us that level of confidence we and the regulators are seeking when faced with making the decision on a technology solution.

I trust this guide will benefit program manager's confidence in the performance of technologies for specific site cleanups. If you have suggestions please call us. As you complete a report, send a copy to Mary McCune of my staff. Her phone number is (301)903-8152.

James Owendoff
Deputy Assistant Secretary
Office of Environmental Restortaion
U.S. Department of Energy

SECTION I
INTRODUCTION

Purpose. This guide and EPA 542-B-95-002 provide the procedures for formally documenting and reporting cost and performance information from completed, full-scale DOE waste cleanup projects. The goal is to highlight a single technology or system. These documents provide information needed by the project technical manager for scoping the documentation effort. These documents also provide guidance for the types of data to collect and how they are presented.

EPA 542-B-95-002 provided the first recommended procedures for documenting results from completed full-scale hazardous waste site remediation projects. The DOE has adopted these procedures and has expanded them resulting in this guide.

Applicability. In order to evaluate new and innovative remediation technologies, the DOE is involved in several field demonstrations which involve extensive data collection and documentation. The DOE is also performing many full-scale cleanups at its sites. This guide applies to all DOE facilities having responsibility for hazardous, toxic, and radioactive waste (HTRW) investigation, design and remedial action as well as technology demonstrations. In addition, in order to receive consideration for future DOE cleanup contracts, potential vendors should provide a cost and performance study describing previous work.

References.

Guide to Documenting Cost and Performance for Remediation Projects, Federal Remediation Technologies' Roundtable, EPA 542-B-95-002, March 1995.

Discussion.

The recommended documentation procedures in this guide are relatively straightforward. The parameters were chosen because they are practical and useful, and the requested information will be relevant to future projects during the remedy selection process. This guide addresses both conventional and innovative treatment technologies. Information on conventional technologies serves as a useful baseline against which data from innovative technologies can be compared.

The DOE has worked with other member agencies from the Federal Remediation Technology Roundtable (FRTR) to prepare guidance on this important issue. When completed, each Cost and Performance Report will assist environmental remediation designers, planners and decision makers to effectively evaluate technology performance; identify the magnitude and impact of actual and potential issues affecting cost and performance of environmental remediation technologies; improve data collection and dissemination; and aid in the review /evaluation of the effectiveness of the remedial action by providing a record of conditions and activities in a readily accessible format. Captured within 10-15 pages, the report will present a synopsis of information on a remedial action at a site to enable a reader to assess the relevance of the completed action and its applicability to future remedial actions at similar sites. This information will be useful in making comparisons between innovative and conventional treatment technologies as well as documenting their long-term performance and maintenance.

The quality of any individual documentation report will depend upon the set of data available at the site. The operations office and the Remediation contractor are jointly responsible for defining the quality of the documentation report and submittal prepared under this guide.

It is recognized that each remediation project is different. Consequently, the data that is appropriate to collect at each site will vary. The site remediation team must judge whether information requested in each section of this guide is appropriate. If treatability studies are part of the remediation effort, they may be included within the report.

Responsibilities. The preparation of the remediation cost and performance documentation report (with the content and in the format shown in this guide) is the responsibility of the appropriate operations offices. If the operations office is using a Integrating contractor and a remediation contractor for the site, the latter may be required to prepare the documentation report. Information for preparing the documentation report will be from two sources: (1) the information available from all site activities prior to the actual remediation and (2) information required from the remediation contractor. The latter information shall be specified by the operations office or the Remediation contractor, through inclusion of an edited guide specification with the bid package provided to the remediation contractor. The operations office or the Remediation contractor shall develop the specifics for the Cost and Performance Report Specification after referring to this guide and the information available from previous site activities.

Report Format. Information available from a project should be reported according to the sections listed in this guide. Appendix A provides a hypothetical example of a completed cost and performance report based on this guide.

SECTION 1
SUMMARY

The summary shall contain a brief overview of the Cost and Performance Report. It shall include a brief description of the historical activities that generated the need for environmental restoration, average characteristics of the contaminated media pre- and post-treatment, and key performance and cost results.

SECTION 2
SITE INFORMATION

Identifying Information. Indicate major facility name, location, site name (e.g., operable unit number, waste area group etc.), regulatory authority (CERCLA, RCRA etc.), and driver (e.g., record of decision - ROD, interim ROD, removal action, corrective action etc.). Include location maps (area map, specific location within area).

Technology Application. Indicate whether the remedial strategy resulted in an entire site remediation, was a partial cleanup of the site, or was a technology demonstration or treatability study. Identify the period of operation. Provide the quantity of material treated during the remedial or removal action.

Site Background. Provide a bulletized description of the historical activities that generated contamination at the site. As requested by the FRTR, include the Standard Industrial Classification (SIC) code for DOE activities (9631A) in order to facilitate the use of possible future electronic searches.

Site History. Provide a brief site history including the primary and secondary activities, waste management practices (using the standard terminology below), years of operation, source(s) of contamination and primary contaminants.

Waste and Materials Management Practice That Contributed to Contamination

- Aboveground Storage Tank
- Co-Disposal Landfill
- Open Burn/Open Detonation Area
- Discharge to Sewer/Surface Water
- Disposal Pit
- Dumping - Unauthorized
- Explosive / Ordnance Disposal Area
- Incineration Residuals Handling
- Industrial Landfill
- Lake or River Disposal
- Landfarm/Land Treatment Facility
- Waste Pile
- Waste Treatment Plant
- Accelerator
- Uranium Manufacturing Facility
- Fuel Reprocessing Facility
- Injection Wells
- Uranium Milling
- Petroleum, Oil, Lubricant (POL) Line
- Recycling (other than a primary operation)
- Road Oiling
- Spill
- Storage-Drums/Containers
- Surface Disposal Area
- Surface Impoundment/Lagoon
- Underground Injection
- Underground Storage Tank
- Other (explain)
- Uranium Enrichment Facility
- Plutonium Manufacturing Facility
- Production Reactor

- Research Reactor
- Administrative Building
- Other Storage Building / Warehouse
- Laboratory
- Trailer
- Security Building

Briefly describe the results of the site investigation that contributed to understanding site conditions, samples collected, and results).

Site Logistics/Contacts. Identify appropriate contacts, addresses, and telephone numbers for the cleanup.

— Site Management
— Project Manager
— State Contact
— Vendor(s)

SECTION 3
MATRIX AND CONTAMINANT DESCRIPTION

<u>Matrix Identification</u>. Indicate the type(s) of matrix(ices) processed by the remediation system during this application, using the following standard terminology that were derived from EPA's VISITT (Vendor Information System for Innovative Treatment Technologies) database and adopted by the FRTR. VISITT 4.0 is downloadable from EPA's home page on the WWW or from EPA's CLeanUp INformation (CLU-IN) BBS at (301) 589-8366 (modem) / -8368 (voice). The use of standardized terminology for matrix and contaminant descriptions will facilitate the storage and retrieval of information, including the future use of electronic search methods.

- Soil (in situ)
- Soil (ex situ)
- Sludge
- Solid (e.g., slag)
- Debris
- Sediment (in situ)
- Groundwater (in situ)
- Groundwater (ex situ)
- Surface Water
- Leachate
- Buildings
- Light Non-Aqueous Phase Liquids (LNAPLs)
- Dense Non-Aqueous Phase Liquids (DNAPLs)

<u>Site Geology/Stratigraphy</u> . Provide a description of the site geology noting the particle size distribution, composition, spatial variability (degree of heterogeneity), depth to groundwater, and depth and thickness of bedrock. Potentiometric contours, hydraulic heads, gradients, and/or water table elevations, permeability and/or hydraulic conductivity, porosity, and flow velocity fields should also be provided.

<u>Contaminant Characterization</u> . Indicate the primary contaminant groups that this technology was designed to treat and/or contain in this application, using the following standard terminology. The key specific contaminants of concern under each group should also be stated.

- Organic Compounds
  - — Volatiles (Halogenated)
    - TCE, PCE, DCE, TCA
  - — Volatiles (Nonhalogenated)
    - BTEX
    - TPH
    - Ketones
    - Styrene
  - — Semivolatiles (Halogenated)
    - Dioxins/Furans
    - PCBs
    - Organic corrosives
    - Organic cyanides
    - Organic pesticides/herbicides
  - — Semivolatiles (Nonhalogenated)
    - Phthalates
    - Polynuclear aromatic hydrocarbons
    - Organic pesticides/herbicides
- Inorganic Compounds
  - — Asbestos
  - — Heavy metals
  - — Inorganic cyanides
  - — Inorganic corrosives
  - — Nonmetallic elements
    - (e.g., As)
  - — Radioactive elements
    - (e.g., Cs, Sr, Pu, U, Th, Ra)
  - — Radionuclides (e.g, tritium)
- Mixed Waste (hazardous & radioactive components)
- Radon
- Explosives/Propellants
- Organometallic Compounds
  Pesticides/herbicides

The groups shown above were selected because they are widely recognized. However, the above groupings are not an exhaustive list for all contaminants.

__Contaminant Properties__ List the properties (chemical formula, density, water solubility, distribution coefficients, partition coefficients, toxicity, flammability, boiling point, vapor pressure etc.) of contaminants focused on during the remediation.

__Nature and Extent of the Contaminants__ For the site, provide drawings of contaminant source locations, geologic or hydrogeologic profiles, aquifer characteristics, and contaminant concentration contours showing plume migration as a function of space and time. If drawings are not possible, describe the conditions, as appropriate.

__Matrix Characteristics Affecting Treatment Cost or Performance__

The parameters that affect technology cost and performance can be broadly categorized as being either matrix characteristics or operating conditions. The first category is the subject of this section while the latter category is discussed later in Section 4. Table 3-1 is a comprehensive list of all the matrix characteristics that should be considered and provides an explanation of why each matrix characteristic is considered important to the cost and performance of various remediation technologies. These parameters define desirable information which may help to guide formulation of future field sampling programs during site remediation. These parameters were selected not only because they affect a technology's cost and performance but also because they are commonly measured in practice. The variables represent standard data sets which will allow a consistent comparison of various applications of a particular technology.

Presumably, a site will have selected a primary treatment technology from those listed in Table 4-1. **The next crucial step is for the remediation contractor to choose a set of relevant characteristics** from Table 3-1 that would be applicable to their selected technology. The resulting set of characteristics need to be reported. The ultimate objective is to develop a comprehensive set of parameters which would be of most value to remediation project managers who are attempting to apply results from a completed cleanup to their own particular site.

Other items besides matrix characteristics and operating conditions are important to document because of their potential impact on cost and/or performance. These include the type and concentrations of contaminants, quantity of material treated, cleanup goals or requirements, and environmental setting. For example, for in-situ technologies, geologic and hydrogeologic characterizations should be included in the documentation.

