

**Final
October 22, 1999**

**COST AND
PERFORMANCE
REPORT**

Soil Vapor Extraction Enhanced by Six-Phase Soil Heating
at Poleline Road Disposal Area, OU-B,
Ft. Richardson, Alaska

October 1999



Prepared by:
U.S. Army Corps of Engineers
Hazardous, Toxic, Radioactive Waste
Center of Expertise

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SITE INFORMATION

IDENTIFYING INFORMATION (1)

Site Name: Poleline Road Disposal Area (PRDA)
Location: Fort Richardson, Alaska
Operable Unit: OU-B
ROD Date: August 8, 1997
Technology: Soil Vapor Extraction (SVE) Enhanced by Six-Phase Soil Heating (SPSH)
Type of Action: Treatability Study

Figure 1 shows the location of the Fort Richardson in Alaska. Figure 2 shows the layout of the PRDA.

TECHNOLOGY APPLICATION (1,2,8,9)

Period of Operation:
Treatability Study – July through December 1997

Quantity of Material Treated During Application:
3,910 cubic yards (CY) or 7,150 tons of solvent-contaminated soil

Three cylindrical arrays were used for the treatability study. Two of the arrays were 27 feet in diameter and one array was 40 feet in diameter. All three arrays were designed to treat soil from 8 to 38.5 feet below ground surface (bgs). For arrays 1 and 2, the soil treatment zone extended past the array perimeter by at least 5 feet (40% of the array radius) based on pre- and post-treatment soil analyses. Removal beyond the array perimeter was not demonstrated in array 3.

BACKGROUND

Site Background (1,3,4):

- Fort Richardson was established in 1940 as a military staging and supply center during World War II. It originally occupied 162,000 acres approximately 10 miles northeast of Anchorage, Alaska. In 1950, Fort Richardson was divided between the Army and Air Force. Fort Richardson now occupies approximately 56,000 acres and is located adjacent to Elmendorf Air Force Base.
- Fort Richardson was added to the U.S. EPA's National Priority List (NPL) in June 1994. In December 1994, the Army, Alaska Department of Environmental Conservation (ADEC) and EPA signed a Federal Facilities Agreement (FFA) that outlined the procedures and schedules required for a thorough investigation of suspected historical hazardous substance sources at Fort Richardson. The FFA divided Fort Richardson into four Operable Units.
- The PRDA, designated as OU-B, was identified in 1990 through interviews conducted by the U.S. Army with two ex-soldiers who were stationed at Fort Richardson in the 1950s and who recalled the disposal of chemicals and other materials in the area. The disposal location was corroborated by a U.S. Army Corp of Engineers (USACE) map dated 1954 showing a "Chemical Disposal Area" at the PRDA and by a 1957 aerial photograph showing trenches in the area. The disposal area was active from approximately 1950 to 1972.



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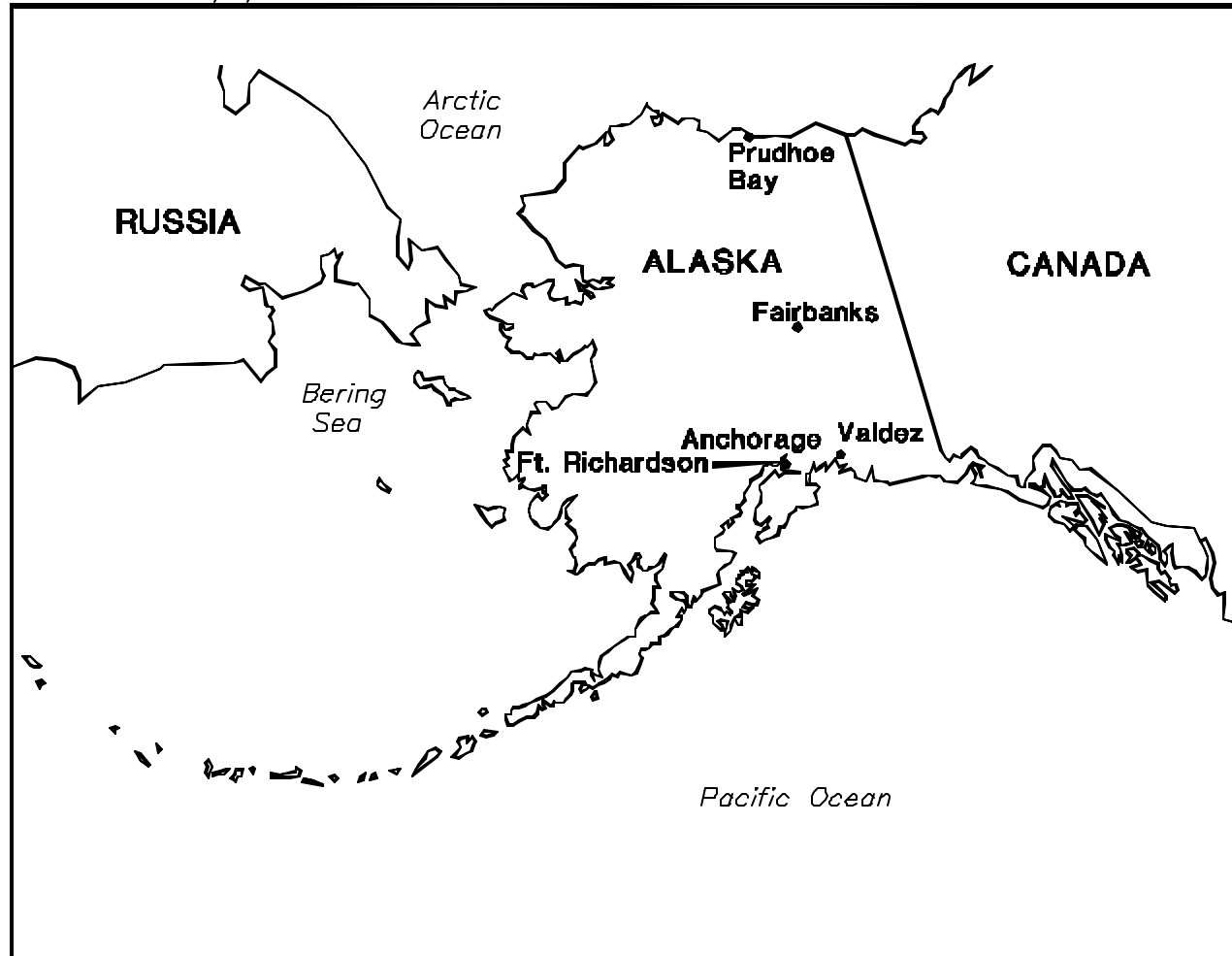


Figure 1. Location of Fort Richardson in Alaska



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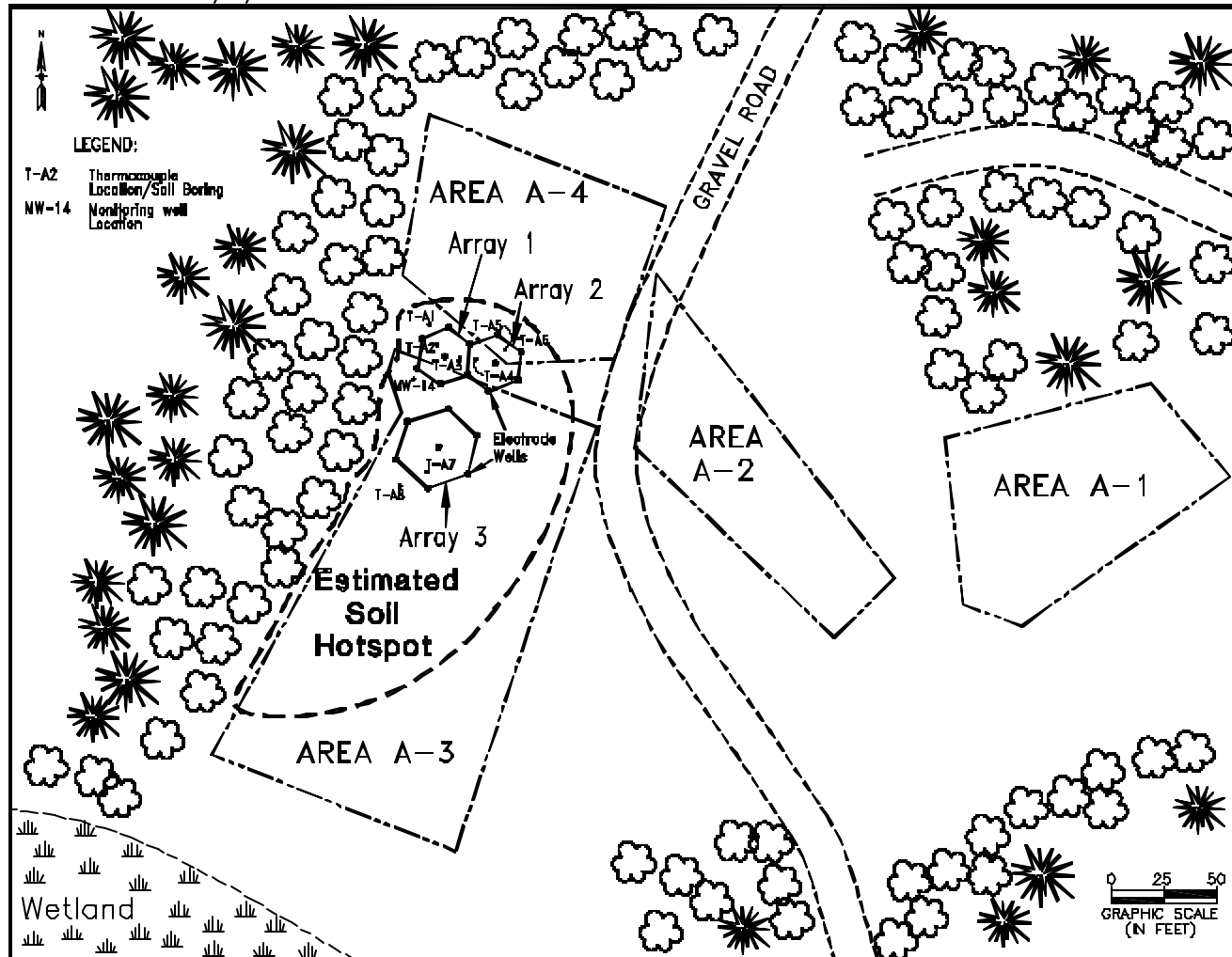


