COST AND PERFORMANCE REPORT

IN-SITU THERMAL DESORPTION

At

The Former Mare Island Naval Shipyard

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INTRODUCTION

This report presents cost and performance data for In-Situ Thermal Desorption (ISTD) using thermal blankets and thermal wells at the former Mare Island Naval Shipyard. The demonstrations were conducted by TerraTherm Environmental Services and RT Environmental Services, in cooperation with the U.S. Navy and the Bay Area Defense Conversion Action Team (BADCAT) Environmental Technology Project (ETP).

SITE INFORMATION

SITE LOCATION

The Mare Island electrical shop is located between Cedar and Suisun Avenues and 11th and 12th Streets, near the center of Mare Island Naval Shipyard, CA. The test site was located in the area of the former 3,000 gallon grease trap and adjacent paved areas located at the northwest corner of Building 866. The facility is on a relatively flat portion of a hillside with a surface elevation approximately 26 feet above mean sea level. To the north and west of the facility, a hill slopes sharply upward to the original grade of the hillside. The grounds and building are surrounded by an eight-foot high chain link fence. The southwest half of the facility is located on bedrock, while approximately three to four feet of fill overlies the bedrock in the northeastern portion of the property.

Building 866 is a five-story concrete block structure built on a concrete slab at grade (no basement). The area of the former grease trap, which was connected to the industrial wastewater (IW) collection system, is now paved. A former transformer storage area is near the northwest side of the building. Figure 1 shows the locations of the thermal wells and thermal blankets.

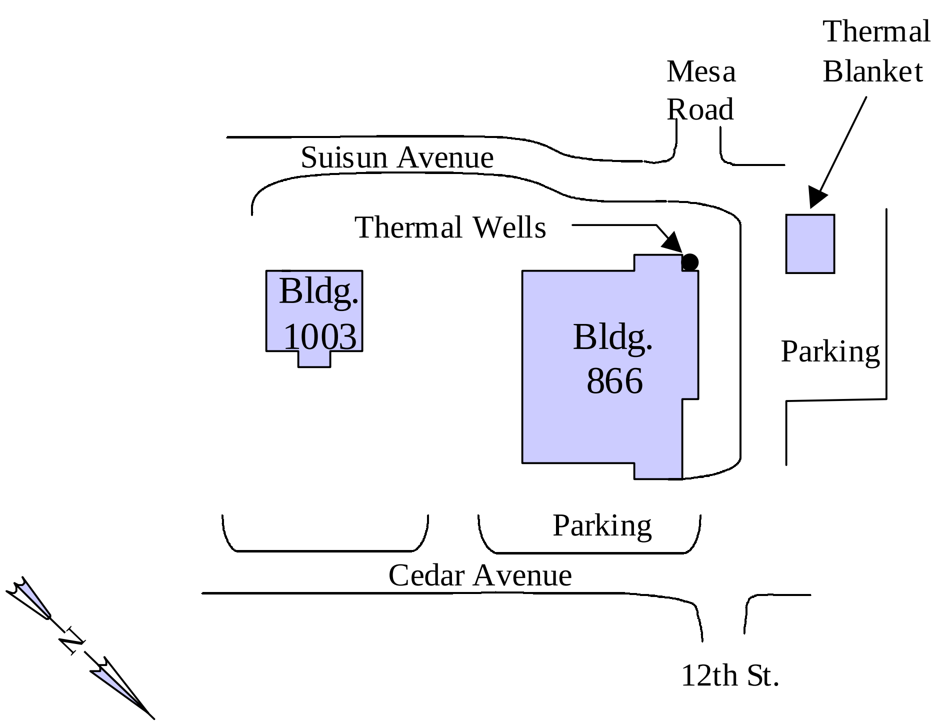

Figure 1. Site location at Mare Island Naval Shipyard.

SITE BACKGROUND

The facility was used as an electrical workshop from 1955 to 1994. Activities in the building included electrical and electronic equipment processing and overhaul. Processing entailed fabricating circuit boards, switches, breakers, transducers, and plugs. Overhaul activities included cleaning, repairing, and decommissioning motors, generators, transducers, transformers, breakers, and electrical instruments. Materials used during the processing and overhaul activities included lubricants, sealants, paints, plating compounds, epoxies, rubber compounds, radioactive materials (including plutonium and cesium), oils, photochemicals, solvents, degreasers, and detergents. Solvents (including methyl ethyl ketone, and stoddard solvent) were frequently used in most of the facility work areas from 1955 until the late 1960s.

The largest equipment cleaning facility, the cleaning room associated with the motor and transformer work area, was built so that workers could easily wash motors and transformers before repairing them or decommissioning the equipment. The cleaning room and the motor and transformer work areas are located on the ground floor in the western corner of the building. Transformers were reportedly stored in the fenced area outside the cleaning room.

From 1955 to 1978, transformers washed in the cleaning room contained polychlorinated biphenols (PCB) oils. Transformer washing procedures included draining the oil and pressure washing the interior of the transformers with steam and degreasing solvents or detergents. All of the oil and washing wastes entered a 30-gallon sump through floor grates and drains. The liquid waste and sludge that accumulated in the cleaning room sump were pumped through a 6-inch diameter drain pipeline into the grease trap near the western corner of the building. The grease trap separated grease and sludge from the liquid waste prior to discharge into the storm water or sanitary sewer (1955 to 1972), or to the IW collection (after its construction in 1972). Grease and sludge from the grease trap were removed periodically.