References:

1. U.S. Environmental Protection Agency. Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with Volatile Organic Compound in Soils. EPA 540-F-93-048, September 1993.

2. Federal Remediation Technologies Roundtable. Remediation Technologies Screening Matrix and Reference Guide. EPA/542/B-94/013, Second Edition, October 1994.

3. U.S. Environmental Protection Agency. Vendor Information System for Innovative Treatment Technologies (VISITT) version 4.0.

Table 3-1. Matrix Characteristics / Parameters and Their Potential Effects on Treatment Cost or Performance

Matrix Characteristics	Potential Effects on Cost or Performance
Soil Types	
Soil Plasticity	Plastic soil, when subjected to compressive forces, can become molded into large particles that are difficult to heat [1].
Soil Classification / Stratification	Soil classification is an important characteristic for assessing the effect on cost or performance of all technologies shown in Table 3-1. For example, in soil vapor extraction, sandy soils are typically more amenable to treatment than clayey soils. (See related information under clay content and/or particle size distribution.)
Clay Content and/or Particle Size Distribution	Clay and particle size distribution affect air and fluid flow through contaminated media. In slurry phase bioremediation systems, particle size affects ability to hold media in suspension. In soil washing, the particle size/contaminant concentration relationship affects the potential for physical separation and volume reduction. For thermal desorption systems, clay and particle size affects mass and heat transfer, including agglomeration and carryover to air pollution control devices.
Hydraulic Conductivity / Water Permeability	This characteristic is important in groundwater remediation technologies including in situ groundwater bioremediation, groundwater sparging, and pump and treat systems. Hydraulic conductivity and water permeability affect the zone of influence of the extraction wells and, therefore, affects the number of wells needed for the remediation effort and the cost of operating the extraction wells.
Moisture Content	The moisture content of the matrix typically affects the performance, both directly and indirectly, of in situ technologies, such as bioventing and soil vapor extraction, and ex situ technologies, such as stabilization, incineration, and thermal desorption. For example, air flow rates during operation of soil vapor extraction technologies are affected by moisture content of the soil. Thermal input requirements and air handling systems for incineration and desorption technologies can also be affected by soil moisture content. (Effects of moisture content on operation of technologies is discussed in Table 4.)
Air Permeability	This characteristic is important for in situ soil remediation technologies that involve venting or extraction. Air permeability affects the zone of influence of the extraction wells needed for the remediation effort and the cost of operating the extraction wells.
pH	The pH of the matrix can impact the solubility of contaminants and biological activity. Therefore, this characteristic can affect technologies such as soil bioventing, soil flushing, land treatment, composting, stabilization, and in situ groundwater bioremediation. pH can also affect the operation of treatment technologies (see Table 4). pH in the corrosive range (e.g., <2 and >12) can damage equipment and typically requires use of personal protection equipment and other special handling procedures.
Porosity	This characteristic is important for in situ technologies, such as soil bioventing, soil vapor extraction, and groundwater sparging, that rely upon use of a driving force for transferring contaminants into an aqueous or air-filled space. Porosity affects the driving force, and thus, the performance that may be achieved by these technologies.

Matrix Characteristics	Potential Effects on Cost or Performance
Transmissivity	This characteristic is important for groundwater pump and treat or fluid cycling systems. Transmissivity affects the zone of influence in this type of remediation which impacts the number of wells and the cost of operating the wells.
Groundwater Properties	
Depth to [ground] water table	Affects the well depths and costs of materials and labor associated with well construction as well as pumping costs.
Thickness of saturated aquifer	Affects the well depths and costs of materials and labor associated with well construction as well as pumping costs.
pH	Groundwater pH can impact the solubility of contaminants and biological activity. Therefore, this characteristic can affect technologies such as in situ groundwater bioremediation. pH can also affect the operation of treatment technologies (see Table 4). pH in the corrosive range (e.g., <2 or >12) can damage equipment and typically requires use of personal protection equipment and other special handling procedures.
Suspended Solids	Suspended solids in pumped groundwater can cause clogging problems for ex situ groundwater treatment technologies such as carbon adsorption, membrane filtration, and reverse osmosis.
Turbidity	High turbidity in pumped groundwater may indicate the presence of materials that will cause scaling problems on equipment surfaces, particularly in applications such as air stripping. High turbidity also reduces light transmission in UV oxidation systems, thereby lowering their effectiveness.
Alkalinity	Materials that cause scaling on equipment surfaces may impact performance and operability, particularly in applications such as air stripping and distillation.
Iron Concentration	Materials that cause scaling on equipment surfaces may impact performance and operability, particularly in applications such as air stripping and distillation.
Major Anion and Cation Concentrations	Materials that cause scaling on equipment surfaces may impact performance and operability, particularly in applications such as air stripping and distillation.
Organics	
Total Organic Carbon (TOC)	TOC affects the desorption of contaminants from soil and impacts in situ soil remediation, soil washing, stabilization, and in situ groundwater bioremediation. TOC content may differ between uncontaminated and contaminated soil.
Oil & Grease (O&G) or Total Petroleum Hydrocarbons (TPH)	O&G and TPH affect the desorption of contaminants from soil. For thermal desorption, elevated levels of TPH may result in agglomeration of soil particles, resulting in shorter residence times.
Nonaqueous Phase Liquids (NAPLs)	NAPLs may be a continuing source of contaminants for in situ technologies. NAPLs may lead to increased contaminant loads and thus to greater costs or longer operating periods for achieving cleanup goals. Under certain conditions, NAPLs may directly interfere with the operation of the treatment process.
Miscellaneous	
Eh	The Eh of a material affects chemical reactions involving oxidation or reduction [2].

Matrix Characteristics	Potential Effects on Cost or Performance
Contaminant Sorption	The affinity of a compound for water, soil, and organic matter affects the performance of technologies that use aqueous or organic liquids to remove contaminants [1].
Temperature	Temperature affects the rate at which many chemical and biological reactions occur.
Field Capacity	Field capacity affects the optimum volume and frequency of irrigation during land treatment of a waste.
Cation Exchange Capacity	The cation exchange capacity of the soil determines the ease with which metals will be removed by technologies such as soil washing.
Btu Value	For incineration technologies, the Btu value of the feed material affects system throughput and fuel usage.
Halogen Content	The fraction of the contaminants that are halogenated determines whether dehalogenation is appropriate. Halogen content also determines the concentration of halogenated by-products from destruction technologies such as incineration and pyrolysis.
Metal Content or Presence of Metals	For technologies (e.g., soil flushing) that can be designed to remove metals or organic contaminants, the metal content affects the design and operation of the remediation system. For other technologies, the metal content of the feed affects the metal content of the residuals (and therefore the disposal options).
Presence of Alkaline Metal Salts	Alkaline metal salts may cause refractory attack and slagging at high temperatures [1].
Bulk Density	Bulk density affects all ex-situ treatment technologies including thermal desorption systems. For ex-situ ground water remediation, higher bulk densities increase the retardation of the contaminants thus prolonging the remedial action.
Lower Explosive Limit (LEL)	The concentration of a material is typically maintained below a set percentage of its LEL to minimize the risk of explosion. This must be considered in the implementation of technologies such as thermal desorption.
Dielectric Properties	The dielectric properties of a matrix affect its absorption of electromagnetic or radio frequency energy, thereby impacting the performance of thermally enhanced recovery technologies that use these types of energy.
Glass-Forming Materials	Vitrification requires that sufficient glass-forming materials be present within the waste matrix to form and support a high-temperature melt.
Electrical Conductivity	Vitrification requires that the waste matrix exhibit a certain degree of electrical conductivity for the process to operate efficiently.
Presence of Inclusions	Inclusions impact the operation of in situ soil remediation technologies by complicating drilling operations or by interfering with the flow of vapors, liquids, or energy through the soil.
Presence of Emulsifying Agents	Emulsifying agents bind contaminants to the matrix, which can interfere with extraction and flushing technologies.
Humic Content	Humic materials affect the desorption of contaminants from soil and water.
Biological Oxygen Demand (BOD)	BOD measurements of contaminated materials provide indications of the biodegradable fractions of the organic contamination.

SECTION 4
REMEDIATION SYSTEM DESCRIPTION

Treatment Technology Type(s) Indicate the treatment technolog(ies) used in this remediation system. Tables 4-1 and 4-2 give examples of standard terminology used to describe remedial action and decommissioning technologies.

Table 4-1: Examples of Remedial Action Treatment Technologies by Media and Method Categories

Soil In Situ	Soil Ex Situ	Groundwater In Situ	Groundwater Ex Situ
Bioremediation Bioventing Capping Soil Flushing Soil Vapor Extraction Solidification/ Stabilization Steam Extraction Vitrification etc.	Chemical Reduction / Oxidation Critical Fluid Extraction Dehalogenation Excavation Incineration Land Treatment Pyrolysis Slurry Phase Bioremediation Soil Washing Solid Phase Bioremediation Solidification/ Stabilization Solvent Extraction Thermal Desorption etc.	Barrier Walls Bioremediation Chemical Reduction/ Oxidation Hot Water/Steam Flushing/Stripping Natural Attenuation Passive Treatment Walls Sparging Surfactants etc.	Pump and Treat with: Air Stripping Carbon Adsorption Chemical Oxidation/ Reduction Chemical Treatment Distillation Membrane Filtration Precipitation Reverse Osmosis Solar Detoxification Solvent Extraction UV Oxidation etc.

Table 4-2: Examples of Technologies Used for Decommissioning Buildings and Structures

Decontamination	Dismantling / Segmentation	Demolition	Waste Disposition
CO_2 Pellet Blasting Grit Blasting Chemical Treatment Laser Heating Scabbler Grinding Microbial Degradation etc.	Diamond Wire Flame Cutting Wrecking Ball / Slab Backhoe Wall & Floor Saw Mobile Shears etc.	Grappler Jackhammer Explosives / Blasting Bulldozer Wrecking Ball etc.	Recycle Store Ship for Disposal Free Release Compaction Melting Smelting Shredding etc.

Note: Refer to *Preferred Decommissioning Technologies Guide*, U.S. DOE, Office of Environmental Restoration, March 1996.

<u>Treatment System Schematic and Technology Description and Operation</u> . Provide an overall schematic of the treatment system from excavation (where appropriate) through treatment/disposal of residuals.

Describe and/or provide drawings for each treatment unit process and include personnel requirements for operating the system, the approach used to operate the system over the course of the remediation, and health and safety requirements and level of personal protective equipment used.

<u>Key Design Criteria</u> Provide bulletized list of such items as timeframe, throughput, residuals expected, and labor requirements. Include type of material used for piping, tanks, filters and their numbers and sizes.