Figure 2. Layout of the Poleline Road Disposal Area



- Previous investigations identified four disposal areas at OU-B. Chemical warfare agents and training materials, smoke bombs, Japanese cluster bombs, and other materials were neutralized and disposed in trenches at PRDA. Geophysical surveys have delineated the waste disposal areas to be approximately 1.5 acres in size.

SIC Code: 9711 (National Security)

Waste Management Practices that Contributed to Contamination (1):

Chemical warfare agents, smoke bombs, Japanese cluster bombs (detonated prior to burial), and other materials were neutralized and disposed at PRDA. The procedure was to first place a layer of bleach/lime in the bottom of the trench. A pallet with the materials to be disposed was placed on top of the bleach/lime layer. Diesel fuel was poured on the materials and ignited with thermal grenades. After burning was complete, a mixture of either bleach or lime, combined with a chlorinated solvent carrier, was poured over the materials. When disposal was completed, the trenches were backfilled to match the surrounding grade.

Site Investigations and Remedial Actions (1,3,4,9):

Several site investigations and a removal action have been conducted at the PRDA since its discovery in 1990:

- Between 1990 and 1992, site investigations were conducted which included a geophysical survey, soil sampling from 10 borings, a soil gas survey, installation of 11 groundwater monitoring wells, groundwater sampling, a water level study, and aquifer (slug) tests. The investigation identified the location of the trenches, buried debris, and solvent contamination in the soil and groundwater.
- In 1993 and 1994, a removal action in areas A-3 and A-4 was conducted. This effort was interrupted due to the discovery of chemical agent identification sets and other chemical warfare training activities. A geophysical survey was conducted in early 1994 to better identify the location of buried objects in these areas. Areas A-3 and A-4 showed the greatest evidence of buried waste and trenching, including possible stacked canisters or cylinders. Contaminated debris and soil were excavated to a maximum depth of 14 feet, where groundwater was encountered, and the excavation was backfilled with clean soil. During this removal action, sampling confirmed that chlorinated solvents were in the soil below the water table. Excavated soil was treated on-site by heat enhanced SVE in two static piles.
- A geophysical survey was performed in June 1995 to determine whether any buried material remained in the recently excavated areas and to more accurately define anomalous zones in areas not excavated in 1993 and 1994. Based on the geophysical survey, areas A-1 and A-2 are expected to contain less significant quantities of buried waste, and therefore smaller volumes of contaminated soil, than areas A-3 and A-4. At the time of this report, areas A-1 and A-2 had not been excavated or sampled. Information provided by an ex-soldier previously stationed at Ft. Richardson indicated that undetonated bomblets from cluster bombs might be buried in these areas.
- In August and September 1995, a remedial investigation (RI) was conducted that included collection of soil, groundwater, surface water, and sediment samples from the site and background areas. Soil samples beneath the previous excavations in Area A-3 exceeded the cleanup criterion for 1,1,2,2-tetrachloroethane used during the excavation.



- Since the completion of the RI in 1995, soil and groundwater sampling and testing has been ongoing at the site to generate data for various treatability studies and to further delineate the nature and extent of contamination.
- A treatability study was conducted in the fall of 1996 as part of a feasibility study for OU-B. The treatability study included tests for SVE, air sparging, pump testing to determine aquifer characteristics, and groundwater sampling for intrinsic remediation parameters. The study concluded that SVE was capable of removing vapors from the subsurface, but at a rate that would require more than 10 years of treatment. Based on these results, it was recommended that SVE treatment enhanced with in-situ soil heating could be used at the site as a means for completing treatment more rapidly.
- A human and ecological risk assessment was completed in September 1996. The risk assessment concluded that the site poses no imminent threat to human health or the environment based on a lack of complete exposure pathways under current and probable future use scenarios. However, if groundwater were to be used as a source of drinking water or if buildings with basements were constructed at the site, groundwater and soil gas could pose unacceptable risks.

SITE LOGISTICS/CONTACTS (1,2)

Role

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MATRIX AND CONTAMINANT DESCRIPTION

MATRIX IDENTIFICATION

Soil (in situ)

SITE GEOLOGY/STRATIGRAPHY (1,3,4)

A 1979 soil survey described most of the soil at PRDA as a Homestead silt loam. The Homestead silt loam is described as a well-drained soil formed over gravelly till. The underlying till varies in compactness and is extremely firm in some areas. Soil matching the Homestead series is found over most of the site, except for the wetlands area where soil is included in the Salamatof series. The Salamatof is a nearly level, poorly drained soil consisting of fibrous peat materials that occur in broad basins and depressions on terraces and moraines.

The subsurface soil sampled during the RI were glacial tills, generally described as silty sands with some gravel. Silt, sand, and gravel were observed in nearly every sample at various percentages. Clay-sized particles were observed in very few samples. The soil was of high density, with blow counts during drilling often greater than 50 blows per 6 inches.

Four separate water-bearing intervals have been identified at PRDA. These water-bearing intervals are a perched interval, a shallow interval, an intermediate interval, and a deep aquifer. All four intervals appear to be interconnected to some degree. Zones of high-density tills separate the saturated intervals. Groundwater is encountered at a depth of 4 to 14 feet bgs.

The deep aquifer and glacial tills overlie bedrock composed of a hard black fissile claystone with fine sandy siltstone interbeds. Bedrock is encountered from approximately 80 to 170 feet bgs and has an unknown thickness.



CONTAMINANT CHARACTERIZATION (1)

Primary Contaminant Group: Organic Compounds – Volatiles (Halogenated)

Key Specific Contaminants: 1,1,2,2-Tetrachloroethane (TCA)
 Tetrachloroethene (PCE)
 Trichloroethene (TCE)

CONTAMINANT PROPERTIES (4,5,6)

Table 1 lists selected properties for the key specific contaminants at OU-B.

Table 1. Contaminant Properties

Property	Units	TCA	PCE	TCE
Chemical Formula	-	Cl ₂ CH-CHCl ₂	Cl ₂ C=CCl ₂	Cl ₂ C=CHCl
Molecular Weight	g/mole	167.86	165.83	131.5
Specific Gravity	-	1.60 @ 20°C	1.626 @ 20°C	1.46 @ 20°C
Boiling Point	°C	146.4	121.4	86.7
Vapor Pressure	mm Hg	5 @ 20°C	14 @ 20°C	60 @ 20°C
Water Solubility	mg/L	2970 @ 25°C	150 @ 25°C	1100 @ 25°C
Octanol-Water Partition Coefficient	log K _{ow}	2.39 – 2.56	2.10 – 2.88	2.29 – 3.30
Soil-Sediment Sorption Coefficient	log K _{oc}	1.663 – 2.07	2.322 – 2.56	1.81 – 2.10
Flammability	-	Not Flammable	Not Flammable	LEL – 8% UEL – 10.5%

NATURE AND EXTENT OF THE CONTAMINANTS (1,3,4)

- Two solvents, TCA and TCE, were found in higher concentrations and over a larger area than any other chemicals detected. PCE was also detected above action levels. Results from the 1995 RI indicated the presence of TCA in the soil at a maximum concentration of 2,030 mg/kg.
- Contaminants were detected in each of the four saturated intervals. These results indicate that there is interconnectivity between the saturated intervals, which has allowed the contaminants to migrate vertically. The highest concentrations of TCA (1,900 mg/L) and TCE (220 mg/L) were detected in the perched interval.
- The 1993-1994 removal action eliminated the major source of contaminants migrating to the groundwater. However, two sources may remain: solvent-contaminated soil beneath and potentially west of the previous excavations and dense non-aqueous phase liquids (DNAPLs). DNAPLs were observed in a monitoring well during the FS. Comparison of dissolved phase concentrations of solvents to their water solubilities indicated that DNAPLs are present in the subsurface.
- Soil excavated from areas A-3 and A-4 was sampled and compared to the following maximum allowable concentrations (as designated for the removal action). These concentrations were drawn from U.S. EPA Region 10's risk-based concentrations using a 10⁻⁵ exposure risk; soil exceeding the criteria was stockpiled for treatment.