In 1981, the Navy cleaned and plugged the floor drains in the cleaning room. The sludge was found to contain PCBs, and further samples revealed PCB contamination in the cleaning room sump, the grease trap, and the IW collection system. As a result, these systems were cleaned and removed from service. The grease trap was subsequently removed, and the lines of the IW collection system were capped.

During the drilling of a dewatering test well for a planned pump test prior to beginning the ISTD demonstration, a pipeline containing oily liquid was encountered. This pipeline is believed to be a portion of the drain system previously connecting Building 866 to the grease trap. This line was pumped out, cut, and capped at the building wall prior to proceeding. Soils excavated from this area were used for the thermal blanket demonstration.

Oily liquids containing some of the compounds used in the cleaning room apparently entered the soil through the grease trap. As previously stated, the area for the ISTD demonstration is located in the vicinity of the former grease trap near the western corner of Building 866. The target compounds in this area are primarily PCBs, although total petroleum hydrocarbons (TPH) in the gasoline range were also detected in concentrations above applicable standards. Concentration reduction of PCBs was the focus of the technology demonstration.

RELEASE CHARACTERISTICS

Organic compounds detected in soil at the Mare Island electrical shop included PCBs, volatile organic compounds (VOC), phenol, TPH, and pesticides. Fifteen percent of the soil samples collected at the site were analyzed for Contract Laboratory Program VOCs, semi-volatile organic compounds (SVOC), and pesticides. The distribution of samples analyzed for these constituents was sufficient to evaluate the presence of contaminants at the site. Of the organic compounds detected, only PCBs were detected in concentrations exceeding soil standards.

The field demonstration was conducted adjacent to a former electrical shop within Installation Restoration Site 11 at the Mare Island Shipyard. Previously at this site, transformers, using oil containing PCBs, were washed out. The liquid waste was pumped to a grease trap prior to discharge to the IW collection system. The grease trap was subsequently removed and backfilled with soils contaminated with PCBs. Levels as high as 2,200 mg/kg were identified at the site during the remedial investigation (IR).

MATRIX DESCRIPTION

MATRIX IDENTIFICATION

The ISTD technology uses two configurations of the heating elements: thermal blankets that treat surface soil up to 18 inches deep and thermal wells that are drilled vertically or horizontally to treat deep or hard-to-reach areas in unsaturated or saturated zones.

CONTAMINANT CHARACTERIZATION

Thermal blankets and thermal wells will destroy volatile and semi-volatile organic compounds, including PCBs, chlorinated solvents, pesticides, and petroleum wastes. Table 1 shows a summary of soil analyses at Mare Island, California.

Table 1. Summary of Soil Analyses at Mare Island, California.

Analyte	Number of Detections/ Analyses	Maximum Detected Conc. (mg/kg)	Average of Detected Conc. (mg/kg)	Number of Samples with Conc. Greater than PRG	Number of Samples with Conc. Greater than PRG and Ambient	PRG Value (mg/kg)	Ambient Value (mg/kg)
Metals							
Arsenic	49/50	26.6	11.7	49	11	0.38	15
Beryllium	18/23	2.5	0.89	18	2	0.14	1.8
Lead	158/167	418	21.0	2	2	13.0	33
Volatile Organic Compounds							
1,2-Dechloroethene (Total)	3/37	0.02	0.01	0	NA	75	NA
Benzene	3/157	0.06	0.06	0	NA	1.4	NA
Ethylbenzene	6/157	7	2	0	NA	2,900	NA
Tetrachloroethene	7/37	0.1	0.02	0	NA	7	NA
Toluene	14/157	0.8	0.1	0	NA	1,900	NA
Trichloroethene	5/37	0.08	0.02	0	NA	7	NA
Xylene (Total)	9/157	34	8	0	NA	980	NA
TOTAL (VOCs)	24/157	42	4	NP	NE	NP	NA
Semi-volatile Organic Compounds							
Phenol	8/19	2	0.6	0	NA	39,00	NA
TOTAL SVOCs	8/19	2	0.6	NP	NE	NP	NA
Pesticides/PCBs							
4,4'-Dde	1/34	0.2	0.2	0	NA	1	NA
Aroclor-1254	3/45	100	35	3	NA	0.07	NA
Aroclor-1260	11/158	2,200	270	8	NA	0.07	NA

Heptachlor	2/34	0.002	0.0009	0	NA	0.1	NA
TOTAL PCBs	14/158	2,200	220	11	NA	0.07	NA
Petroleum Indicators							
Diesel Range	4/168	9,100	3,100	NP	NE	NP	NA
Gasoline Range	16/169	12,000	1,300	NP	NE	NP	NA
Motor Oil Range	4/168	320	140	NP	NE	NP	NA
TRPH	3/23	47	20	NP	NE	NP	NA
Miscellaneous							
Total Organic Carbon	2/7	54,000	45,000	NP	NE	NP	NA

mg/kg = milligrams per kilogram
PRG - U.S. EPA preliminary remediation goal for residential use (EPA 1995)
Ambient = Estimated ambient metal concentrations in fill soils
ND - Not detected
NP - No PRG has been established
NA - No ambient limit has been established
NE - No PRG or ambient limit has been established
TRPH - Total recoverable petroleum hydrocarbon

SUBSURFACE CHARACTERISTICS

Geology

Prior to the demonstration activities, forty-nine soil borings had been drilled and logged at the Mare Island electrical shop during the RI study. Borehole depths ranged from 8 feet to 34 feet below ground surface (bgs). Three geologic units were identified in the region of the test site. These included, from top to bottom stratigraphically, (1) artificial fill material, (2) silt clay, and (3) weathered bedrock.