<u>Operating Parameters Affecting Treatment Cost or Performance</u>

The parameters that affect technology cost and performance can be broadly categorized as being either matrix characteristics or operating conditions. The latter category is the subject of this section while the former category was discussed earlier in Section 3. Table 4-3 is a comprehensive list of all the operating conditions that should be considered and provides an explanation of why each operating condition is considered important to the cost and performance of various remediation technologies. These parameters define desirable information which may help to guide formulation of future field sampling programs during site remediation. These parameters were selected not only because they affect a technology's cost and performance but also because they are commonly measured in practice. The variables represent standard data sets which will allow a consistent comparison of various applications of a particular technology. Identify the measurement procedures used for each parameter as appropriate.

Presumably, a site will have selected a primary treatment technology from those listed in Table 4-1. **The next crucial step is for the remediation contractor to choose a set of relevant operating conditions** from Table 4-3 that would be applicable to their selected technology. The resulting set of conditions need to be reported. The ultimate objective is to develop a comprehensive set of parameters which would be of most value to remediation project managers who are attempting to apply results from a completed cleanup to their own particular site.

Other items besides matrix characteristics and operating conditions are important to document because of their potential impact on cost and/or performance. These include the type and concentrations of contaminants, quantity of material treated, cleanup goals or requirements, and environmental setting. For example, for in-situ technologies, geologic and hydrogeologic characterizations should be included in the documentation.

Table 4-3. Operating Parameters and Their Potential Effects on Treatment Cost or Performance

Operating Parameters	Potential Effects on Cost or Performance
System Parameters	
Operating Time (or Curing Time)	Operating time (or curing time) is important whenever it is not appropriate to measure residence time or system throughput. Operating time is generally reported for in situ technologies; curing time is generally reported for solidification, stabilization, or vitrification.
Air Flow Rate	Air flow rate affects the rate of volatilization of contaminants in technologies that rely on transferring contaminants from a soil or aqueous matrix to air, such as soil bioventing, soil vapor extraction, and groundwater sparging. For technologies involving oxidation processes, this parameter affects the availability of oxygen and the rate at which oxidation occurs (e.g., for bio-treatment or incineration processes).
Mixing Rate/Frequency	The mixing rate affects the rate of biological activity (through increased contact between oxygen and contaminants) and volatilization of contaminants.
Moisture Content	The moisture content affects the rate of biological activity in soil bioventing, land treatment, composting, and slurry phase bioremediation technologies. Contaminants must be in an aqueous phase for bioremediation to occur, and water is typically added to a soil to maintain a sufficient level of moisture to support biodegradation.
Operating Pressure/Vacuum	Operating pressure/vacuum affects the rate of volatilization of contaminants in technologies that rely on transferring contaminants from a soil or aqueous matrix to air (i.e., soil bioventing, soil vapor extraction, and groundwater sparging).
pH	pH affects the operation of technologies that involve chemical or biological processes (i.e., soil flushing, soil washing, and bioremediation processes). For example, in soil washing, contaminants are extracted from a matrix at specified pH ranges based on the solubility of the contaminant at that pH.
Pumping Rate	Pumping rate affects the amount of time required to remediate a contaminated area, and is important for technologies that involve extraction of groundwater (i.e., soil flushing and pump and treat).
Residence Time	Residence time is important for ex situ technologies (i.e., land treatment, composting, slurry-phase soil bioremediation, incineration, and thermal desorption) to measure the amount of time during which treatment occurs.
System Throughput	System throughput affects the costs for capital equipment required for a remediation and operating labor for ex situ technologies (i.e., slurry phase soil bioremediation, soil washing, incineration, and thermal desorption).
Temperature	For bioremediation technologies, temperature affects rate of biological activity. For stabilization, incineration, and thermal desorption, temperature affects the physical properties and rate of chemical reactions of soil and contaminants.

Operating Parameters	Potential Effects on Cost or Performance
Washing/Flushing Solution Components/Additives and Dosage	For soil flushing and washing technologies, the types and dosages of additives affects the solubility and rate of extraction for contaminants, and thus affects the costs for constructing and operating flushing and washing equipment.
Biological Activity	
Biomass Concentration	Biomass concentration is an important parameter for slurry phase soil bioremediation and in situ groundwater biodegradation. Biomass is necessary to effect treatment and thus the concentration of biomass is directly related to performance.
Microbial Activity Oxygen Uptake Rate (OUR) Carbon Dioxide Evolution Hydrocarbon Degradation	Microbial activity is an important parameter for soil bioventing, land treatment, composting, and slurry phase soil bioremediation technologies. Hydrocarbon degradation is commonly used as an indicator of treatment performance for these technologies, while OUR and carbon dioxide evolution are used in specific applications to supplement the hydrocarbon degradation data.
Nutrients and Other Soil Amendments	Nutrients and other soil amendments can affect soil bioventing and in situ groundwater biodegradation as this parameter directly affects the rate of biological activity and, therefore, contaminant biodegradation. This is also applicable to ex situ soil remediation technologies (i.e., land treatment, composting, and slurry phase soil bioremediation).
Soil Loading Rate	The soil loading rate affects the rate of biological activity and can impact the costs for operation.
Miscellaneous	
Electrical Energy Applied	The amount of electrical energy per unit amount of material treated is important in determining performance and cost-effectiveness when the treatment method directly uses electricity (or electricity converted to another form of electromagnetic energy).
Compressive Strength	The compressive strength of the treated material is important in evaluating the effectiveness of stabilization, solidification, and vitrification.
Change in Volume	Stabilization, solidification, composting, and vitrification may each significantly change the volume of the material treated.
Bulk Density	The bulk density of the treated material may be used to evaluate the effectiveness of stabilization.
Permeability	The permeability of the treated material is important in evaluating the effectiveness of stabilization, solidification, and vitrification.
Steam Flow Rate	Steam flow rate affects the rate of volatilization and removal of contaminants by steam extraction or steam flushing/stripping.

SECTION 5
REMEDIATION SYSTEM PERFORMANCE

Treatment technology performance data are more difficult to standardize than the other items described in this guide such as matrix and contaminant characteristics and even costs. While performance is usually measured as a removal percentage or the concentration level attained, this information alone may not be adequate to assess the overall performance of the technology. Establishing performance levels for in-situ treatment processes is particularly challenging due to the difficulty involved in accurately characterizing the level and extent of contamination. Described below in Table 5-1 are the types of performance-related information which should be reported to the extent possible in order to provide analysts with a better understanding of the technology application. The information may be provided in the form of a table. For ease of use for the reader of the report, contaminant data, compliance levels, and detection limits should be kept in the same table.

Table 5-1: Recommended Performance-Related Information to be Documented

PERFORMANCE-RELATED TOPIC	TYPE OF INFORMATION
Cleanup Goals	- Cleanup level - Cleanup goals or objectives - Criteria for terminating operation
Remediation Plan	- Process Optimization Efforts - Sequence of Events (major phases) - Construction - Treatment, storage, disposal - Transportation
Quantity of Material Treated	- Quantity of material treated during the application - For in situ technologies, area , depth, thickness, volume of contaminated material treated. - For Decommissioning projects, provide gross square footage (area) of the site. Volume or tonnage can be estimated.
Quantity of Material Stored or Disposed	- Quantity of material or waste stored or disposed of in-place or in a disposal cell.
Quantity of Material Transported	- Quantity of material or waste transported to an on-site or off-site disposal cell.
Untreated and Treated Contaminant Concentrations	- Measurement of initial conditions - Measurement of contaminant concentration before, during, and after treatment (matched untreated/treated pairs of data and corresponding operating condition data. - Assessment of percent removal achieved and method used to derive it.
Comparison with Cleanup Objectives	- Assessment of how well the technology operation achieved cleanup objectives - Assessment of whether the technology was operated to go beyond the cleanup goal
Risk Reduction	- Define exposure scenario(s) including populations, intake pathways, toxicity assessments - Provide risk levels before and after remediation
Residuals	- Types of residuals generated (e.g., off-gases, wastewaters, or Sludges) - Measurement of mass or volume, and contaminant concentration, in each treatment residual

SECTION 6
REMEDIATION SYSTEM COST

The Design Engineer will obtain the needed cost information from the bid documents and any change orders that occur for the project.

Procurement Process. Describe the procurement process for the treatment system and associated activities. Identify the prime contractor, subcontractors, and equipment vendors, their responsibilities, and description of services provided. Indicate the bid costs per unit of contaminants expected to be treated.

Work Breakdown Structure

A standardized work breakdown structure (WBS) utilized throughout the environmental industry (LMI, 1994 and HTRW-ICEG, 1996) has been adopted by the FRTR and the Interagency Cost Estimating Group (ICEG) for Hazardous, Toxic, and Radioactive Waste (HTRW). The WBS incorporates five levels of detail for the various cost elements. However, for simplicity, DOE sites will be required to document costs only at the second level of detail which is described here. The second-level WBS cost elements of a remediation project are shown in the second column of Table 6-1. Project cost documentation should follow this WBS as far as possible. This system is well-suited to compare costs of the same or similar technologies applied at different sites.

Finally, the report should attempt to identify capital costs separately from operating and maintenance costs so as to calculate total life-cycle costs. If possible, clearly identify sampling and analysis costs. For both capital and operating costs, list significant cost elements or alternative costs where different procurement approaches could be taken that would affect the cost of remediation.

The documentation should identify unit costs and number of units for each cost element, as appropriate. Costs for activities directly attributed to treatment should be shown as a total cost and as a calculated cost on a per unit of media treated basis, and on a per unit of contaminant removed basis, as appropriate. Such a system is best suited to compare costs for different technologies applied at the same or similar sites.

It is anticipated that the WBS described here will be the basis for federal procurements for site remediation services. Data collected by various agencies according to this WBS will be stored electronically in a Historical Cost Analysis System (HCAS). This will provide a mechanism to compare DOE costs to those of other agencies.

References:

Logistics Management Institute (LMI), 1994. "Environmental Restoration Remedial Action Work Breakdown Structure for Hazardous, Toxic, & Radioactive Waste (HTRW)", IR-518-LN1, December 1994.

HTRW - ICEG (USACE, Navy, Air Force, EPA, DOE) Remedial Action Work Breakdown Structure, February 1996.

Table 6-1: SECOND LEVEL OF WBS FOR COLLECTING COST INFORMATION

GENERAL ACTIVITY AREAS	COST ELEMENTS
Preliminary Activities	- Characterization - Assessment - Design
Preparatory Work	- Mobilization - Monitoring, Sampling, Testing, and Analysis - Site Work
Containment, Collection & Control	- Surface Water Collection and Control - Groundwater Collection and Control - Air Pollution/Gas Collection and Control - Solids Collection and Containment - Liquids/Sediments/Sludges Collection and Containment
Treatment	- Biological Treatment - Chemical Treatment - Physical Treatment - Thermal Treatment - Stabilization/Fixation/Encapsulation - Decommissioning
Disposal	- Disposal (other than Commercial) - Disposal (Commercial)
Demobilization	- Site Restoration - Demobilization
Long-Term Surveillance & Maintenance	- Institutional Controls - Monitoring - Maintenance - Security

SECTION 7
REGULATORY/INSTITUTIONAL ISSUES

Regulatory/Institutional Issues. Discuss what approvals, licenses, and permits were required to operate at the site and the activities and timelines to obtain them.