- TCE - 600 mg/kg,
- PCE - 100 mg/kg, and
- TCA - 30 mg/kg.



- Soil samples were collected from borings drilled around the perimeter of areas A-1 and A-2 and through the fill at areas A-3 and A-4. Concentrations of contaminants in soil outside of the disposal areas are generally well below removal action levels. None of the samples collected from the fill soil exceeded the removal action criteria used during the excavation. However, two soil samples collected beneath the previous excavation in area A-3 had levels of TCA which exceeded the removal action criteria.
- The highest concentrations of contaminants detected in soil and groundwater samples were found in Areas A-3 and A-4 in a hot spot area of approximately 150 feet by 300 feet. Soil sampling data indicated that there was a layer of soil with high contaminant concentrations starting at around 16 feet bgs and extending to around 27 feet bgs in this area. Figure 2 shows the approximate location of the hot spot.
- Lower concentrations of contaminants were detected in the soil and groundwater near areas A-1 and A-2 (soil and groundwater within areas A-1 and A-2 were not sampled due to the potential presence of unexploded ordnance). Trends in the contaminant concentrations suggest that contaminants detected near the saturated intervals in areas A-1 and A-2 migrated from areas A-3 and A-4 in the direction of groundwater flow. Contaminants do not appear to have been released in areas A-1 and A-2, except for potential surface spills that may have been the source for contaminants detected in shallow soil near area A-2. Historical information indicates that it is unlikely that chemical warfare materials were disposed in areas A-1 or A-2, and therefore, chlorinated solvents were not needed for neutralization.
- Groundwater modeling performed using MODFLOW and MT3D estimated that the solvents would not reach the nearest downgradient receptor (Eagle River) for over 100 years.

MATRIX CHARACTERISTICS AFFECTING TREATMENT COST OR PERFORMANCE (3,4,6,8)

Table 2 lists selected characteristics of untreated soil from OU-B.

Table 2. Matrix Characteristics

Parameter	Value	Measurement Procedure
Soil Classification	SP – gravelly sand GP – sandy gravel GM – silty sandy gravel	Unified Soil Classification System
Clay Content and/or Particle Size Distribution	Low clay content; silt, sand and gravel observed	Visual
Moisture Content	7.3 – 13.9%	Method 7-2.2, Methods of Soil Analysis
Air Permeability	$1.6 \times 10^{-7} \text{ cm}^2$	Calculated using field measurements and steady state equation
Porosity	21 – 27%	Estimated from Grain Size
Depth bgs or Thickness of Zone of Interest	8 to 35 feet bgs	Not Applicable
Total Organic Carbon	0.19 – 0.66%	ASA 90-3.2
Presence of Nonaqueous Phase Liquids (NAPLs)	DNAPL found in a 2" monitoring well	Visual
Electrical Conductivity	Acceptable	Not Available



TREATMENT SYSTEM DESCRIPTION

PRIMARY TREATMENT TECHNOLOGY (1)

Soil In Situ – **Soil Vapor Extraction**
– **In Situ Heating (Six-Phase Soil Heating)**

SUPPLEMENTARY TREATMENT TECHNOLOGIES (1)

Post-treatment (Air) – **Condenser**
Post-treatment (Air) – **Catalytic Oxidation** (only used during the beginning of the study)
Post-treatment (Water) – **Air Stripping**

TREATMENT SYSTEM SCHEMATIC AND TECHNOLOGY DESCRIPTION AND OPERATION

Figure 3 shows a process flow diagram for the SPSH SVE system used to treat in-situ soil at OU-B.

Initial Activities (2,8)

The contractor mobilized to the site in June 1997. Pre-treatment soil samples were collected from the areas covered by each array. Three arrays were constructed and operated at the OU-B site. The array 1 SPSH and SVE system was installed in June 1997. System shakedown at array 1 occurred from July 1 through July 10, 1997. The array 2 SPSH and SVE system was installed in August 1997. The array 2 shakedown period lasted approximately two weeks due to grounding problems that prevented effective soil heating. The array 3 SPSH and SVE system was installed in October 1997. Only two days were needed for shakedown at array 3.

Technology Description and Operation (1,2)

General Description of SVE Enhanced by Six-Phase Soil Heating

SPSH is a patented, multi-phase electrical technique that utilizes common power line frequency (60 Hz) to resistively heat soil. SPSH can turn groundwater into steam that will strip volatile and semivolatile contaminants from the soil. The steam stripping facilitates movement of contaminants from low permeability zones into more permeable zones where the contaminants are removed by the SVE system. In situ heating also allows the contaminants to volatilize more readily.

Electrical power is delivered throughout the area being treated by steel electrodes inserted vertically into the soil. The electrodes are placed in a circular array consisting of six electrodes on the periphery and one electrode in the center. Each periphery electrode is connected to one of the six single-phase transformer wires. Six conventional single-phase transformers convert standard three-phase electricity into six-phase electricity at the desired voltage. Each electrode is operated at a different voltage phase, so the electricity conducts with all the other electrodes in proportion to the voltage differences. The electrode spacing and the connected electrical phases are both 60 degrees apart, resulting in a uniform ratio of voltage difference to physical distance between all electrodes in the array. The result is a relatively even heating pattern. The seventh neutral electrode is located at the center of the array. Each electrode also serves as an SVE vent.



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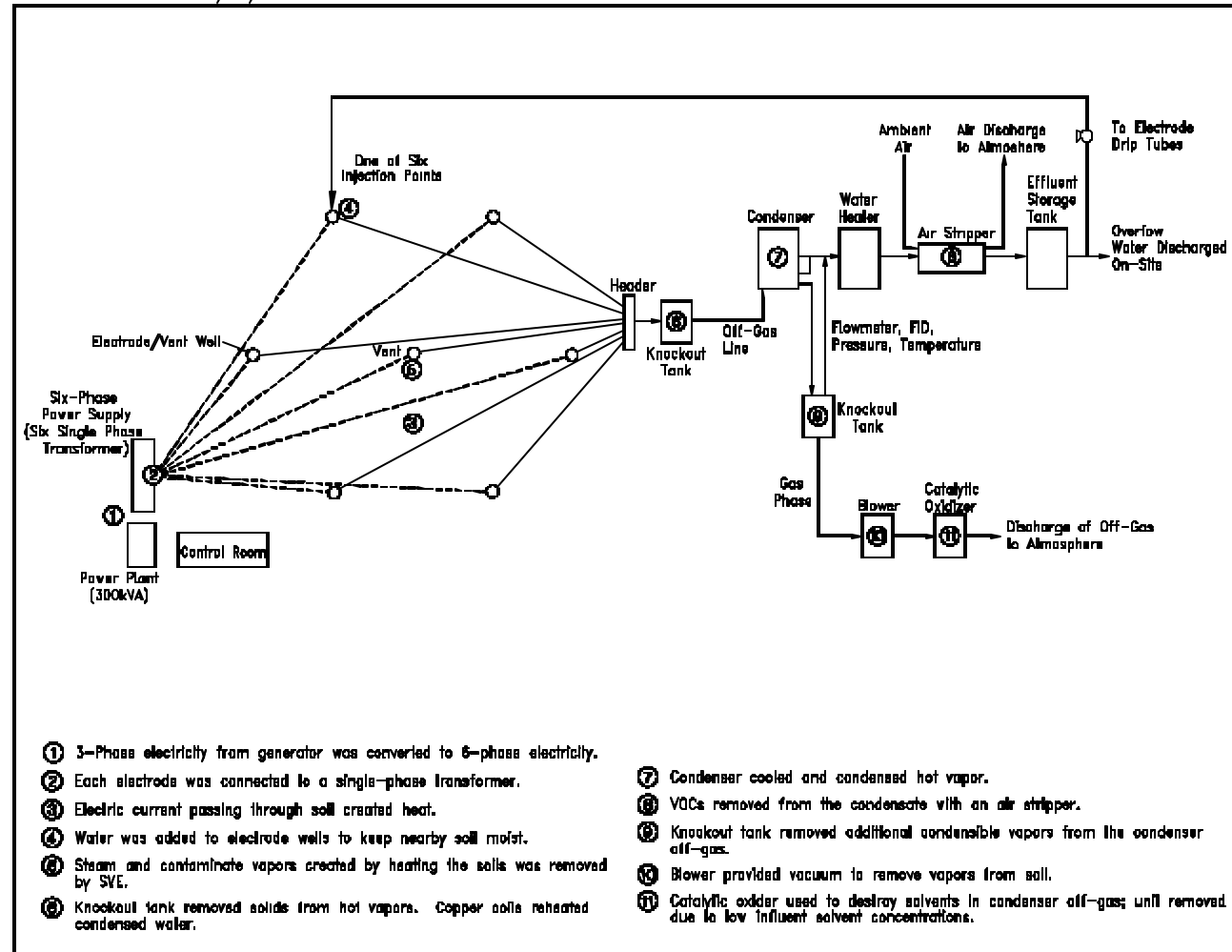


Figure 3. Process Diagram



The electricity will follow the path of least resistance between two electrodes. Saturated fine-grained soil has high conductivities, so the electricity will initially flow readily through this type of soil. As the soil is heated, the conductivities will change. These changes occur when the groundwater is turned to steam and is removed by the SVE system. By removing the groundwater, the moisture content and consequently the conductivity of the soil is reduced. As the moisture content decreases, the electricity will find a more conductive path through the soil. More electrical energy is required to maintain the system due to reductions in the conductivity. This is offset by increased air permeability of the dry soil, which enhances vapor recovery.