Based on lithologies of the geologic materials and the depth to groundwater, siltstone/fine-grained sandstone bedrock was the only hydrogeologic unit identified at the Mare Island electrical shop. The overlying artificial fill and clay units do not come in contact with groundwater. The thermal well system was installed within the un-consolidated fill present in the vicinity of the former grease trap. The grease trap structure was removed prior to the installation of the system.

Hydrogeology

Groundwater in the uppermost aquifer beneath Building 866 was encountered approximately 9 feet to 15 feet bgs; groundwater elevations ranged between 10.5 to 17.69 feet above mean sea level. The direction of flow in the shallow water-bearing zone at the Mare Island electrical shop is to the east toward Mare Island Strait. Most of the underground utility pipelines were above the groundwater table. Neither these utility pipelines nor the backfill materials are expected to affect groundwater flow at the site. The 48-inch diameter storm water pipeline that runs southwest to northeast under Building 866, is below the water table (approximately 20 feet bgs) and may act as a preferential flow pathway. This pipeline was installed in a tunnel under the site. Data are not available on the influence of this utility pipeline on shallow groundwater flow; the influence may not be significant if the static groundwater level at the site is within relatively impervious bedrock. It is possible that the tunnel, or possible leakage into the pipeline, may act as a preferential groundwater pathway altering flow in the vicinity of the pipeline.

The geologic cross sections for the Mare Island electrical shop provided in the RI indicate that the wells are screened in a mostly homogeneous weathered bedrock unit, which consists primarily of weathered siltstone and fine-grained sandstone. A site-specific value for the hydraulic conductivity of the siltstone/fine-grained sandstone is not available. A slug test performed in June 1997 on an existing well near the demonstration area indicated a preliminary conductivity value of $1x10^{-5}$ cm/sec. A pump test scheduled to be conducted within the actual demonstration area was canceled after two wells drilled in the demonstration area to a depth of 16 feet were dry.

MATRIX CHARACTERISTICS AFFECTING TECHNOLOGY COST OR PERFORMANCE

- Moisture Content - Higher moisture content requires more energy and more time to boil off the soil moisture. Initial natural moisture content is helpful, as boiling off one pore volume of water facilitates steam stripping of contaminants from soils.

- Depth of Contaminated Zone - For a given volume, a deeper contaminated zone over a smaller area requires fewer (deeper) wells, but has no effect on cycle time.

- Soil Type - Soil (or rock) type has little overall effect on treatment time. Thermal conductivity values for all types of soil and rock fall in a narrow range (approximately a factor of two).

- Underground utilities, such as electrical and gas lines, could be damaged if too close to the heaters or hot soil.

- Dewatering may be required if the treatment zone is below the water table. It may be feasible to treat an area below the water table without dewatering if the hydraulic conductivity is very low. Neither of these cases, however, have been demonstrated.

- Contaminants of Concern - Each contaminant of concern has a unique boiling point. Contaminant desorption occurs at temperatures below the boiling point, but desorption occurs at a much more rapid rate when the boiling point is reached. Therefore, the target treatment temperature is generally at the boiling point of the highest boiling contaminant on site. A higher boiling point translates into a higher target temperature, and a longer treatment cycle.

- Contaminant Concentration - Contaminant concentration has minimal effect on treatment cycle time over the wide range of contaminant concentrations typically found in contaminated media. Sites with a high organic content (greater than several percent of PCBs, oil, or other organics) may require a slower heating rate or larger vapor treatment system.

- Well Spacing - The length of each treatment cycle is directly proportional to the distance between wells.

Table 2 lists the matrix characteristics affecting cost and performance.

Table 2. Matrix Characteristics Affecting Cost and Performance

Factors Affecting Cost and Performance	Typical or Measured Value
SOIL TYPES	
Soil Classification	Silt With Sand
Clay Content/Particle Size Distribution	82% passes #200 sieve
AGGREGATE SOIL PROPERTIES	
Moisture Content	~20%
Air Permeability	0.20 = 0.050 Darcy
Porosity	~30%
ORGANICS IN SOIL	

Total Organic Carbon	~1.0%
Oil & Grease or Total Petroleum Hydrocarbons	Not Determined
Non Aqueous Phase Liquids (NAPL)	None observed
MISCELLANEOUS	
Contaminant Sorption	PCB Aroclor 1254 has a Koc of 810,000; Aroclor 1260 has a Koc of 1,800,000
BTU Value	Not Determined
Halogen Content	3.3 E-3 % (calculated based on PCB Content)
Presence of Metals	Background levels for RCRA metals
Thermal Conductivity	Not Measured - Typically between 1 and 5 cal/m/hr/^{0}C for all soil types

TECHNOLOGY SYSTEM DESCRIPTION

TECHNOLOGY

ISTD combines thermal desorption and vacuum extraction to remove organic compounds from soils in-situ. A thermal well assembly was used to treat contaminated soils at depth. A thermal blanket desorption unit was applied directly to the surface to treat shallow contaminated soils. Thermal wells and thermal blankets were both deployed at the Mare Island facility in consecutive demonstrations.