Specify the cleanup criteria that was established for the site.

SECTION 8
SCHEDULE

Schedule. Either in tabular or Gantt chart form specify the major tasks associated with the remedial activities, indicating their start/end dates and/or the duration of the task.

Provide a chronological list of the key elements for the application of the treatment system through completion of remediation. Identify key milestones (i.e., treatability test date; design completion; site mobilization; demobilization; excavation; site preparation; treatment start date; and end date).

SECTION 9
OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned. Summarize observations or lessons learned concerning **COST** for this treatment system. Identify key factors that affected project costs, and major items that caused costs to differ from estimates. Describe areas for potentially reducing costs in future applications.

Performance Observations and Lessons Learned. Summarize observations or lessons learned concerning treatment system **PERFORMANCE** for this application. Identify items that caused performance to differ from goals, and context for those items. Describe lessons learned from scaling-up treatability studies to full-scale activities, including how accurate such treatability studies were in predicting the full-scale application cost and performance. Describe areas for potentially improving performance in future applications, including information from treatment system vendors.

Other Observations and Lessons Learned. Discuss what may cause major impacts on the remediation schedule (i.e., weather, material availability, obtaining permits, etc.). Summarize observations or lessons learned from treatment application not directly related to cost or performance.

SECTION 10
REFERENCES

References. Include the DOE contract number and any references that are key to the project, such as the location of the administrative records. General references related to the technology may be included. For each major section in the report, identify the references by number that were used in that section.

SECTION 11
VALIDATION STATEMENT

Finally, the report must contain a signed validation statement as follows:

"This analysis accurately reflects the performance and costs of the remediation"

Signatories:

- the "owner" of the problem (e.g.the responsible DOE operations office program manager)
- a representative of a regulatory agency regulating the cleanup of that problem (e.g. representative of the governing state regulatory agency or representative of the appropriate regional EPA office)

APPENDIX A

Hypothetical Cost and Performance Report Example

cst-prf8.w61

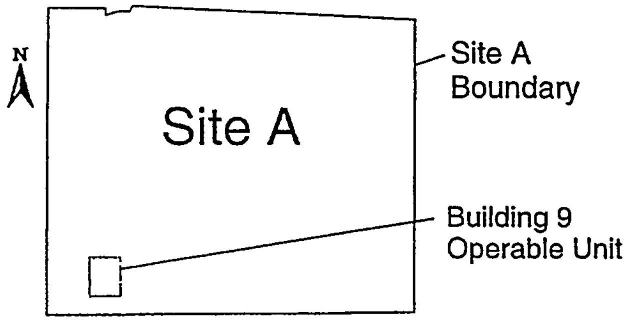
HYPOTHETICAL COST AND PERFORMANCE REPORT

Soil Vapor Extraction and Groundwater Remediation Using Conventional and Innovative Technologies at Facility X, Building 9 Operable Unit

August 8, 1996

U.S. Department of Energy

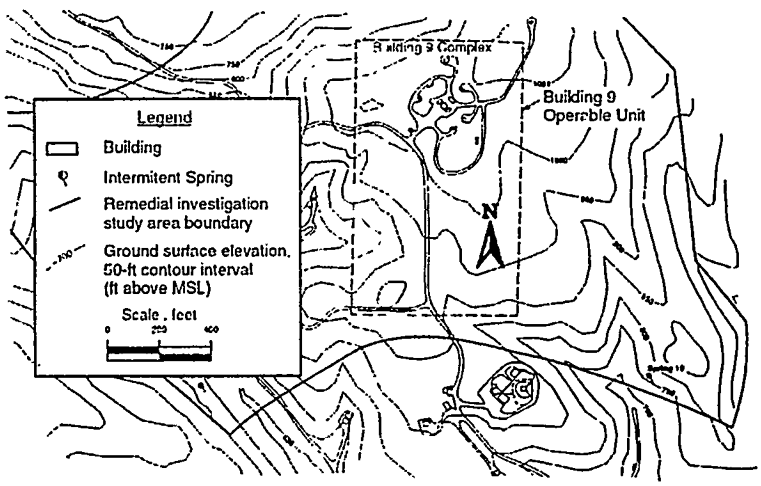
1.0 SUMMARY



This analysis reports ongoing efforts to remediate soil vapor and shallow perched groundwater contaminated with volatile organic compounds (VOCs) at the Building 9 Operable Unit (OU), Facility X. A summary of the site history and conditions is presented, along with a description of innovative technologies demonstrated, analysis of past remedial actions, and a description of selected remedial alternatives. The chemicals of primary concern include trichloroethylene (TCE), diesel fuel, and *tetra*-2-ethylbutylorthosilicate (T-BOS), a silicon-based lubricating oil. Remediation efforts include soil vapor extraction enhanced by localized dewatering with nonaqueous phase liquid (NAPL) separation and a program of innovative technology development and testing to characterize the extent and expedite the removal of dense nonaqueous phase liquids (DNAPLs) in the subsurface. Remediation system installation included development of automated controls and data acquisition equipment to minimize future labor costs, enhance system control and data quality, and provide real-time detailed monitoring of remediation progress.

2.0 SITE INFORMATION

Identifying Information



Topographic map of Building 9 Operable Unit.

- The Building 9 OU consists of ~52 acres located on top of an isolated ridge at Facility X in the rugged hills of county, state. The Building 9 Complex, consists of 13 small buildings and test cells located at the highest elevation in the northern part of the OU and is the location of multiple VOC releases to the ground surface.
- Except for limited paved areas and earthen safety berms, the site consists of introduced annual grassland and native perennial grassland. There are no sources of surface water except for intermittent precipitation runoff during the winter months.
- The climate is semiarid and windy with predominantly west to southwest winds. The temperature extremes range from the low 100s (°F) in July/August to the mid-20s (°F) in December. The estimated potential evaporation is about 30.6 in. per year, exceeding the average annual rainfall of about 10 in. per year.
- Like the rest of the Facility X, access to Building 9 OU is restricted and protected by fencing and full-time security patrols.

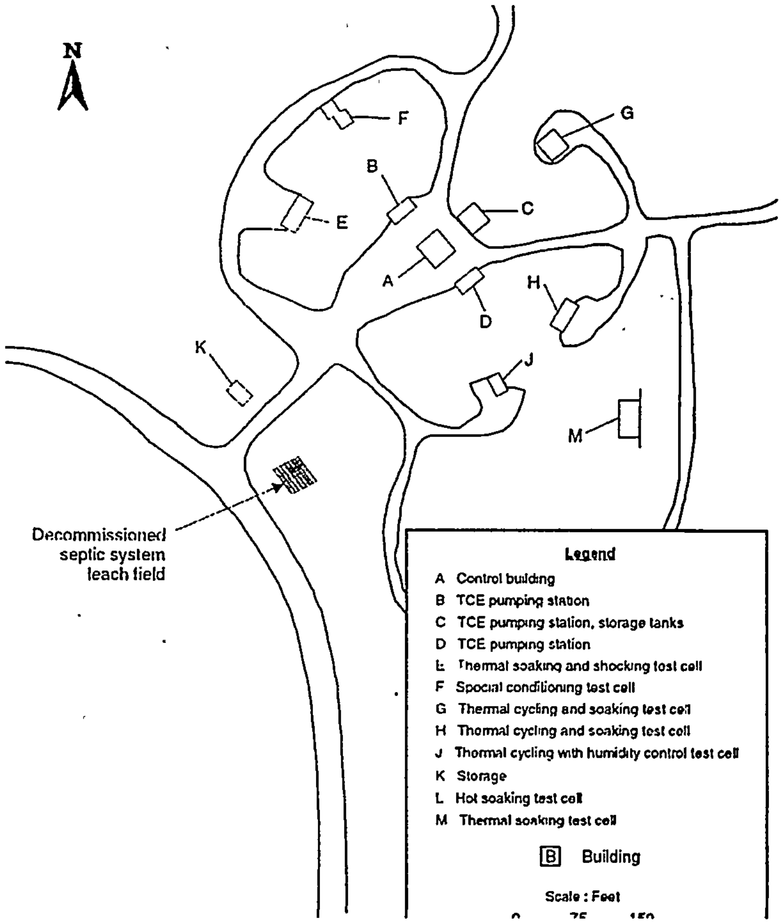
Site Background

- Because the site is remote and the contaminated groundwater is isolated in a shallow perched water-bearing zone, the Building 9 OU is uniquely suited for innovative technology testing and development. Building 9 has been recognized by State and Federal regulatory agencies and local stakeholders as an ideal innovative technologies test-bed. This concept was incorporated into the Building 9 OU Interim Record of Decision (ROD), which permits the development, demonstration, and implementation of innovative DNAPL remediation technologies.
- Remedial actions to date include excavation of TCE-contaminated soil adjacent to the release sites, removal of an underground diesel storage tank, and installation and operation of a soil vapor and groundwater extraction and treatment system. This site has been used to test several innovative technologies including an EPA Superfund Innovative

Technology Evaluation (SITE) test of a pulsed ultraviolet soil-vapor treatment system (PURUS™), an electrical soil-heating pilot test, a demonstration of an electron accelerator to treat soil vapor, and the development of cost-effective dual-function groundwater-soil vapor extraction wells.

Release Characteristics

- In the late 1950s and early 1960s, buildings and other structures in the Building 9 Complex were constructed, primarily for use in weapons component testing. TCE served as the primary heat transfer fluid for these operations until the system was dismantled between September 1993 and May 1994.
- Historical information and analytical data confirm that VOCs, primarily TCE, were released at ten release sites at the center of the Building 9 Complex between the early 1960s and mid-1980s. An estimated 550 gal (6700 lb) of TCE was released in the vicinity of the Building 9 Complex through leakage from pipes, pumps, and valves, and surface spills.
- The highest VOC concentrations detected in soil were reported in samples collected in the vicinity of TCE pump stations 9C and D, where free-product TCE is known to have spilled or leaked from the Building 9 Complex TCE heat-transfer system. Because of the unique hydrogeologic characteristics of the site, TCE remains highly concentrated in soil, soil vapor, and groundwater.
- Other confirmed release sites include Buildings 9B, E, F, G, H, and J, the septic system, and a diesel fuel tank. T-BOS (a silicon-based lubricant mixed with TCE heat-transfer fluid) has been identified in groundwater samples collected adjacent to Building 9D. Consequently, Building 9 OU has both DNAPL and light nonaqueous phase liquids (LNAPL) in the subsurface.