Site-Specific Description

After the initial system shakedown period, the three arrays were operated at the OU-B site. Each array was operated for a six-week period. A 455-kW diesel generator powered arrays 1 and 2. Array 3 used a 1200 kW diesel generator. Initially, two 500-gallon aboveground storage tanks supplied diesel for the generators. Additional aboveground storage tanks were added during operation of array 3 so that refueling trips could be reduced. Each generator supplied 3-phase, 480-volt power to the six-phase transformer and to other equipment on site.

The electrodes were installed in a circular array 27 feet in diameter for arrays 1 and 2 and 40 feet in diameter for array 3. All of the arrays were installed to heat soil from 8 to 38.5 feet bgs. The screened interval for each electrode extended from 10 to 20 feet bgs. This interval was selected to ensure that rising steam was captured by the SVE system and to intercept the most highly contaminated zone. Electrodes consisted of galvanized steel casings surrounded by granular graphite to enhance current flow. An 8-foot section of 6-inch diameter CPVC was placed over the upper portion of the casing to electrically isolate the upper 8 feet of soil from the electrode. This prevented active heating of the upper 8 feet of soil.

Quarter-inch drip tubes were attached to each electrode to allow for the injection of water into the soil immediately surrounding the electrode. Soil close to the electrode has a tendency to dry before the majority of the soil has completely heated. The decrease in soil conductivity requires higher voltages to be applied. By adding a small amount of water adjacent to the electrode, the conductivity is increased and the voltage requirements are lowered.

Based on a November 1996 feasibility study conducted at OU-B, the radius of influence of the SVE system was estimated at 25 feet. The SPSH treatability study was conducted at similar vacuum flow rates as demonstrated in the feasibility study. A 20-hp positive displacement blower was used to pull soil vapors from the extraction wells through a knockout tank to remove any solids from the hot vapors before entering a condenser. Copper coils in the knockout tank reheated any condensed vapors. The condenser cooled the vapors pulled from the extraction wells and separated the liquid and vapor phases. The gas phase passed through a second knockout tank prior to the blower to remove residual condensable vapors. This condensate and the liquid phase from the condenser were preheated and then pumped through an air stripper that used ambient air. After treatment, the air stripper effluent was used in the electrode drip tubes with the excess water discharged to area A-2.

During initial operations at array 1, a catalytic oxidizer was used to treat off-gas from the blower. Since the concentration of solvents in the off-gas was less than expected, the oxidizer was removed from the site before treatment at array 1 was completed.

System Operation and Monitoring

Operation of the treatment system was automated, but was monitored and adjusted daily. The major system adjustments that could be made at each electrode included the electrode voltage, the water drip flow rate, and the SVE system vacuum. Voltages were adjusted to maintain a constant power input to the



electrodes of approximately 400 kW. Higher voltages were required to maintain the desired power input as the soil dried and the soil conductivity decreased. The computer that monitored the six-phase transformer calculated the phase resistance at each electrode. The water flow rate was increased to electrodes that had higher resistances.

While the test was running, several parameters were monitored to help estimate the performance of the system. Some parameters were monitored by electrical sensors and automatically recorded by the on-site computer. These parameters included:

- Condenser off-gas pressure, flow, and temperature;
- Soil temperature from thermocouples placed at locations within each array that would be the last to heat;
- Transformer voltages, amperages, and total power; and
- Soil resistivity.

Other parameters were observed and manually recorded from various gauges. These parameters included:

- Generator amperage;
- Fuel levels;
- Vacuum at SVE knockout tanks;
- Off-gas photoionization detector levels; and
- Effluent water tank levels.

Post-Operation (1,2,8)

Treatment system shutdown and demobilization occurred in December 1997. Post-treatment soil samples were collected in January 1998. After operation of the treatment system, no additional restoration activities (e.g., final grading, landscaping) were necessary at the site.

Personnel Requirements (8)

Operation of the treatment system normally required one person on-site 8 hours per day, 5 days per week, and several hours each weekend day. An off-site project manager spent several hours each day managing the project (e.g., calling the client, locating parts, working with subcontractors, etc.).

Health and Safety Requirements (4,8)

For the RI, initial drilling operations were performed in Level B personal protective equipment (PPE), which included supplied breathing air and chemical resistant clothing, boots, and gloves. Approximately halfway through the field investigation, the health and safety requirements were reviewed and approval was granted by the USACE to downgrade to Level D PPE. The downgrade was requested because no chemical warfare materials had been detected in the area most likely to be contaminated.

All work related to the treatment system was performed in Level D PPE. During drilling operations, fans were used to dissipate solvent vapors.

OPERATING PARAMETERS AFFECTING TREATMENT COST OR PERFORMANCE (1,2,3,8)

The following table lists values for parameters associated with operation of the SVE system at PRDA OU-B. The parameters were selected for this report based on USACE guidance.



Table 3. Operating Parameters

Parameter	Design	Actual
Soil pH	Not Applicable	6.08 – 7.26
Soil Temperature	100°C	40 – 100°C after 2 weeks
Electrical Power Input	455 kW (Arrays 1 and 2) 1,200 kW (Array 3)	400 kW (Arrays 1 and 2) 200 – 800 kW (Array 3)
Air Flow Rate of the SVE System	Not Available	200 – 260 acfm (20°C and 10 – 11 psia)
Operating Pressure/Vacuum of the SVE System	Not Available	100 – 150 inches water
Condenser Flow Rate	Not Available	600 gal/day
Condenser Temperature	Not Available	140°C – Inlet Ambient – Outlet

TIMELINE (1,2)

Date	Activity
1990	The OU-B site was identified
1990-1992	Preliminary investigations conducted at the site
1993-1994	Removal action conducted at the site
June 1994	Fort Richardson added to the NPL
December 1994	FFA signed by the Army, ADEC and EPA
August - September 1995	Remedial investigation conducted
September 1996	Human and ecological risk assessment completed
January 1997	Feasibility study completed
August 8, 1997	ROD signed by U.S. EPA Region X Administrator
June 1997	Site mobilization, system set-up, and collection of pre-treatment soil samples
July 1 – 10, 1997	System shakedown
July 11 – August 22, 1997	Treatment conducted at Array 1
August 24 – October 9, 1997	Treatment conducted at Array 2
November 6 – December 18, 1997	Treatment conducted at Array 3
December 1997 – January 1998	Demobilization and collection of post-treatment soil samples

TREATMENT SYSTEM PERFORMANCE

PERFORMANCE OBJECTIVES (1,2)

System performance was evaluated against three primary criteria:

- The ability of each six-phase heating array to heat soil in-situ;
- Demonstrated removal of contaminants, as measured in the condenser off-gas and condensate; and
- Demonstrated reduction of soil contamination, as measured by the pre- and post-treatment soil sampling results.

The air stripper was operated so that the effluent concentrations were below Alaska's maximum contaminant levels (MCLs) for drinking water. Table 4 presents the MCLs for contaminants of concern at the site.



Table 4. Alaska Maximum Contaminant Levels (3)

Chemical	Alaska MCL (µ/L)
Benzene	5
Carbon Tetrachloride	5
Chlorobenzene	Not Established
Chloroform	100
1,4-Dichlorobenzene	Not Established
1,2-Dichloroethane	Not Established
1,1-Dichloroethene	7
cis-1,2-Dichloroethene	70
trans-1,2-Dichloroethene	100
Hexachloroethane	Not Established
TCA	Not Established
PCE	5
Toluene	1,000
1,1,2-Trichloroethane	5
TCE	5

TREATMENT PERFORMANCE DATA (1,2)

Figure 4 presents temperature profiles for each of the three arrays. Each thermocouple boring provided temperature readings at three depths within the arrays.

Condenser off-gas and condensate were sampled to determine concentrations of contaminants extracted by the system. Off-gas and condensate were collected from the condenser approximately every other day during operation. The off-gas samples were collected in summa canisters and sent to an analytical laboratory for volatile organic chemical (VOC) analysis by EPA Method TO-14. Water samples were analyzed for VOCs by EPA Method 8260A.

Table 5 presents the condenser off-gas sample results for arrays 1, 2, and 3. Condensate results from the three arrays are provided in Table 6. These results were used to calculate the mass of contaminants removed in the off-gas and condensate, respectively. While data was collected for a standard list of VOCs, only results for TCA, TCE and PCE are presented in these tables.