The thermal well assembly consists of five components: (1) stainless steel well casing, (2) a subsurface heating element, (3) a vacuum barrier of shimstock, (4) a layer of insulating material, and (5) an impermeable sheet. The heaters initiate a thermal front which moves laterally through the soil by thermal conduction. As the soil is heated, organic compounds and water vapor are desorbed and evaporated from the soil matrix. Negative pressure is induced throughout the treatment zone by a pressure blower, while an impermeable liner and insulation minimize fugitive emissions and heat loss. The soil vapor is drawn via the vacuum blower and treated in a trailer-mounted air pollution control (APC) system.

The APC system used during this demonstration was comprised of an electric heated flameless thermal oxidation unit, followed by a heat exchanger to reduce the vapor temperature, and a final polishing by granular activated carbon augmented with pelletized calcium hydroxide.

The thermal blanket system used the same vapor extraction and APC systems. However, heat was supplied from the surface, using two (2) thermal blanket assemblies. The principal components of each thermal blanket were: (1) a surface heating element, (2) an insulating mat, and (3) an impermeable sheet.

SYSTEM DESCRIPTION

The subsurface installation included an array of twelve thermal wells used for heat application and vapor extraction. The surface equipment consisted of a process trailer containing the system controls and vapor treatment equipment, an administrative trailer/office, a health and safety trailer, a storage trailer, as well as a network of piping. These primary components and the utility, instrumentation, and control requirements are described below.

The 12 thermal/vapor extraction wells were installed with a standard drill rig to a depth of 14 feet. Removable stainless steel well casings with a screened interval from 6 inches to 14 feet bgs were installed. The heating elements were installed upon completion of casing installation activities. The wells were sealed, piped via a manifold to the MU-125 treatment system, and connected to the power supply. The entire treatment area was covered with a steel shimstock liner to provide a surface seal and to control fugitive emissions from near surface soils.

The ISTD technology is modular in construction, and process trailers have been constructed in a number of sizes. Units constructed to date or planned include the MU-125 (Mobile Unit-125 cfm) used at the Mare Island demonstration, as well as the MU-1000, MU-1800, MU-3000, and MU-6000 (each model number designates the vapor flow rate of the treatment unit).

The MU-125 treatment system trailer was equipped with a cyclone separator, flameless thermal oxidizer, heat exchanger, carbon vessels (one standard activated carbon and the other containing a combined carbon and hydrochloric acid (HCl) adsorbent medium), and dual vacuum blowers. The MU-125 system trailer also houses the emergency generator and a control room containing the continuous emission monitoring (CEM) system and the Programmable Logic Controller (PLC) data acquisition system. The same process/control trailer was used for the thermal blanket demonstration. Figure 2 shows the thermal blanket and thermal well system.

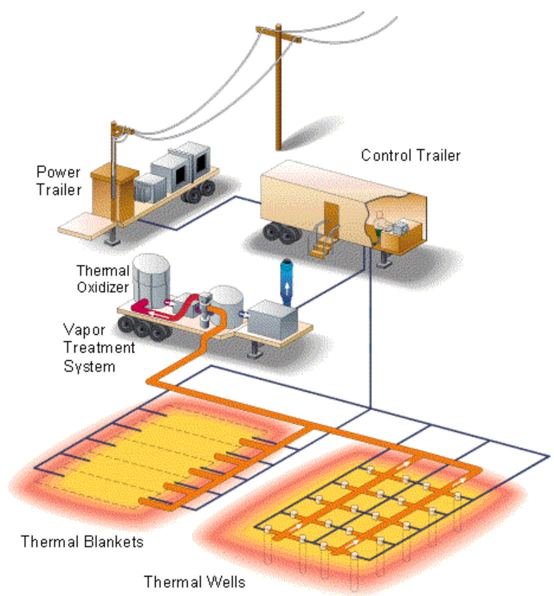

Figure 2. The thermal blanket and thermal well system.

The instrumentation and controls for the ISTD treatment system consist of both manual and automatic components. Manual components were used where practical with automatic shutdown controls for critical system components. The ISTD piping system is monitored using vacuum gauges, header section isolation valves, and thermocouples. Monitoring and control of the extraction system included magnehelic gauges, a differential pressure cell, a calibrated orifice plate to monitor process flow, manually operated flow control gate valves, and an automatic vacuum relief valve.

The heating system instrumentation consisted of thermocouples on each heating element with a feed back controller and manual override to adjust the delivery of electric current to each group of heating elements.

Automatic controls were provided to protect equipment and personnel during instances of equipment failure. The process treatment system also had an emergency backup generator, to be used in the event of a primary power failure. The generator ensured that the vacuum blower and all control systems continued to operate, removing volatilized vapors from the heated area for treatment by the thermal oxidizer and carbon/Sorbalit® beds.

The process vapor stream was continuously monitored for concentrations of CO_2, CO, THC, and O_2, using a calibrated Rosemount continuous emission monitoring (CEM) system. The CEM utilized an extractive sample probe and conditioning system. The sample stream was introduced to a non-destructive infrared analyzer for the quantification of CO and CO_2 prior to the analysis of O_2 using a zirconium oxide detector and THC using a flame ionizaton detector. CEM data was acquired electronically and displayed graphically. The data was time stamped and stored using computer software for system operations documentation.

SYSTEM OPERATION

The operation occurred in several phases. The following subsections describe the three operating phases after system check-out had been completed.