Building 9 Complex.

Performance Criteria

- The remediation system agreed upon in the Interim ROD and employed at Facility X was designed to address the potential worker inhalation risk by reducing soil-vapor concentrations in the vadose zone to a health-protective Interim Soil Vapor Cleanup Level of 250 $ppm_{v/v}$. Although groundwater remediation is not a primary component of the Interim ROD, groundwater extraction will be conducted to enhance the effectiveness of the soil vapor extraction by lowering the local water table and exposing more soil to vacuum influence.

- Vapor discharge permits issued by the local regulatory agency require that TCE concentrations in extracted soil vapor must be reduced to below 6 $ppm_{v/v}$ prior to atmospheric discharge. Any extracted groundwater must also be treated to reduce contaminant concentrations to below analytical laboratory detection limits (i.e., <5.0 µg/L for TCE) established in Substantive Requirements issued by the state.

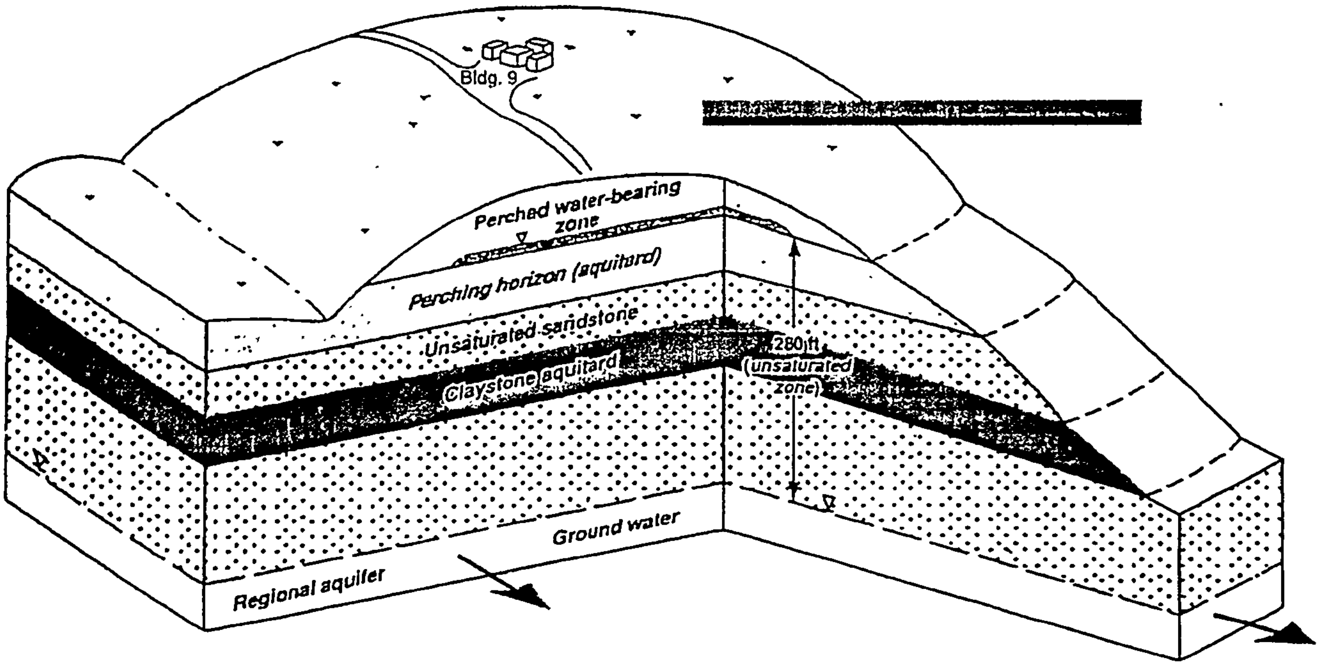
- Source-area DNAPL contamination represents a significant technical challenge and has exposed the technical limitations of groundwater extraction. As such, negotiations by Facility X led to the acceptance of an Interim Remedial Action that focuses on risk reduction through soil-vapor extraction, and DNAPL extraction and treatment through the application of innovative technologies. Groundwater recharge and plume mobilization will be minimized by paving areas near suspected releases and upgrading the surface drainage diversion system, as well as by perched water-bearing zone dewatering during soil vapor extraction. The Interim Remedial Action has been agreed upon by the Department of Energy (DOE), Facility X, and state and federal regulatory agencies in a four-year Interim ROD. During this interim period, the regulatory agencies have agreed to allow DOE/Facility X to demonstrate and implement appropriate innovative DNAPL remediation technologies to identify suitable technologies for long-term application.

3.0 MATRIX AND CONTAMINANT DESCRIPTION

Matrix Identification

- The primary risk at the Building 9 OU is on-site worker inhalation exposure from TCE volatilizing from contaminated subsurface soils in the vicinity of the release sites. Thus, soil vapor is the medium of immediate health concern. Although the local perched groundwater is significantly impacted, it is not a source of drinking water, and cleanup goals have not yet been established. A secondary driver for remediation at the OU is regulatory concern for potential migration of VOCs.

Geology / Stratigraphy / Hydrogeology [redacted]



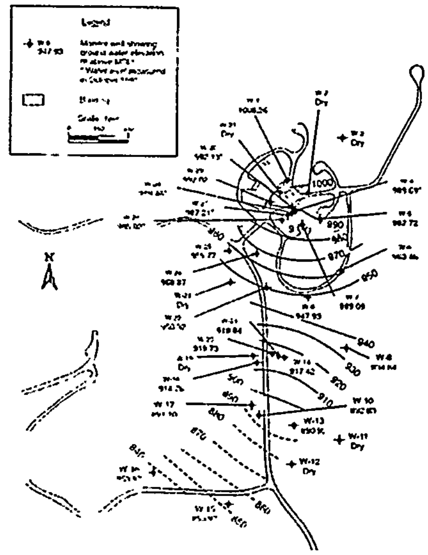
Conceptual hydrogeologic model of the Building 9 area.

- In order of increasing depth from ground surface, the hydrogeologic units beneath the Building 9 OU are:

	Unit	Thickness	Property
(1)	perched water-bearing zone	<1 to 81 ft	variably saturated
(2)	perching horizon	10 to 80 ft	unsaturated
(3)	upper sandstone	40 to 70 ft	unsaturated
(4)	claystone aquitard	36 to 68 ft	unsaturated
(5)	regional aquifer	> 200 ft	semi-confined

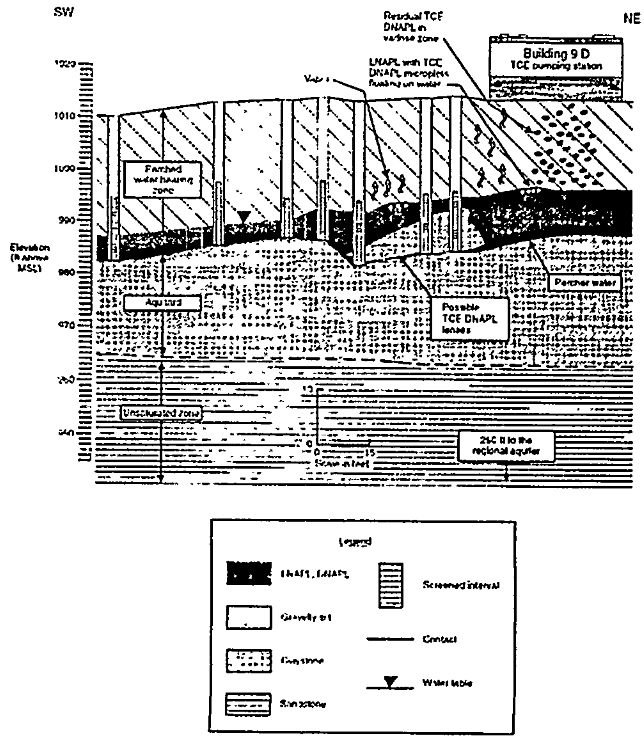
Hydrogeology

- The perched water-bearing zone consists of a heterogeneous mixture of low-moderate permeability clay, silt, sand, and gravel channel deposits and contains a shallow, hydraulically isolated perched water body that extends ~1800 ft downgradient (south) and is approximately 700 ft wide. Depth to perched groundwater ranges from 20 to 70 ft below ground surface, depending on local topography. Saturated thickness ranges from 3 to 11 ft, with the greatest thickness along the center axis of the water-bearing zone. Average groundwater flow is ~155 ft/year, with a gradient of 0.1 to the south-southwest. Groundwater recharge occurs primarily at the northern portion of the OU in the area of highest groundwater VOC concentrations. Perched water-bearing zone monitor well yields are low, typically less than 100 gal/day, which significantly limits treatment capacity.



Elevation of perched groundwater table.

- The top of the deep regional aquifer sandstone is located about 180 ft below ground surface and is separated from the perched water-bearing zone by two thick aquitards (the perching horizon and the siltstone/claystone aquitard), as well as unsaturated sandstone. Because the upper portion of the regional aquifer sandstone is unsaturated, the saturated portion of the regional aquifer is ~280 ft below ground surface. Beneath the OU, the average groundwater flow in the regional aquifer is ~78 ft/year, with a gradient of 0.03 to the south. The regional aquifer is believed to be continuous throughout the study area.



Schematic cross section of the Building 9 Complex.

Contaminant Characterization and Properties

Soil

- Benzene
- Ethylbenzene
- Tetrachloroethene (PCE)
- Toluene
- Trichloroethene (TCE)
- Trichlorofluoromethane (Freon 11)
- Xylenes

Note: Soil contamination is the driver for cleanup because of risk to human health.