Air stripper effluent results for TCA, TCE, and PCE are also provided in Table 6 for comparison to influent concentrations. Sampling of the effluent was terminated once the air stripper demonstrated the ability to comply with the Alaska MCLs.

Soil samples were collected to determine pre- and post-treatment soil concentrations. Pre-treatment soil samples were collected during drilling for the thermocouple borings, and post-treatment soil samples were collected by drilling a boring adjacent to the thermocouple boring. Sampling at array 1 included two borings within the array and two outside the array. Sampling at arrays 2 and 3 each included one boring within the array and one outside the array. Sample locations are shown on Figure 2. Soil samples were analyzed for VOCs by EPA Method 8260A.

Table 7 presents a comparison of soil samples taken pre- and post-treatment. Results for the principal contaminants of concern at OU-B (TCE, PCE and TCA) are shown in the table. Detection limits were used to calculate removal efficiencies for samples where contaminants were not detected.



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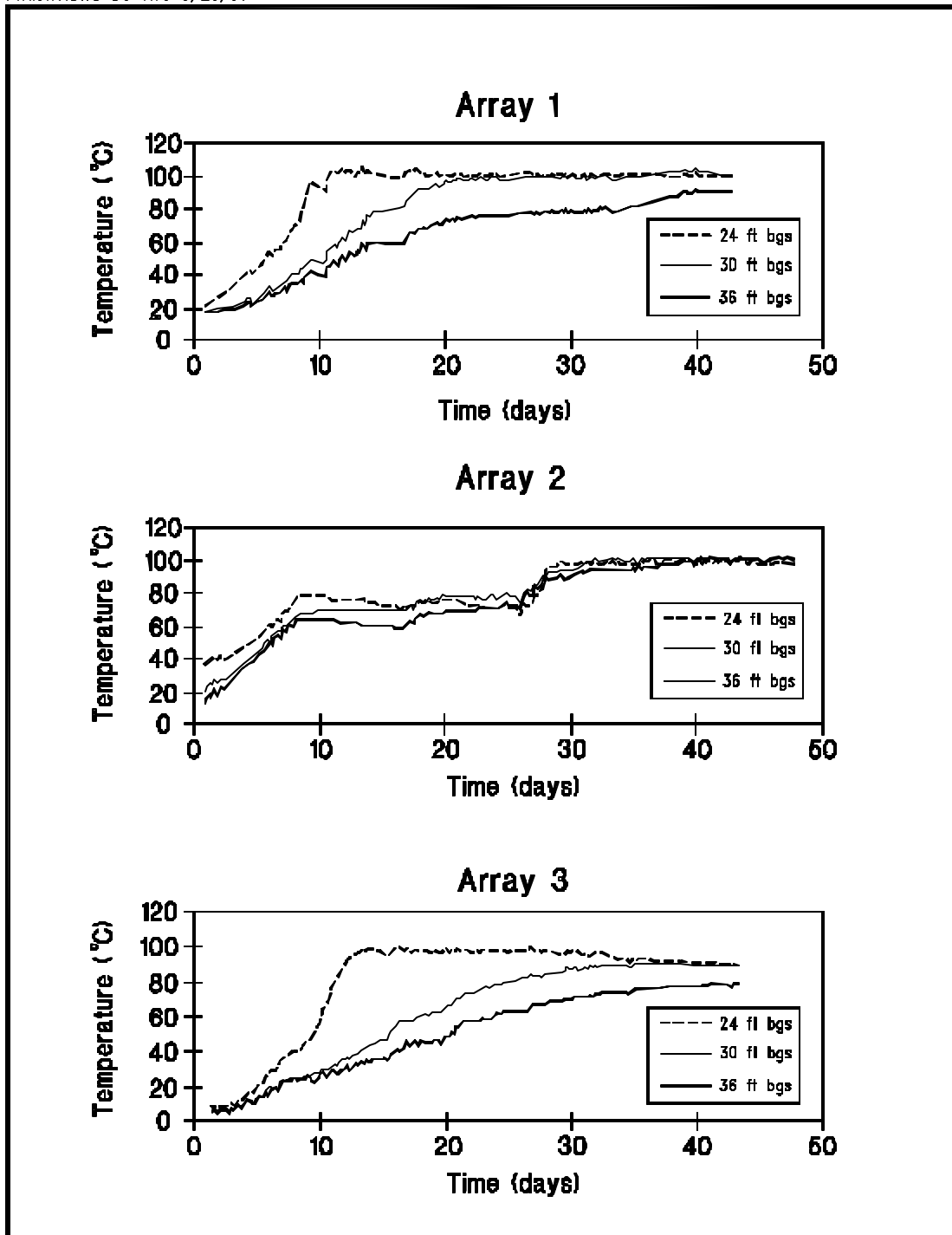


Figure 4. Temperature Profiles Within the Arrays



Table 5. Contaminant Concentrations in Condenser Off-Gas (ppmv)

Array	Sample Date	TCA	TCE	PCE
1	7/15/97	20	93	2.1
	7/19/97	50	200	6
	7/21/97	58	180	4.2
	7/24/97 condenser	2.3	53	1.3
	7/24/97 catox	5	9.4	0.38
	7/29/97	9.4	140	3.5
	7/31/97	130	340	11
	8/2/97	46	190	7.4
	8/4/97	18	120	3.6
	8/6/97	4.7	120	4.1
	8/8/97	5.8	73	2.4
	8/12/97	4.5	64	2
	8/16/97	1.4	100	2.8
	8/18/97	4.8	82	2.4
	2	8/26/97	5	140
8/29/97		5.9	120	3.5
9/5/97		5.3	50	1.6
9/10/97		5.5	52	1.5
9/20/97		3.3	85	3.2
9/23/97		5.4	110	4.1
9/25/97		6.7	100	3.6
9/27/97		4.4	130	4.7
9/29/97		2.4	55	1.8
10/1/97		2.4	30	0.98
3	10/4/97	8.1	36	1.2
	11/18/97	2	49	1.7
	11/20/97	0.38	18	0.56
	11/22/97	0.73	42	1.3
	11/24/97	0.38	56	1.7
	11/26/97	0.63	26	0.81
	11/28/97	1.3	38	1.2
	11/30/97	0.46	20	0.66
	12/2/97	0.6	23	0.76
	12/4/97	1	27	1.1
	12/6/97	0.18	17	0.66
	12/8/97	1.3	31	1.3
	12/10/97	2.3	30	1.2
	12/12/97	1.6	32	1.2
12/14/97	1.5	27	1	
12/16/97	1.1	21	1.5	
12/18/97	1.5	20	0.94	



Table 6. Contaminant Concentrations in the Condensate (mg/L)

Array	Sample Date	TCA		TCE		PCE	
		Condensate/Air Stripper Influent	Air Stripper Effluent	Condensate/Air Stripper Influent	Air Stripper Effluent	Condensate/Air Stripper Influent	Air Stripper Effluent
1	7/15/97	53,000	420	9,300	23	120	ND (1)
	7/19/97	130,000	160	20,000	6	760	ND (1)
	7/21/97	41,000	150	6,100	5	130	ND (1)
	7/24/97	15,000	34	2,100	3	26	ND (1)
	7/29/97	14,000	4	2,000	3	23	ND (1)
	7/31/97	20,000	NS	2,700	NS	33	NS
	8/2/97	14,000	NS	2,100	NS	38	NS
	8/4/97	11,000	NS	1,600	NS	25	NS
	8/6/97	13,000	NS	1,700	NS	33	NS
	8/8/97	19,000	NS	2,200	NS	15	NS
	8/10/97	25,000	NS	2,700	NS	17	NS
	8/12/97	18,000	NS	2,300	NS	15	NS
8/16/97	6,500	NS	1,400	NS	8	NS	
8/18/97	14,000	NS	2,000	NS	13	NS	
2	8/26/97	8,900	NS	2,400	NS	33	NS
	8/29/97	12,000	NS	2,900	NS	49	NS
	9/10/97	8,500	NS	1,400	NS	20	NS
	9/20/97	8,800	NS	1,800	NS	34	NS
	9/23/97	5,700	NS	1,900	NS	43	NS
	9/25/97	3,200	NS	1,200	NS	24	NS
	9/27/97	5,200	NS	3,300	NS	57	NS
	9/29/97	8,100	NS	1,500	NS	30	NS
	10/1/97	2,600	NS	890	NS	14	NS
10/4/97	4,000	NS	1,300	NS	17	NS	
3	11/18/97	20,000	NS	2,200	NS	33	NS
	11/20/97	12,000	NS	1,300	NS	20	NS
	11/22/97	8,800	NS	1,800	NS	28	NS
	11/24/97	19,000	NS	4,600	NS	64	NS
	11/26/97	7,400	NS	1,500	NS	21	NS
	11/28/97	8,300	NS	1,800	NS	27	NS
	11/30/97	4,900	NS	1,200	NS	17	NS
	12/2/97	11,000	NS	1,800	NS	33	NS
	12/4/97	8,500	NS	1,600	NS	25	NS
	12/6/97	7,100	NS	1,300	NS	23	NS
	12/8/97	4,700	NS	920	NS	15	NS
	12/10/97	2,800	NS	590	NS	10	NS
	12/12/97	3,100	NS	1,100	NS	13	NS
	12/14/97	3,900	NS	1,200	NS	15	NS
12/16/97	3,600	NS	1,100	NS	14	NS	
12/18/97	3,600	NS	1,100	NS	14	NS	

NS – Not Sampled. Sampling of the air stripper was stopped once the unit demonstrated the ability to comply with the Alaska MCLs.