Startup

The first phase of operation was ramp-up of process equipment temperatures. The thermal oxidation system was heated to the target operating temperature of 1,600°F to 1,800°F for PCB destruction. This typically takes about 12 hours.

Heating

The thermal well heating elements were then slowly ramped up to temperature. The final operating temperature of these heaters was set between 1,400°F and 1,600°F. Depending on the boiling point of the contaminants of concern and moisture content, heating usually takes 24 to 36 hours.

Contaminant destruction occurred during the heating phase when the heating elements were at full temperature and the soil around the wells was slowly increased to the target treatment temperature. For treatment of PCB Aroclor 1260, the target treatment temperature was set at 600°F. Soil gases were extracted and oxidized throughout the operation. The heating (or treatment) phase was complete when the thermocouples in the center triangle of the thermal well array reached the final target temperature. The heating phase was conducted for a period of 35 days to reach the target temperature of 600°F at the four central monitoring locations. The heaters were then kept energized for an additional 48 hour period, for a total heating time of 37 days.

Cool down

Cool down was the final phase of operation. During this period, the heating elements were de-energized and soils were allowed to cool.

OPERATING CONDITIONS

The EPA requires that the overlap from placement of the heater modules (including the 12 inch cold ends on the heater modules) from one treatment plot to an adjacent plot is a minimum of 18 inches, unless TerraTherm confirms through a formal demonstration, that the overlap should be less than 18 inches. A demonstration at the Missouri Electric Works (MEW) site in Cape Girardeau, MO was conducted using an overlap of 12 inches of the heated area of the heater modules. This condition did not apply for the BADCAT demonstration as only one placement of the heater modules was conducted.

Prior to operations TerraTherm or its authorized agent must survey the treatment location for buried drums, containers, and tanks. TerraTherm or its authorized agent must use industry-accepted subsoil detectors such as metal detectors or other probes, or must use data from past surveys such as a CERCLA assessment, pursuant to 40 CFR 300 Subpart D. All containers detected in the subsoil to be treated must be removed. Removal of the grease trap prior to the performance of the thermal well demonstration was performed by the Navy. Based on information provided from the Bldg 866 RI, no additional buried drums, containers, or tanks were known to be present.

Thermal Blanket and Thermal Well Operating Parameters

- **Heater Element Temperatures:** Temperature of the heater elements must be a minimum of 1,000°F at termination of treatment. Heater elements were operated in excess of 1,000° F during both demonstrations.

- **Soil Temperature in Treatment Zone:** The soil temperature nearest the outer edge of the heater module (or the midpoint between groups of 3 heater wells) must reach 600°F prior to heater Element power shut off. Prior to de-energizing the heater elements, the average soil temperature at the center of each thermal well pattern and at the base of each thermal blanket treatment cell exceeded 600°F.

- The thermal blanket or thermal wells must maintain a negative draft throughout the system sufficient to preclude fugitive emissions from the blanket or wells. Manual monitoring of the process vacuum gauges indicated that the system maintained a negative draft throughout the demonstrations. Ambient air monitoring using a handheld organic vapor monitor indicated that fugitive emissions were not detected above background levels during the operation of the ISTD system.

- The particulate emissions rate must not exceed 0.08 grains/dry standard cubic foot, corrected to 7% oxygen, using the procedure given in 40 CFR 264.343 (c). The HCl emissions must not exceed the greater quantity of 4.0 lbs/hr or 1% of the chlorides exhausting the off-gas hood, assuming all organic and inorganic chlorides react to form HCl. As indicated by manual readings, the emission rate limit of 4.0 lbs/hr was not exceeded during the demonstrations.

Thermal Oxidizer

- The Thermal Oxidizer (TO) must operate at a minimum temperature of 1,700°F. These limits were maintained throughout the demonstrations.

- Excess oxygen shall not be less than 7%. The Thermal Blanket must be shutdown whenever excess oxygen decreases to 3% or below. During the transition from the Thermal Well to the Thermal Blanket treatment systems, the excess oxygen was recorded at between 10 to 12%. The excess oxygen was greater than 7% throughout the demonstrations.

- Carbon monoxide must be maintained at a level consistent with those demonstrated in the trial burn. A nominal CO level of less than 10 ppm shall be maintained, electrodes shutdown automatically or by operators following standard operating procedure instructions, taking effect when CO levels exceed 10 ppm with a 3 minute lag. CO readings throughout the demonstrations met these criteria without exception.

- The destruction and removal efficiency (DRE) for PCBs in the thermal blanket shall be a minimum of 99.9999% calculated as follows:

$$DRE = 100 \times \frac{\text{PCB Rate In, lb/hr - PCB Exhaust Emissions, lb/hr}}{\text{PCB Rate In, lb/hr}}$$

where,

PCB Rate In = Soil Treatment Rate x PCB concentration, lb/hr
PCB Exhaust Emissions = Exhaust Gas Volume Rate x PCB concentration, lb/hr.

The MU-125 ISTD treatment system DRE was demonstrated in April and May 1997 at MEW, under similar operating conditions. The unit provided a DRE in excess of 99.9999% for PCB (Aroclor 1260).

Operating Controls and Interlocks

The power to the heater elements of the thermal blanket shall stop automatically or by operator as instructed by the standard operating procedures, unless otherwise stated when any one or more of the following conditions occur:

- The TO temperature falls below 1,700°F for three minutes when treating soils and solid material containing PCB levels equal to and greater than 50 ppm.