Groundwater

- 1,1,1-Trichloroethane (1,1,1-TCA)
- 1,1-Dichloroethene (1,1-DCE)
- Acetone
- Benzene
- Chloroform
- *cis*-1,2-Dichloroethene (*cis*-1,2-DCE)
- Ethylbenzene
- Methylene chloride
- Tetrachloroethene (PCE)
- Toluene
- Trichloroethene (TCE)
- Trichlorotrifluoroethane (Freon 113)
- Xylene
- *tetra*-2-ethylbutylorthosilicate (T-BOS)

Contaminant Physical Properties

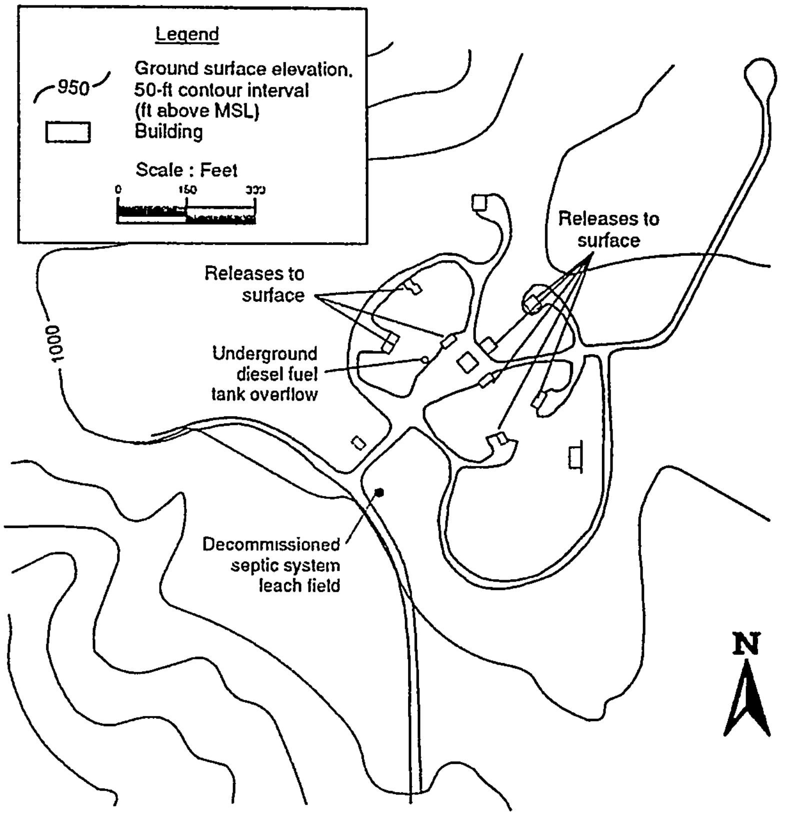
Contaminant	Vapor pressure (mm Hg)	Henry's Law constant (atm-m³/mol)	Density constant (g/cm³)	Water solubility (mg/L)	Octanol-water partition coefficient (K_{ow})	Organic carbon partition coefficient (K_{oc})
Acetone	2.70E+02	3 97E-05	0 7906	1.00E+06	0.58	0.37
Benzene	9.52E+01	5 40E-03	0.8680	1.75E+03	131.83	87.10
Chloroform	1.60E+02	3 23E-03	1.4890	8.00E+03	79.43	43.65
1,1-Dichloroethene (1,1,1-DCE)	5.91E+02	1 80E-02	1.2180	2.25E+03	69.18	64.57
trans-1,2-Dichloroethene[a] (*trans*-1,2-DCE)	2.65E+02	7.20E-03	1.2565	6.30E+03	123.03	58.88
Ethylbenzene	7.08E+00	6.60E-03	0.8669	1.52E+02	1348.96	158.49
Methylene chloride	3 79E+03	8 82E-03	0 9159	7.25E+03	19.95	8.71
1,1,1-Trichloroethane	1.00E+02	1 62E-02	1.3390	1.55E+03	295.12	151.36
Tetrachloroethene (PCE)	1.40E+01	1 53E-02	1.6227	1.50E+02	398.11	263.03
Toluene	2.20E+01	6 70E-03	0.8669	5.15E+02	446.68	151.36
Trichloroethene (TCE)	5 78E+01	9 10E-03	1.4642	1.10E+03	338.84	107.15
Trichlorofluoromethane	6 87E+02	1 10E-01	1 4870	1 10E+03	338.84	158.49
Xylenes[t]	9 02E+00	6 46E-03	0 8685	1 69E+02	1288.25	346.74

[a] *trans*-1,2-DCE was used instead of *cis*-1,2-DCE
[t] Total xylenes were estimated by averaging *o*-xylene, *m*-xylene, and *p*-xylene
Note: all properties were calculated at 20° C 1 atm Reference: Knox, R. C., Sabatini, D. A., and L. W Canter, *Subsurface Transport and Fate Processes* Lewis Publishers, Boca Raton, Florida, 1993.

Henry's Law Constant: Compounds with constants greater than 1E-3 readily volatilize from water; compounds with constants less than 1E-5 are not as volatile.
Density: Compounds with a density of greater than 1 have a tendency to sink (i.e., DNAPLs); compounds with a density of less than 1 have a tendency to float (i.e., LNAPLs).
Water Solubility: Highly soluble chemicals can be rapidly leached from wastes and soils and are mobile in groundwater; the higher the value, the higher the solubility.
Octanol-Water Partition Coefficient (K_{ow}): Used in estimating the sorption of organic compounds on soils (high K_{ow} tends to adsorb more easily).
Organic Carbon Partition Coefficient (K_{oc}): Indication of the capacity for an organic chemical to adsorb to soil because organic carbon is responsible for nearly all adsorption in most soils (the higher the value, the more it adsorbs).
Vapor Pressure: The higher the vapor pressure, the more volatile.

Nature and Extent of Contamination

- VOC releases were mostly to the ground surface at the locations shown. Investigations have determined that soil/rock and shallow perched groundwater have been significantly impacted. As a result of past releases, the perched groundwater has become contaminated with TCE (a DNAPL) and other VOCs including tetrachloroethene (PCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), 1,1,1-trichlotoethane (1,1,1-TCA), acetone, benzene, chloroform, 1,1-dichloro-ethene (1,1-DCE), ethylbenzene, Freon 113, methylene chloride, toluene, and xylene. A localized release of diesel occurred in the vicinity of an underground storage tank resulting in a commingled LNAPL plume at Building 9C. T-BOS (used in the facility's TCE-transfer system) has been detected as an LNAPL in wells near Building 9D.



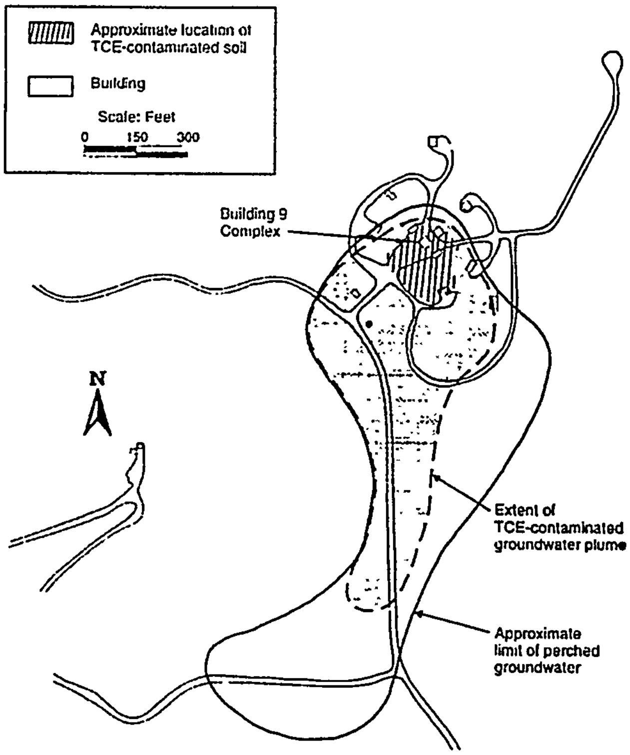
Confirmed release sites at the Building 9 Operable Unit.

Nature and Extent of Contamination (continued)

Soil/Rock

- Residual TCE is mainly confined to subsurface soils above or within the perched water-bearing zone in the vicinity of Buildings 9B, C, and D. However, the vertical and lateral distribution of TCE concentrations in soil/rock near the release areas is highly variable and is attributed to multiple releases of varying amounts and lithologic heterogeneity. The highest detected concentration of TCE in soil was 12,000 mg/kg in shallow soil behind Building 9C. This area was excavated in 1982. The highest detected TCE concentration for soil currently in place is 970 mg/kg, located at the base of the perched water-bearing zone, ~29 ft below ground surface near the Building 9D release site. Other VOCs in soil/rock include PCE, Freon 11, benzene, ethylbenzene, toluene, xylene, and diesel fuel.

- The primary driver for site cleanup is the potential risk to on-site workers who may inhale TCE volatilizing from subsurface soils.



Distribution of TCE in perched groundwater, December 1992.

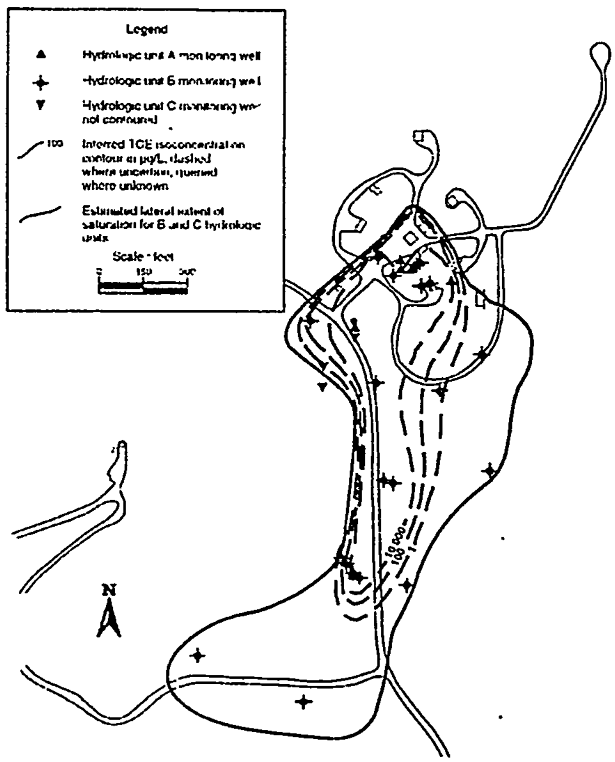
Groundwater

- Groundwater contamination is limited to a small perched water-bearing zone that underlies the OU. Depth to the perched water ranges from 10 to 70 ft below ground surface, depending on local topography. The groundwater gradient is ~0.1 to the south.

- TCE has been detected in groundwater at concentrations of up to 800,000 µg/L in the vicinity of Building 9D, indicating the presence of a DNAPL. The location of maximum groundwater TCE concentrations corresponds to the area of maximum perched-zone saturated thickness (up to 11 ft thick). The TCE plume extends ~1500 ft downgradient (i.e., south) and is up to 500 ft wide. The plume shape is controlled by the limit of perched zone saturation. High concentrations (over 10,000 µg/L) were detected throughout the body of the plume, indicating that the plume is relatively mature. TCE degradation products (e.g., *cis*-1,2-DCE) were also detected in groundwater samples collected from the perched water-bearing zone.

- T-BOS (a LNAPL) has been detected in groundwater samples collected near Building 9D. Analysis of the samples indicates that T-BOS has a tendency to sorb TCE. These samples also contain TCE and other VOCs.