Table 7. Pre- and Post-Treatment Soil Concentrations (mg/kg)

Array	Sample ID	Sample Depth (ft)	TCA Concentrations			PCE Concentrations			TCE Concentrations		
			Pre-Treat	Post-Treat	% Removal	Pre-Treat	Post-Treat	% Removal	Pre-Treat	Post-Treat	% Removal
1	T-A2 Inside Array	5-6.5	0.56	0.08	86	0.67	ND (0.07)	90	6.6	0.20	97
		10-11.5	0.12	ND (0.05)	58	0.05	ND (0.05)	0	1.3	0.51	61
		15-16.5	11	ND (0.05)	100	0.85	ND (0.05)	94	7.1	0.28	96
		20-21.5	1000 D	ND (0.06)	100	8.9	ND (0.06)	99	110 D	1.10	99
		25.5-27	32 D	ND (0.06)	100	0.48	ND (0.06)	88	5.5	0.86	84
		30-31.5	0.43	ND (0.05)	88	ND (0.05)	ND (0.05)	-	1.35	0.37	72
		35-36.5	0.41	ND (0.05)	88	ND (0.06)	ND (0.05)	-	1.6	0.19	88
1	T-A3 Inside Array	4.5-6	ND (0.07)	ND (0.06)	-	0.26	ND (0.06)	77	2.5	0.07	97
		9.5-11	0.17	0.105	38	0.07	ND (0.055)	21	2.15	0.53	75
		14.5-16	36 D	ND (0.05)	100	0.64	ND (0.05)	92	9.2	0.29	97
		19.5-21	190 D	0.23	100	3.3	ND (0.05)	98	39 D	6.10	84
		24.5-26	160 D	1.1	99	1.2	ND (0.06)	95	11	1.5	86
		29.5-31	130 D	0.13	100	2.4	ND (0.06)	98	36 D	0.56	98
1	T-A1 5 ft Outside Array	5-6.5	0.35	0.25	29	2.3	0.07	97	7.1	0.65	91
		9.5-11	0.5	0.25	50	0.55	0.10	82	2.2	0.78	65
		15-16.5	0.52	ND (0.05)	90	0.1	ND (0.05)	50	2.0	0.58	71
		20-21.5	72	26	64	0.86	0.49	43	3.8	13	-242
		25-26.5	200	0.91	100	0.35	ND (0.05)	86	3.0	1.3	57
		30-31.5	2.6	0.17	93	0.08	ND (0.06)	25	2.5	0.96	62
		35-36.5	4	ND (0.05)	99	ND (0.05)	ND (0.05)	-	0.91	0.46	49
1	T-A4 3 ft Outside Array	4.5-6	0.26	ND (0.06)	77	0.23	ND (0.06)	74	3.2	0.66	79
		9-11.5	0.70	0.15	79	0.2	0.05	75	4.8	1.4	71
		14.5-16	4.9	0.6	88	0.24	ND (0.06)	75	4.0	0.85	79
		19.5-21	26	0.13	100	0.98	0.20	80	11	5.90	46
		24.5-26	230	0.66	100	18.3	0.16	99	185	3.30	99



Table 7 (Continued)

Array	Sample ID	Sample Depth (ft)	TCA Concentrations			PCE Concentrations			TCE Concentrations		
			Pre-Treat	Post-Treat	% Removal	Pre-Treat	Post-Treat	% Removal	Pre-Treat	Post-Treat	% Removal
2	T-A5 Inside Array	3.5-5.5	0.35	0.08	77	2.80	ND (0.06)	98	69 D	0.87	99
		10-12	0.35	ND (0.05)	86	0.08	ND(0.05)	38	3.30	0.58	82
		15-17	0.43	ND (0.05)	88	0.08	ND (0.05)	38	2.30	0.18	92
		20-22	3.50	ND (0.05)	99	0.17	ND (0.05)	71	3.70	0.06	98
		25-27	110 D	ND (0.05)	100	8.10	ND (0.05)	99	270 D	0.09	100
		29-31	0.36	ND (0.06)	83	0.41	ND (0.06)	85	1.90	ND (0.06)	97
		34-36	0.35	NS	-	ND (0.06)	NS	-	2.00	NS	-
38-40	0.67	NS	-	0.07	NS	-	3.10	NS	-		
2	T-A6 5 ft Outside Array	5-7	0.33	0.12	64	0.77	0.13	83	6.30	1.9	70
		10-12	0.11	ND (0.05)	55	ND (0.05)	ND (0.05)	-	1.50	0.57	62
		15-17	6.1	ND (0.05)	99	1.10	ND (0.05)	95	14	0.68	95
		20-22	1.8	ND (0.05)	97	0.14	0.16	-14	3.20	2.1	34
		25-27	34	ND (0.05)	100	1.80	0.17	91	31	1.9	94
		30-32	0.23	ND (0.06)	74	0.42	ND (0.06)	86	1.70	0.65	62
		35-37	1.5	ND (0.06)	96	ND (0.06)	ND (0.06)	-	1.90	0.89	53
3	T-A7 Inside Array	15-16.5	4.0	NS	-	0.06	NS	-	1.7	NS	-
		20-21.5	51	ND (0.06)	100	0.60	ND (0.06)	90	25 D	0.32	99
		25-26.5	34	ND (0.05)	100	0.77	0.06	92	17 D	1.7	90
		30-31.5	0.67	ND (0.05)	93	ND (0.05)	ND (0.05)	-	1.3	0.92	29
		35-36.5	ND (0.06)	ND (0.05)	-	ND (0.06)	ND (0.05)	-	0.11	0.94	-755
3	T-A8 8 ft Outside Array	15-16.5	0.31	48	-15384	0.57	3.8	-567	5.9	15	-154
		20-21.5	18	12	33	0.47	0.53	-13	6.6	3.7	44
		25-26.5	6.9	NS	-	0.15	NS	-	2.5	NS	-
		30-31.5	0.11	1.9	-1627	ND (0.06)	0.15	-150	1.9	1.8	5
		35-36.5	0.65	0.07	89	ND (0.06)	ND (0.05)	-	1.4	1.3	7

D – Diluted Sample
 ND () – Not Detected (detection limit)
 NS – Not Sampled



PERFORMANCE DATA ASSESSMENT (1,2)

The SPSH design verification study successfully achieved all of the criteria established for performance of the system. The performance criteria were:

- Heating the soil;
- Demonstrating removal of contaminants in the condenser effluent; and
- Demonstrated reduction of soil contamination.

SPSH successfully heated soil in situ in all three arrays. Data collected from the thermocouples show that the soil was heated to near 100°C in each array. Once the soil was heated to the boiling point of water, the water within the soil turned to steam and was removed by the SVE system. Where soil moisture was not replaced, the conductivity of the soil decreased and the temperature of the soil decreased in the latter part of the test. Where there was adequate groundwater flow, the soil moisture and conductivity were maintained and the temperature remained near 100°C.

SPSH removed significant quantities of contaminants as indicated by the condenser off-gas and condensate sample results. As shown in Table 8, the mass of solvents removed in the off-gas was significantly higher than the mass removed in the condensate. This difference is most likely due to the volatility of the contaminants present at this site.

Table 8. Treatment Summary

Array	Soil Treated		Contaminant Mass Removed – Method 1			Contaminant Mass Removed – Method 2		
	CY	Tons	in Off-Gas (lbs) ¹	in Condensate (lbs) ²	Total (lbs)	in Soil Pre-Treat	in Soil Post-Treat	Change (lbs) ³
1	1,260	2,300	386	7.6	393.6	506	6	500
2	1,230	2,250	217	2.7	219.7	211	4.4	206.6
3	1,420	2,600	138	4.9	142.9	142	7.6	134.4

¹ Estimate based on total VOCs in off-gas. Mass was calculated daily using daily air flow rate through the condenser and contaminant concentration from the closest day that data was available.

² Estimate based on total VOCs in the condenser water effluent. Mass was calculated daily using daily flow rate from the condenser and laboratory data from the closest day that data was available.

³ TCE, PCE, and TCA were used to calculate masses. Estimates are averages of soil concentrations found on site.

Table 8 provides pre-and post-treatment contaminant masses for each array and the mass of contaminant observed in the SVE condenser off-gas and condensate (before treatment by catalytic oxidation and air stripping, respectively). Theoretically, the amount of contaminant reduction in the soil should equal the amount of contaminant removed by the SVE system. In reality, these amounts were not equal. Use of differing sampling and calculation methods most likely caused this difference. Condenser off-gas and condensate flow rates were available for every day the system was operating, but contaminant concentrations were available only every other day at best. For days where there were no sample results, results from the closest day that had results were used as the concentration for that day. Post-treatment soil samples were collected as near to the same location as the pre-treatment soil samples as possible. While this minimizes the introduction of variability, it cannot eliminate it. Considering the variability normally associated with environmental sampling, the results are considered representative.