- The excess oxygen at the TO outlet falls below 7% for three minutes or, in the event of analyzer failure, at the TO outlet for three minutes.

- The carbon monoxide in the TO outlet exceeds 10 ppm for three minutes.

- The blanket draft attains ambient pressure for greater than a 10-second interval. When the blanket draft exceeds -0.25 inches of water, an audible/visual alarm will activate within the control room.

- Failure of any of the monitoring or recording operations specified in the draft permit.

The exhaust gas shall be monitored continuously for O_2, CO, and CO_2 when PCBs are being treated.

OPERATING PARAMETERS AFFECTING TECHNOLOGY COST OR PERFORMANCE

The operational parameters affecting cost and performance are summarized in Table 3.

Table 3. Operating Parameters Affecting Cost and Performance Factors

Operating Parameters	
Air Flow Rate	125 scfm for Thermal Well Demonstration (Typically 1 scfm per foot of well) 60 scfm for Thermal Blanket Demonstration (Typically 1.5-2 scfm per square foot)
Operating Vacuum	Typically 5 inches w.c. in collection header, minimum 0.1" w.c. measured in soil.
Flameless Thermal Oxidizer Bed Temperature	>1700^0 F
Treatment Cycle Duration	30 to 45 days for Thermal Wells (37 days at Mare Island) 6 to 8 days for Thermal Blankets (7 days at Mare Island)
Heater Temperature	>1000^0 F Typically 1400^0 F-1600^0 F
Target Soil Temperature	Boiling Point of Contaminant to be Treated (600^0 F for PCB Aroclor 1254 and 1260 at Mare island)
Utility Requirements	480 V 3 Phase Service, 350 W/linear foot of heater

TIMELINE

This section describes the field activities that were performed at the thermal well demonstration site. A chronology of field operations is provided in Table 4.

Table 4. Demonstration Operations Chronology

DATE	EVENT
September 8, 1997	General site mobilization and site set-up.
September 11	SSPORTS removed asphalt from well field area and dug 6' trench to expose drain line. Collected pre-demonstration samples from four predetermined center locations in well configuration.
September 12	SSPORTS finishes drain line closure and backfills trench with original soil. Pre-demonstration well soil samples were shipped to Pacific Analytical for PCB analysis. Drill rig on-site and started well installation. Three wells were completed to 14'
September 13	Installation of 12 wells and well screens completed.
September 18	MU-125 unit in place.
September 19	Installed 4 combination temperature/vacuum monitoring points as well as 3 additional temperature monitoring points.
September 25	Thermal well field configuration completed. All wellheads, heater cans, and well field piping is completed. Perimeter is constructed around the well array and is filled with vermiculite. Silicone blanket is placed over the entire well array.
September 26	Well heater element installation and associated electrical connections completed.
September 27	The MU-125 unit was started, drawing ambient air, for equipment shakedown.
October 2	Start-up sequence for MU-125 was initiated. The thermal oxidizer was ramped up to the desired temperature of approximately 1900^{0}F.
October 4	The well field heaters were turned on and the air flow valves to the process unit were opened.
October 6	The MU-125 unit, as well as the well heaters, were shut-down due to a high pressure drop across the oxidizer and a low vacuum in the well field. The unit continued to draw air from the well field.

	SSPORTS on-site to remove asphalt from blanket area and prepare a 16' x 19' x 12" deep area for the blanket demonstration.
October 11	Maintenance on the oxidizer was completed. The oxidizer had been taken apart, parts had been replaced, and the oxidizer was cleaned to allow improved air flow. The MU-125 unit and well heater elements were restarted.
October 12	The Thermal blanket demonstration soil was placed into the Thermal Blanket demonstration area and compacted.
October 15	Pre-demonstration blanket soil samples were collected and shipped to Pacific Analytical for PCB analysis.
October 18	Soil temperatures in the well field at 12' bgs reached the boiling point plateau. The temperatures ranged from 209^{0}F to 211^{0}F.
October 28	All magnehelic gauges measuring the well field vacuum were relocated from the original position above the silicone blanket to an elevated panel adjacent to the west side of the well configuration in order to limit condensation interference and provide a more accessible area to record hourly field measurements.
October 30	All thermocouples at 9' bgs show temperatures were above the boiling point plateau. The temperatures ranged from 259^{0}F to 660^{0}F.
November 7	Monitoring point TC4 at 12' bgs had the lowest temperature of 491^{0}F. TC4 controlled the duration of the thermal well demonstration.
November 9	The BCV-5 heating element was removed for inspection, and was found to be burned out in the upper section.
November 11	The heater element in BCV-10 burned out. BCV-3 was extracted and a replacement heater can and element was installed. The maximum temperature set-point was decreased from 1750^{0}F to 1650^{0}F to extend heater element life.
November 14	BCV-6, BCV-10, and BCV-12 were removed for inspection and BCV-10 was replaced with a new heater can and element.
November 15	The temperature in monitoring point TC4 at 12' bgs reached 600^{0}F. The well field was then operated for an additional 48 hour period with temperatures above 600^{0}F.
November 17	The well field was turned off and the piping was disconnected. The process piping for the Thermal Blanket demonstration area was connected.
November 18	The power was turned on for the blanket heating elements with a temperature setpoint of 1500^{0}F to 1 700^{0}F.
November 20	All heater cans and elements were removed from the well field.
November 25	The Thermal Blanket demonstration was deemed complete, with soil temperatures above 700^{0}F. The Thermal Blankets were shut down.
November 26	Personnel left the site for Thanksgiving break. Security guards were scheduled to patrol the area during the break.
December 1	Personnel return on-site from holiday break.
December 2	Geoprobe on-site to obtain soil samples from the four predetermined center locations in the well field. Four borings were completed to a depth of 12' bgs. The samples were shipped to Pacific Analytical for PCB analysis.
December 3	Soil samples were obtained from the Thermal Blanket area soil. Composite samples were collected from 0-6" and 6-12" from predetermined locations. The samples were shipped to Pacific Analytical for PCB analysis. General site demobilization started. The MU-125 process unit was shipped off-site. The well screens were removed.
December 10	Demobilization was completed.