- Because of the substantial thickness of the unsaturated siltstone/claystone aquitards and sandstones between the perched water-bearing zone and the regional aquifer, TCE in the perched water-bearing zone has not migrated vertically, and the regional aquifer remains uncontaminated.

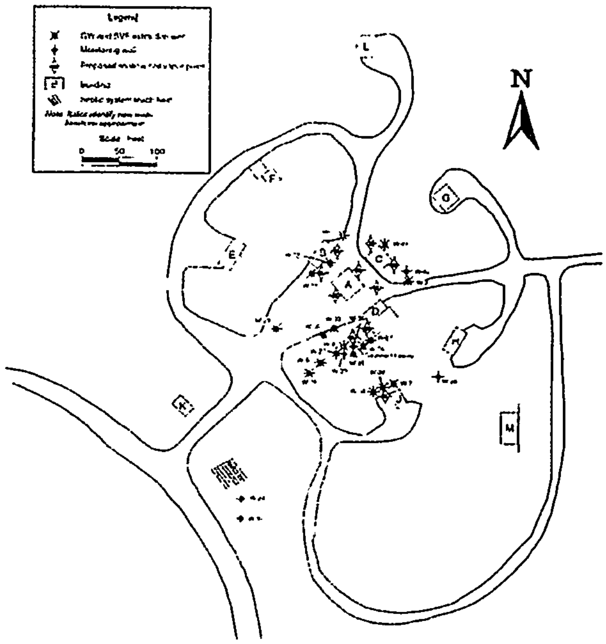


Extent of perched groundwater and TCE contamination, second quarter 1993.

4. 0 REMEDIATION SYSTEM DESCRIPTION

Treatment Technology

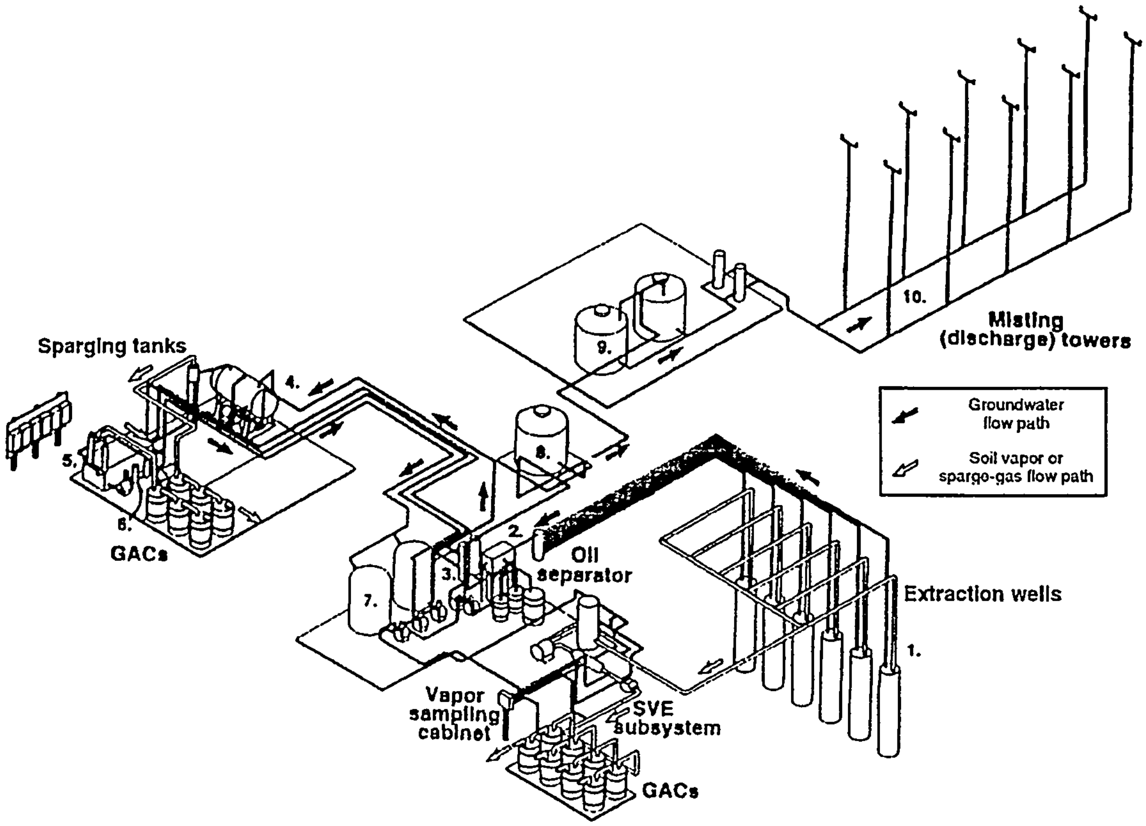
- Current system includes six combination soil-vapor and groundwater extraction wells located in the vicinity of Building 9D.
- Proposed system will expand the existing system to include up to 19 combination soil-vapor and groundwater extraction wells.
- Up to four wells may be fitted with LNAPL skimmers to remove floating diesel and/or T-BOS.



Extraction Well Locations (existing & proposed)

Treatment System Schematic

- **Groundwater treatment process** includes (1) groundwater extraction via air-displacement pumps; (2) NAPL separation in coalescing skimmer; (3) particulate removal to 20 μm; (4) sparger one – stainless steel high-vacuum vessel with 35-gal/min recirculating pump and 42-nozzle air-injection system; (5) sparger two – recycled stainless steel vessel for final sparging; (6) woven carbon-impregnated filter system for final polishing and removal of residual T-BOS and dissolved VOCs; and (7) short-term storage in two 500-gal steel tanks. Upon completion of the treatment process, the treated groundwater is pumped to two 500-gal holding tanks on a hill approximately 100 yards from the treatment system then atomized via 10 air-misting towers. Should freezing conditions occur, all treated groundwater is drained into a freeze draindown tank to prevent damage to the discharge lines.
- **Soil vapor treatment** includes extraction wells, a heat exchanger to cool air and increase condensation, a demister to remove vapor moisture, a 350-scfm variable-speed blower, a blower muffler, granular activated carbon (GAC) tanks, and discharge to the atmosphere.



Treatment system schematic.

- **Vapor treatment** includes GAC treatment of air emissions from the groundwater treatment system and soil-vapor extraction system. The treatment system is modular to incorporate the demonstration/implementation of innovative vapor treatment or destruction technologies, such as resin adsorption and pulsed-beam destruction.

Operating Parameters

Current soil-vapor extraction system (with dewatering operational):

- Applied vacuum: up to 11 inches mercury.
- Total area of vacuum influence: previous field tests produced 15,000 ft^2 of vacuum influence using one extraction well with a 40-scfm 28-in. mercury liquid-ring vacuum pump. Area of influence has not yet been measured using the current lower vacuum, higher flow, variable speed vacuum pump.
- Total flow rate: up to 350 scfm (variable speed).
- TCE concentrations in extracted vapor. up to 920 $ppm_{v/v}$.
- TCE mass removal rate: up to 10 lb TCE / day (with three wells).

Current groundwater extraction system:

- Total yield: up to 80 gal/day (three wells).
- Combined TCE concentration: up to 775,000 µg/L TCE.
- TCE mass removal rate: <0.5 lb TCE /day.

5.0 REMEDIATION SYSTEM PERFORMANCE

Performance Goals

Because potential human health risk lies with soil vapor and not groundwater, the system is designed to reduce soil vapor concentrations to acceptable levels. Groundwater migration is naturally restricted by the limited lateral extent of the perched water-bearing zone and the underlying aquitard. Groundwater extraction in the immediate vicinity of the source areas is necessary to lower the water table thus enhancing the effectiveness of soil vapor extraction, which is more effective at removing VOC mass. The remediation system is designed to accomplish the following goals:

- Capture contaminated soil vapor at the source areas to prevent potential on-site worker inhalation risk from volatilizing VOCs.
- Treat air emissions from soil vapor extraction system and air strippers in accordance with air permit requirements (i.e., below 6 $ppm_{v/v}$).
- Separate any recovered LNAPL (diesel and T-BOS) from the ground-water waste stream prior to air stripping.
- Reduce VOC, T-BOS, and diesel fuel concentrations in extracted groundwater to below analytical laboratory detection limits (<5.0 µg/L for TCE) prior to discharge through misting system.
- Facilitate development, demonstration, and implementation of innovative remediation technologies.

Table 5-1: Remediation System Performance Summary

PERFORMANCE PARAMETERS	VALUE
Cleanup Goals	TCE Air = 6 ppm by volume Ground Water = 5 ppb
Remediation Plan	see Table 5-2
Quantity of Material Treated	Soil Vapor <= 350 scfm Ground Water <= 80 gpd
Quantity of Material Stored or Disposed	N/A
Quantity of Material Transported	N/A
Untreated and Treated Contaminant Concentrations	TCE Untreated Concn. / Removal Rate Soil: 970 ppm / -- Extracted vapor: 920 ppm / 10 lb/day Ground Water: < 800 ppm / 0.5 lb/day
Comparison with Cleanup Objectives	In compliance
Risk Reduction	Initial risk to workers on-site from TCE vapor inhalation = 1×10^{-3}
Residuals	Treated ground water is atomized in misting towers. Therefore, no residual water to discharge at surface. Spent GAC filters

Remediation Plan

The site has been and will continue to be used for the development and testing of remediation and treatment technologies for VOCs in soil vapor, groundwater (both DNAPL and LNAPL phases). Tests to date have focused primarily on above ground treatment/destruction of extracted soil vapor and groundwater as well as development of data collection equipment. However, some testing has been performed on innovative technologies for enhanced removal of VOCs from the subsurface. A chronological summary of remediation work at the Building 9 Complex is presented below.