SPSH achieved significant reductions in soil contamination as measured by pre- and post- treatment soil sampling. Average contaminant removal rates are shown in Table 9 for soil inside and outside the arrays. Removal rates were greater than 90% for soil inside the first two arrays. Contaminant removals for PCE and TCE at array 3 were lower than arrays 1 and 2 possibly due to lower starting concentrations and increased soil resistivity. Use of a larger array increased soil resistivity and therefore resulted in less efficient soil heating.



Table 9. Average Removal Efficiencies for Soil Remediation

Array	TCA		PCE		TCE	
	Inside	Outside	Inside	Outside	Inside	Outside
1	100%	96%	96%	96%	94%	92%
2	100%	99%	96%	84%	99%	85%
3	100%	-198%	82%	-332%	89%	-49%

Soil sample results from areas outside arrays 1 and 2 indicate that contaminant removal is significant but less efficient than inside the arrays. This may be due to the zone of heated soil not extending as far outside of the arrays as the radius of influence for the SVE system. The SPSH zone extended at least to the outside sampling point for arrays 1 and 2 (approximately 40% of the array radius, or 5 feet, beyond the array boundary); the SPSH zone did not extend as far (percentage wise) beyond the array boundary for array 3.

The pre- and post-treatment soil sampling results indicated that the contaminant concentrations in several locations actually increased during the treatment period. Several negative removal rates were calculated. This is most likely a result of sampling variability and not an actual increase in the concentration of contaminants.

Performance of the SPSH-SVE system was compared with performance of the SVE-only system, which was tested at OU-B in November 1996. This test involved extracting soil gas vapors from MW-14, located directly adjacent to array 1 (shown on Figure 2). Table 10 presents the range of total VOC concentrations in the condenser off-gas under test conditions with and without SPSH. The tests were conducted at similar vacuum flow rates.

The concentration of total VOCs in extracted soil gas was significantly higher in samples collected during the SPSH study. This increase in VOC concentrations is attributed to the increased soil temperatures induced by the SPSH system.

Table 10. Comparison of VOC Removal With and Without SPSH

Test	Total VOC Concentration (ppmv)
SVE treatability study (without SPSH)	15 – 70
Array 1 (SVE with SPSH)	50 – 499
Array 2 (SVE with SPSH)	36 – 161
Array 3 (SVE with SPSH)	20 – 60

PERFORMANCE DATA QUALITY (4)

The following QA/QC requirements were followed during the RI performed at OU-B:

- Applicable EPA sampling and analysis methods were used. Where EPA methods were not available, standard industry methods were used.
- Laboratory data packages included complete raw data deliverables and documentation sufficient to perform a USACE Level III data validation.
- QC samples and procedures were utilized by the off-site laboratory.
- A Level III data validation was performed on the off-site laboratory data. Guidelines recommended in EPA’s Laboratory Data Validation Functional Guidelines for Evaluating Organic or Inorganic Analyses were followed.



- Duplicate samples were collected at a frequency of 10% and sent to the USACE Quality Assurance Laboratory for analysis.
- For generation of field screening data, applicable organic methods were used in the field laboratory and QC samples and procedures were utilized by the field lab.
- Rinsate blanks, field duplicates, and trip blanks were collected and submitted to the off-site laboratory for analysis to provide a means for assessing field QC.

TREATMENT SYSTEM COST

PROCUREMENT PROCESS (1,8)

The SPSH study was implemented as a delivery order to a pre-placed indefinite delivery type architect-engineer (IDT-AE) contract. As such, the scope of work for each array was defined by the government and negotiated with the contractor. The result of the negotiation was a firm-fixed price contract for accomplishment of the work described in the defined scope.

Woodward-Clyde Federal Services was selected as the contractor to perform the SPSH study. Woodward-Clyde subcontracted with the following companies to perform the listed project tasks:

<u>Subcontractor/Equipment Vendor</u>	<u>Tasks</u>
Current Environmental Solutions	Treatment system vendor, monitoring the on-site computer
Tester Drilling	Drilling operations
Multichem	Analytical laboratory
Pye-Per Fuels	Diesel fuel delivery
Craig Taylor Rental	Rental of 455 kW generator
NC Machinery	Rental of 1200 kW generator
H2Oil	Rental of blower and air stripper

TREATMENT SYSTEM COST (1,8)

The total budgeted cost for this project was \$967,822. Costs for each array includes installation of the electrode wells, thermocouple wells, and all ancillary equipment for operation of the system (generator, blowers, piping, etc.) All sampling, testing, and monitoring costs are also included. Table 11 summarizes the budgeted costs for the SPSH study. The contractor indicated that these costs were fairly close to the actual costs incurred.

The contract price for the first array included costs for mobilization of the SPSH transformer equipment, a catalytic oxidizer for treatment of off-gas, and other startup and operational troubleshooting costs not included in subsequent arrays.

Unit costs were calculated using the sum of the budgeted capital and operation and maintenance (O&M) costs. These unit costs are shown in Table 11. The soil treatment costs calculated for the treatability study at OU-B ranged from \$189 to \$288 per CY of soil treated or \$103 to \$158 per ton of soil treated. On a contaminant basis, the soil treatment costs ranged from \$726 to \$2,552 per pound of contaminant removed.



Table 11. Cost Summary

Cost Category	Cost Element	Array 1	Array 2	Array 3	Total
Capital Costs (\$)	Mobilization and Demobilization	13,254	0	1,431	
O&M Costs (\$)	Planning and Preparation	0	0	1,508	
	Subcontractors	286,740	180,507	188,798	
	Site Work				
	Startup and Testing				
	O&M Labor				
	Performance Testing and Analysis	36,541	25,146	56,265	
	Equipment and Appurtenances	1,494	1,195	848	
	Materials/Supplies	25,213	25,213	94,130	
	Fuel				
Capital + O&M Costs (\$)	(used to calculate unit costs)	363,243	232,061	342,980	938,284
Other Technology Specific Costs (\$)	Sampling IDW and DNAPL	5,362	0	8,532	
Other Project Costs (\$)	Travel Expenses	8,593	3,090	3,961	
Total Project Cost (\$)		377,198	235,151	355,473	967,822
Treated Soil (CY)		1,260	1,230	1,420	3,910
Treated Soil (ton)		2,300	2,250	2,600	7,150
Contaminant Removed (lbs)		393.6 – 500	206.6 – 219.7	134.4 – 142.9	734.6 – 862.6
Unit Cost (\$/CY)		288	189	241	240
Unit Cost (\$/ton)		158	103	132	131
Unit Cost (\$/lb contaminant removed)		726 – 923	1,056 – 1,123	2,400 – 2,552	1,088 – 1,277



For cost comparison purposes, the cost of treating the same soil (soil excavated from areas A-3 and A-4) in ex-situ static piles by heat enhanced SVE was \$150 per CY not including excavation, sampling, and testing costs. The supplier of the technology reported that costs can be reduced to a range from \$30 to \$85 per CY of treated soil for easily accessible sites where commercial power is available. The cost of off-site disposal at the Defense Reutilization and Marketing Office is approximately \$2,400 per CY, not including excavation or packaging.

COST SENSITIVITIES (1)

A significant portion of the operating cost of the treatment system came from the large power requirements of the treatment equipment. Because the site was in a remote location, power was provided by mobile, diesel fuel-powered electric generators. Because of this, fuel consumption and rental of the generators and storage tanks added a significant cost to the project that would not be incurred at sites where commercial electrical power is available.

REGULATORY/INSTITUTIONAL ISSUES

Because this project was performed under CERCLA regulations, it was not necessary to obtain permits from local regulatory authorities for on-site activities. It was necessary, however, to meet the substantive requirements of potentially applicable regulations.

The following table lists the remedial action objectives for soil treated at OU-B. These objectives were established in the ROD.

Table 12. Treated Soil Objectives (2)

Chemical	Performance Criteria (mg/kg)
TCA	0.1
PCE	4.0
TCE	None Provided

The remedial objective for groundwater at OU-B is to reduce contamination to comply with Alaska's MCLs for drinking water. The applicable MCLs are provided in Table 4.

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

APPLICABILITY OF THE TECHNOLOGY (2,3,7)

The media of concern for evaluation in the FS at OU-B were the perched, shallow and intermediate groundwater intervals, and "hot spot" soil, all potential sources of continuing contamination to the deep aquifer at the site. The FS evaluation focused on contaminated soil and groundwater to a depth of 60 feet bgs. The depth of 60 feet bgs was chosen because it was deeper than the most highly contaminated groundwater, modeling showed that treatment to this depth would be sufficient to capture contaminants, and it is the depth below which specialized and overly expensive equipment would be necessary for trenching.