TECHNOLOGY SYSTEM PERFORMANCE

PERFORMANCE OBJECTIVES

The primary performance objective for both the thermal well and thermal blanket demonstrations was to safely remove and destroy PCBs from the soil to a concentration of less than 2 mg/kg. Since the demonstration was defined by CalEPA as a technology demonstration and not a removal action, no specific cleanup standard was set for the project.

The ISTD system does not have a "throughput rate" equivalent to a traditional ex-situ system. The objective was to complete the soil treatment cycle within the time estimated by the thermal model; 40 days for the thermal well demonstration and 8 days for the thermal blanket demonstration.

PERFORMANCE DATA

Performance data collected and analyzed during the demonstrations consisted of three main types:

- Soil Data (used to determine whether the target treatment level of 2 mg/kg was reached).
- Operational data, including soil and process temperatures and flow rates (used to monitor operations and determine when treatment was complete).
- Emissions data (used to ensure that emissions were within normal limits).

Soil Data

Soil samples were analyzed for PCBs using EPA Method 8081. There were no reported matrix problems and analytical quantitation limits of 10 ug/kg were achieved. Pre-treatment analyses of Aroclors 1254 and 1260 (the aroclors present on site) were conducted on sample extracts prepared with a 10 times dilution to achieve accurate quantitation.

Pre-treatment and post-treatment PCB test results for the thermal well demonstration are summarized on Table 5. All post-treatment samples had no-detectable PCB concentrations at a quantitation limit of 10 ug/kg.

Pre-treatment and post-treatment PCB test results for the thermal blanket demonstration are summarized on Table 6. All post-treatment samples had no-detectable PCB concentrations at a quantitation limit of 10 ug/kg.

Table 5. Soil Sample Results - Thermal Well Demonstration

Sample Location		Pre-Treatment Results	Post-Treatment Results
Thermal Wells Composite 0-1 Foot Depth	Sample ID	BSW10001.1	BC-W2-0-1.01
	Lab Sample #	J9301PS	K5903PS
	Aroclor 1254	4,090 ug/kg	<10 ug/kg
	Aroclor 1260	844 ug/kg	<10 ug/kg
	Total PCB	**4,934 ug/kg**	**<10 ug/kg**
Thermal Wells Composite 4-5 Foot Depth	Sample ID	BCW10405.1	BC-W2-4-5.01
	Lab Sample #	J9302PS	K5904PS
	Aroclor 1254	81,190 ug/kg	<10 ug/kg
	Aroclor 1260	12,553 ug/kg	<10 ug/kg
	Total PCB	**93,743 ug/kg**	**<10 ug/kg**
Thermal Wells Composite 8-9 Foot Depth	Sample ID	BCW10809.1	BC-W2-8-9.01
	Lab Sample #	J9303PS	K5906PS
	Aroclor 1254	58,830 ug/kg	<10 ug/kg
	Aroclor 1260	8,230 ug/kg	<10 ug/kg
	Total PCB	**67,060 ug/kg**	**<10 ug/kg**
Thermal Wells Composite 11-12 Foot Depth	Sample ID	BCW11112.1	BC-W2-11-12.01
	Lab Sample #	J9304PS	K5907PS
	Aroclor 1254	43,050 ug/kg	<10 ug/kg
	Aroclor 1260	5,372 ug/kg	<10 ug/kg
	Total PCB	**48,422 ug/kg**	**<10 ug/kg**
Thermal Wells Average Concentrations	Aroclor 1254	46,790 ug/kg	<10 ug/kg
	Aroclor 1260	6,750 ug/kg	<10 ug/kg
	Total PCB	**53,540 ug/kg**	**<10 ug/kg**

Table 6. Soil Sample Results - Thermal Blanket Demonstration

Sample Location		Pre-Treatment Results	Post-Treatment Results
Thermal Blankets Side A 0-6” Depth	Sample ID	BC-B1-A-0.5.01	BC-B2-A-0.5.01
	Lab Sample #	K3101PS	K5908PS
	Aroclor 1254	4,517 ug/kg	<10 ug/kg
	Aroclor 1260	11,239 ug/kg	<10 ug/kg
	Total PCB	**15,756 ug/kg**	**<10 ug/kg**
Thermal Blankets Side A 6-12” Depth	Sample ID	BC-B1-A-1.0.01	BC-B2-A-1.0.01
	Lab Sample #	K3102PS	K5909PS
	Aroclor 1254	5,340 ug/kg	<10 ug/kg
	Aroclor 1260	14,822 ug/kg	<10 ug/kg
	Total PCB	**20,162 ug/kg**	**<10 ug/kg**