Table 5-2: Characterization and Remedial Actions to Date at the Building 9 Operable Unit

Date	Characterization and Remedial Actions
1980	Surveyed potential TCE releases with a site inspection of pump stations and test cells.
1981	Characterized a release site at Building 9C. Excavated test pit and collected soil samples.
1983	Assessed the extent of TCE in soil, rock, and groundwater. Drilled and sampled ten boreholes, completed two as monitor wells.
June, July 1983	Excavated and aerated ·100 yd^3 of soil containing up to 12,000 mg/kg of TCE from behind Building 9C.
1985 to 1986	Assessed the extent of TCE in the perched zone north of the Building 9 Complex Installed seven shallow wells; installed one deep well that did not reach the regional aquifer.
1986 to 1987	Performed initial short-term soil vapor extraction testing using selected wells near Building 9D (area of highest groundwater contamination) to estimate radius of vacuum influence and flow rates and extracted TCE concentrations with a high vacuum (28 in. Hg) low-flow (50 to 80 scfm) liquid ring vacuum pump. Test were also intended to determine required capacity of soil vapor extraction equipment.
1986 to 1988	Defined downgradient extent of TCE plume, produced hydrographs, sampled regional groundwater. Installed 24 shallow wells, installed 2 regional aquifer wells, collected samples, and obtained water-level measurements.
1988 to 1990	Conducted Remedial Investigation. Refined hydraulic characteristics, evaluated water-bearing zones in the perching horizon, installed vapor and water extraction wells, installed 11 shallow wells and 1 deep-vapor sampling well, assessed fate and transport, and conducted infiltration hydraulic tests.
1988	Performed series of short-term soil vapor extraction tests coupled with groundwater extraction. Tested effectiveness of Dual-Tank Air-Stripping Remediation System for extracted groundwater treatment. Refined data on mass removal rates and radius of vacuum influence.
1988 to 1989	Performed similar soil vapor and groundwater extraction tests on wells at downgradient (southern) end of plume (away from suspected sources). Conducted pilot test to evaluate the feasibility of vacuum extraction at the Building 9 Complex adjacent to Building 9D. Extracted groundwater at three shallow wells, induced venting at ten wells, sampled vapor stream and measured vacuum radius of influence, and treated TCE-bearing water by aeration.
July 1994	Free product diesel detected in a nearby monitor well prompted the excavation of an underground diesel tank south of Building 9B. TCE was detected in soil samples collected in the tank excavation pit. Three soil vapor extraction wells were completed in tank excavation pit.
1994 to 1995	Completed final upgrades to the treatment system. Upgrades include stainless steel air stripping vessels and the installation of an array of high-pressure spray nozzles to atomize treated water, thereby eliminating concerns of accelerated local soils erosion and minimizing discharge permit requirements. The treatment system is designed to allow modular in-line incorporation of innovative treatment/destruction technology for future field demonstrations.
June 1995	Developed and installed fully automated controls to facilitate remote operation and real-time monitoring of soil vapor and groundwater extraction systems including on-line gas chromatograph for vapor analysis. Included recycled components of site's dismantled TCE distribution system. Performed bench-scale tests to develop treatment of T-BOS in extracted groundwater. Tests determined the best/most cost-effective method to be carbon-impregnated cartridge filters to be installed downstream of air-stripping tanks.

6.0 REMEDIATION SYSTEM COSTS

- Because of the difficulty in treating T-BOS LNAPL, the current remediation system has not been operated for any extended period of time. Full-scale startup is expected to begin in early FY 1996.
- Because the current treatment system was constructed and modified between 1989 and 1994 and long-term operation costs are not available, estimated costs are based on previous equipment purchases and cost estimates performed for the Building 9 OU Feasibility Study. All costs are in 1994 dollars.
- Annual GAC operating costs are expected to decrease substantially as soil-vapor concentrations decrease after the first year of soil-vapor extraction.

Table 6-1: Second Level of Work Breakdown Structure (WBS) for Collecting Cost Information

GENERAL ACTIVITY AREAS	2nd LEVEL COST ELEMENTS	COST ITEMS	COSTS ($)	Subtotals ($)
Preliminary Activities	- Characterization / Assessment - Design		320,000 320,000	640,000
		Subtotal	640,000	
Preparatory Work	- Mobilization - Monitoring, Sampling, Testing, and Analysis - Site Work	- System Initialization - Sampling & Analysis	30,000 112,000 20,000	162,000
		Subtotal	162,000	
Containment, Collection & Control	- Groundwater Collection and Control - Air Pollution/Gas Collection and Control	- Extraction Equipment - Electrical - Instrumentation - Maintenance - Operation	180,000 50,000 25,000 40,000 50,000	345,000
		Subtotal	345,000	
Treatment	- Physical Treatment	- GAC System - Electrical - Instrumentation - Air Misting Towers - Electrical Power - Maintenance - Operation	10,000 50,000 25,000 10,000 12,000 40,000 50,000	197,000
		Subtotal	197,000	
Disposal	- Disposal (other than Commercial) - Disposal (Commercial)		NYI	
Demobilization	- Site Restoration - Demobilization		NYI	
Long-Term Surveillance & Maintenance	- Institutional Controls - Monitoring - Maintenance - Security		NYI	
		TOTAL	1,344,000	1,344,000

NYI: Not Yet Incurred

The above system of cost-collection described in Table 6-1 is well-suited to compare costs of the same or similar technologies applied at different sites.

Table 6-2: Calculation of Key Unit Cost Parameters

Qualitative Parameter	Quantitative Value
Total Capital Cost	$ 1,080,000
Annual Operating & Maintenance (O&M) Cost	$ 265,400
Ground Water Extraction Rate	80 gpd = 2.92E4 gall/yr
O&M / gallon water extracted	$ 9.10 per gallon
Soil vapor extraction rate	350 scfm = 1.84E8 ft^3/yr
O&M / 1000 ft^3 vapor extracted	$ 1.44 per 1000 ft^3
TCE Removal Rate from soil vapor and ground water	10.5 lb/day = 3832.5 lb/yr
O&M / lb TCE removed	$ 69.25 per lb

The system shown in Table 6-2 is best suited to compare costs for different technologies applied at the same or similar sites.

7.0 REGULATORY / INSTITUTIONAL ISSUES

- The driver for soil vapor cleanup is based on baseline risk assessment calculation of excess lifetime cancer risk to on-site workers of $1x10^{-3}$ and a hazard index of 35.9 from potential inhalation of VOCs volatilizing from the subsurface.
- The perched groundwater-bearing zone is currently considered a potential drinking water source by the state. The state requires complete restoration of groundwater to "background" concentrations. Because the perched water-bearing zone background water quality is poor, is naturally high in Total dissolved solids, and wells yield less than 200 gal/day, this water does not meet state requirements for a drinking water supply. Facility X has submitted a proposal to amend the plan to remove the perched water-bearing zone as a potential drinking water source, thus eliminating the requirement for complete groundwater restoration. The amendment is currently under review by the state.
- The local regulatory agency requires that emissions to air from the soil vapor extraction system and groundwater air-stripping system be treated for TCE (and other VOCs) to 6 $ppm_{v/v}$. Currently, this goal is met by treating emissions with GAC. The existing permit and Interim Record of Decision allow the GAC to be readily supplemented by innovative treatment/destruction technologies to identify a more cost-effective method of treating the extracted soil vapor.
- Local regulatory agency requirements for treatment of VOC-contaminated groundwater are met by LNAPL phase separation and air stripping, followed by carbon adsorption of T-BOS not removed by air stripping. A surface discharge permit is not required because discharged water is atomized through misting towers, rather than discharged to ground surface.

8.0 SCHEDULE

1981	Soil contamination identified in Building 9 Complex.
1982	Began initial site characterization.
1983	Excavated contaminated soil near primary release sites.
1987	Designed pilot-scale soil-vapor and groundwater extraction/treatment system.
1988	Completed definition of extent of contamination.
1989	Enhanced design of soil vapor and groundwater extraction/treatment system.
1990	Completed preliminary Remedial Investigation/Feasibility Study.
1991	Electron accelerator demonstrated to destroy TCE in extracted soil vapor.
1992	PURUS™ demonstration was funded by EPA SITE Program; electrical soil heating/soil-vapor extraction demonstration.
1994	Sitewide Remedial Investigation Report was published.
1994	Final Feasibility study was completed.
1995	Proposed Plan submitted to public.
1995	Interim Record of Decision issued.
1995	Completed T-BOS characterization and identified treatment technology.
1995	Final upgrades to current soil-vapor and groundwater extraction/treatment system under way

9.0 OBSERVATIONS AND LESSONS LEARNED

Implementation Considerations

- Characterizing the complex DNAPL / LNAPL waste stream was important to developing the final treatment system. To accomplish this, Facility X located a chemical manufacturer in Germany that still produces T-BOS and ordered a quantity of industrial-grade product to develop a proper analytical procedure, then relayed this procedure to the contract analytical laboratory for routine sample analysis. Treatment of nonvolatile T-BOS requires filtration with carbon-impregnated particulate filters.

- Pilot demonstrations indicated that the concentrated TCE / VOC waste stream requires special sparging equipment and process. The initial pilot treatment system used two industry-standard 500-gal polyethylene tanks to batch treat extracted groundwater via air sparging. During a 6-week pilot test, treatment times lengthened from 72 hours to over 300 hours. Field experiments indicated that high TCE concentrations in extracted groundwater were permeating into the walls of the polyethylene tanks and slowly diffusing back into the groundwater during treatment. The two sparge tanks were replaced with stainless steel vessels obtained at no cost through Facility X's equipment salvage program.

- Perched water-bearing zone dewatering with soil vapor extraction and DNAPL removal technology development, demonstration, or implementation has been identified as the effective remedial strategy. This approach has been established with an Interim ROD for the Building 9 OU and is strongly supported by the state and federal regulatory agencies.

Technology Limitations

- Residual DNAPL in the subsurface significantly limits the effectiveness of dewatering and soil-vapor extraction and treatment at the source areas. Additional characterization will be needed to address DNAPL remediation. In FY 1996 Facility X will be using partition tracer test technology to characterize the location of DNAPL near Building 9D.

- During the field demonstration of a pulsed UV photolysis system for in-line contaminated vapor effluent destruction, photo-oxidation products were detected during TCE oxidation. Although TCE concentrations were reduced by 99%, the photo-oxidation products will require additional treatment for full-scale implementation.

- Low well yields (<0.5 gal/min) limit the effectiveness of pump and treat for groundwater restoration and source removal. Long-term groundwater extraction will be considered as a technique to enhance soil-vapor extraction for the purposes of source removal.

Future Technology Selection Considerations

- Based on discussions with GAC vendors, sites that have high chlorinated contaminant concentrations in extracted soil vapor will experience high initial GAC expenses. Such sites will have to carefully investigate innovative vapor treatment or destruction technologies, such as resin adsorption and pulsed-beam destruction to reduce GAC consumption, disposal, and operation costs.

- Upon DNAPL characterization with partitioning tracers, a proof-of-concept field demonstration using surfactants to remove DNAPL will be initiated at the release area. Should this demonstration prove successful, the project may be scaled up for broader application at the Building 9 OU.

- Because of the presence of residual DNAPL contamination at the release areas, technology development to address the removal of DNAPL is critical to reducing source area contaminant mass and future source mass migration. The approach taken at the Building 9 OU has been to design an extraction/treatment system to facilitate the development, demonstration, and implementation of innovative technologies from within Facility X and from other public or private institutions. The unique hydrogeology of the Building 9 OU and strong regulatory support make this an ideal research test-bed for such innovative technologies.

10.0 REFERENCES

11.0 VALIDATION

"This analysis accurately reflects the performance and costs of the remediation"

Signatories:

- DOE operations office program manager ______________________________

- Representative of the governing state regulatory agency
  or/ Representative of the appropriate regional EPA office______________________________