A treatability study was performed that included pilot testing of SVE and air sparging. The SVE system was run for 5 days with the air sparging test conducted on the last day. Samples of extracted soil gas showed that SVE was effective at removing TCA and TCE, the designated indicator chemicals. With the air sparge blower on, TCE concentrations were increased in the SVE off-gas but TCA concentrations were not significantly affected. Although the SVE test was considered successful, the FS recommended that SVE treatment enhanced with in situ soil heating could be used at the site as a means for completing treatment more rapidly.

USACE requested an analysis of heat enhancement methods. After a comparison of several different methods to heat the subsurface soil, electrical resistance (e.g., SPSH) was selected for evaluation at OU-B over radio frequency heating because it more efficiently delivers energy to the fine-grained soil found on site. This is important because, with either technology, electrical costs represent a significant portion of the total cost of remediation.

SPSH simultaneously heats and ventilates soil in situ to remove volatile and semivolatile organic contaminants. SPSH is applicable for treatment of contaminated subsurface environments (soil, sludge, or sediments) in which contamination may be sorbed onto soil particles, dissolved in groundwater, or in the vapor phase. These media may be either fully or partially saturated with water. The process has been proven greater than 99% effective at removing VOCs in the vadose zone.

COMPETING TECHNOLOGIES (2,7)

The SPSH technology has many advantages over currently available and comparable technologies. There are several different accepted methods for heating subsurface soil. These include steam injection, use of radio frequency, and use of electrical resistance (e.g., SPSH). Steam injection is typically effective in more permeable and heterogeneous soil. High soil permeability is necessary to allow the steam to move through the soil. Steam injection was rejected as a potential heating technology at OU-B because contamination at OU-B is predominantly found in finer-grained soil.

Radio frequency and electrical resistance heating methods work well with moist, fine-grained, low-permeability soil. Soil heterogeneity is not necessary since steam is generated within the soil matrix. Both technologies require large amounts of electrical power, however electrical resistance heating is more efficient in delivering energy to the soil. Approximately 55% of the energy supplied by an electrical source is delivered to the soil by the radio frequency method compared to nearly 100% energy delivery by the electrical resistance method. In contrast to electrical resistance heating, radio frequency heating does not require the presence of water to carry electrical current. As a result, radio frequency heating can increase soil temperatures above 100°C, the limiting temperature for electrical resistance heating. In addition, SPSH uses standard power frequency systems which are more robust and less expensive than higher frequency systems. At the time of this report, a treatability study was being conducted at Fort Wainwright, near Fairbanks, Alaska to compare the performance characteristics of radio frequency and SPSH.

The SPSH process results in accelerated and more complete removal of target contaminants from soil when compared to conventional SVE treatment and does not require excavation. Compared to pump-and-treat systems, SPSH provides an increased rate and extent of remediation, reduced O&M costs due to shorter time on site, and is applicable to low-permeability, heterogeneous, and LNAPL/DNAPL-contaminated soil. In addition, SPSH has several advantages over excavation and ex-situ treatment. SPSH provides lower risk of contaminant exposure to humans and the environment, lower cost (20% to 30% of the cost of excavation and on-site treatment), and is applicable to sites with deep contamination (excavation is difficult below the water table).



SPSH has the following disadvantages compared to alternate technologies. However, some of these disadvantages are common to several alternate technologies. SPSH:

- Is limited to heating soil to 100°C;
- Does not address non-volatile organics, metals, and other inorganics;
- Requires treatment of contaminants above ground in the off-gas treatment system;
- Requires access roads for equipment, materials, and system transport;
- Requires site mobilization, operation, and demobilization of equipment;
- Is emerging on the commercial market, so demonstration experience is limited;
- Excludes people from the treatment zone; and
- Requires a relatively large source of electrical power.

SPSH is a patented technology available through Battelle or Battelle's industrial partners working in a collaborative relationship. Battelle created Current Environmental Solutions (CES) for the purpose of commercializing the SPSH technology.

MATURITY OF THE TECHNOLOGY (1,7)

Development of SPSH began at Battelle in 1989. Before 1996, SPSH used on saturated soil had only been tested at the bench scale although SPSH had been successfully demonstrated and was commercially available for removing contaminants from the vadose zone. In 1996, Battelle performed a technology demonstration of saturated soil at the National Test Site at Dover Air Force Base. Since then, CES has conducted pilot-scale studies in Alaska and full-scale remediation of DNAPL in the saturated zone at sites in Chicago, Seattle and Niagara Falls.

OBSERVATIONS AND LESSONS LEARNED

COST OBSERVATIONS AND LESSONS LEARNED (2,8,10,11)

The most critical factor in controlling energy costs is the volume of soil treated. The amount of electricity that needs to be applied to a site increases in proportion to the volume of soil treated. Other treatment system costs such as blowers, air strippers, sampling and labor to operate the system do not increase as quickly. Other factors that affect energy costs include the cost of electricity, soil type, moisture content, and the length of time needed to reach remediation goals, which depends on initial contaminant concentrations, physical/chemical properties of the contaminants, and the remediation goals.

Energy consumption can be estimated for a site by calculating the energy required to heat a known volume of water to a certain temperature, which, in the case of SPSH, is typically 100°C. The volume of water to be heated is calculated based on the dimensions of the soil to be treated and the moisture content of the soil.

Larger arrays require larger generators. For example, array 3 used a 1200 kW generator while arrays 1 and 2 used a 455 kW generator. A large generator can potentially use several thousand gallons of fuel each day. The fuel requirement can significantly impact operating costs and can, therefore, restrict the size of a cost-effective array.

Since the treatability study was completed, the Army installed a buried electric line to OU-B from an access point one mile away. The installation cost was approximately \$108,000. Any additional SPSH remedial actions at OU-B will have lower costs since generator rental and fuel purchase costs will be eliminated.



PERFORMANCE OBSERVATIONS AND LESSONS LEARNED (1,2)

There may be limitations to the size of the array that can effectively treat soil at a particular site. The size of the array is limited by the resistivity of the soil and power requirements. In array 3, voltage could not be effectively transferred to the soil throughout the array due to the increased resistivity of the volume to be treated. The result was decreased heating. It is recommended that arrays should not be constructed greater than 30 feet in diameter at OU-B unless electrode construction and water delivery systems are improved.

Soil temperatures can be maintained near 100°C in areas where soil moisture can be replaced.

Lower initial contaminant concentrations in array 3 reduced the treatment efficiency. As can be expected with many treatment systems, it is more difficult to remove contaminants at low concentrations.

Preferential flow pathways due to discontinuities in the soil may cause increased contaminant concentrations in some areas. Several concentration increases were measured, particularly in array 3 in which incomplete heating reduced removal efficiencies.

While TCE was present at lower concentrations than TCA in the soil prior to treatment, TCE was measured at an order of magnitude higher than TCA in the condenser off-gas. This is to be expected because TCE is much more volatile than TCA, and TCA has been shown to hydrolyze to TCE in the presence of water. Elevated temperatures may increase the rate of hydrolysis.

Effluent water from the condenser must be heated prior to treatment in an air stripper. The water leaving the condenser was sufficiently cold that the treatment efficiency of the air stripper was diminished. As a result, the air stripper did not meet treatment objectives initially. Pre-heating of the water leaving the condenser solved this problem.

OTHER OBSERVATIONS AND LESSONS LEARNED (1,2,8)

Use of a hollow stem auger caused problems during installation of the electrodes. The 6-inch auger casing barely allowed sufficient space for installation of the 4-inch electrode, the drip tubes, and the granular graphite. The drillers had problems reaching the desired depths with the augers because large cobbles were present at the site. Other problems occurred because of water that moved into and remained in the augers while drilling below the water table. The granular graphite often bridged at the water table interface, forcing the drillers to remove the electrode materials and start over. Future electrode installations that extend below the water table should be made with an air rotary drill rig. The air rotary drill rig provides a larger inside diameter workspace and allows easy removal of water within the casing.

The voltages induced by the SPSH in the soil can cause problems with site safety and the operation of sensitive electrical equipment. Significant grounding problems were encountered during operation of arrays 1 and 2. Electrical equipment used during operation of arrays 1 and 2 was located, in some cases, as close as 25 feet from the nearest electrode. Despite the fact that each piece of equipment was equipped with an individual grounding rod, problems with proper grounding still occurred. These problems were avoided during operation of array 3, by moving the equipment farther from the array. The equipment was placed 70 to 80 feet from the nearest electrode while heating array 3. In addition, a properly sized grounding mat was used and the problems were mitigated. For future applications, it is recommended that equipment not be sited closer than 80 feet from any electrode. An experienced electrical engineer should design the grounding system.



Use of SPSH has been a limitation at some sites where there are electrically conductive utilities. Modifications to the design and installation of the SPSH system allowed its use at a site in Seattle with buried utilities for sewer, electrical, water, and natural gas; similar modifications may be possible at other sites.

Consideration should be given to the substantive regulatory requirements that may be triggered by using on-site generators at remote locations. The air emissions from the generators are more likely to be regulated than are the relatively low emissions from the treatment system. Depending on the estimated potential air emissions, New Source Review/Prevention of Significant Deterioration and other Clean Air Act requirements may be applicable. Potential emissions must be calculated assuming year-round operation of the system (8,760 hours per year).

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