Thermal Blankets Side B 0-6" Depth	Sample ID Lab Sample #	BC-B1-B-0.5.01 K3103PS	BC-B2-B-0.5.01 K5910PS
	Aroclor 1254	14,883 ug/kg	<10 ug/kg
	Aroclor 1260	18,382 ug/kg	<10 ug/kg
	Total PCB	**33,265 ug/kg**	**<10 ug/kg**
Thermal Blankets Side B 6-12" Depth	Sample ID Lab Sample #	BC-B1-B-1.0.01 K3104PS	BC-B2-B-1.0.01 K5911PS
	Aroclor 1254	3,980 ug/kg	<10 ug/kg
	Aroclor 1260	9,263 ug/kg	<10 ug/kg
	Total PCB	**13,243 ug/kg**	**<10 ug/kg**
Thermal Blankets Average Concentrations	Aroclor 1254	7,180 ug/kg	<10 ug/kg
	Aroclor 1260	13,427 ug/kg	<10 ug/kg
	Total PCB	**20,607 ug/kg**	**<10 ug/kg**

Operational Data

Operational data collected and logged by the PLC data acquisition system included:

- Thermal Well element temperatures at 3 elevations in 12 wells (used to monitor performance and automatically control the heater power supplies).
- Soil temperatures at 3 elevations in 7 locations (used to monitor progress and determine when treatment is complete).
- Process temperatures along the pipe manifold and throughout the process, including 3 locations within the flameless thermal oxidizer, before and after the carbon vessels, and in the exhaust stack.
- Process flow rate.
- Alarm status.

Soil temperatures rose rapidly until the boiling point of soil pore water (212°F) was reached. The time to reach the boiling point of water ranged from approximately 3 to 5 days. The soil temperature remained at this level until the soil was dried. The soil temperatures exceeded 212°F from approximately 6 to 15 days from the start of the heating cycle. The soil temperature rose at a rate of approximately 1.25°F per hour until the target temperature of 600°F was reached. At shutdown of the thermal well heaters, soil temperatures ranged from 600°F to 810°F at the thermocouple arrays placed at the centroids of the thermal well pattern.

The treatment time to remove the soil pore water was approximately 70 hours for thermal blanket #1 and 84 hours for thermal blanket #2. The cumulative time to reach the target temperature of 600°F was 160 to 165 hours.

Process flow rates ranged from a minimum of 38 to a maximum of 82 standard cubic feet per feet (scfm). Process vapor flow rate was maintained at above 65 scfm to accommodate steam generation during the initial heating of soil. After the removal of the soil pore water, the process flow rate was reduced while maintaining a negative pressure within the process piping.

The flameless thermal oxidizer was monitored using Inconel sheathed K-type thermocouples placed within the ceramic reaction bed matrix. During the treatment of extracted soil vapors during the demonstrations, the reaction bed temperature was in excess of 1800°F.

Emissions Data

Emissions data collected and logged by the PLC data acquisition system included:

- Stack CO concentration (ppmv, dry basis).
- Stack CO_2 concentration (ppmv, dry basis).
- Stack THC concentration (ppmv, dry basis).
- Stack Dry O_2 concentration (ppmv, dry basis).
- Stack Wet O_2 concentration (ppmv, wet basis).
- Exhaust temperature.
- Exhaust flowrate.

A complete data set is available for review. Operation of the CEM system was interrupted for a period of 15 hours at approximately 154 hours of the thermal blanket demonstration due to a loss of instrument carrier gas. Emissions data was collected manually during this time period. No process deviations were noted during this period as monitored by temperature, flow, and other factors.

Vapor samples were collected and analyzed using colorimetric indicator tubes on a daily basis to monitor emissions of HCl**.** Stack samples collected throughout the demonstrations were observed to be less than 1.0 parts per million by volume (ppmV).

Process vapor samples were also collected from a sampling port located prior to the first scrubber bed which contained Sorbalit® HCl reduction media. HCl concentrations ranged from non-detect to 8 ppmV. These data demonstrate that HCl concentrations before scrubbing were within allowable limits. Further, the Sorbalit® HCl reduction media was effective in further reducing concentrations without introducing any operational difficulties.

DATA ASSESSMENT

The set of data collected during the demonstration was adequate to allow an assessment of the demonstration's objectives. Following is a summary of the process data recorded during the demonstrations.

Carbon monoxide (CO) emissions were recorded continuously by the CEM system. Emissions were recorded below 10 ppmV with a 3 minute lag throughout the demonstrations. The mean concentration was approximately 2 ppmV. Total hydrocarbon (THC) emissions were recorded using a flame ionization detector calibrated to methane (CH_4). THC readings observed during the demonstrations ranged from 0 to 8 ppmV. The median discharge was less than 0.002 lb/hr as CH_4.

Carbon dioxide (CO_2) emissions were recorded continuously by the CEM system and were observed at less than 2% throughout the demonstrations. The concentration was generally higher during the initial heating of the soil with a gradual decrease as the target treatment temperature (600°F) was achieved.

Excess oxygen (as indicated by the percent of oxygen in the system emission measured on a wet basis) was at or above 12% throughout the demonstrations with one exception. During the shutdown of the thermal well system and change over to the Thermal Blanket demonstration, the wet oxygen measurements ranged from a low of 10% to approximately 14%. Generally, the excess oxygen was observed to be greater than 14% throughout the demonstrations.

Exhaust temperature was monitored by a thermocouple placed in the CEM sample port and recorded by the MU-125 data acquisition system. The temperature was maintained at approximately 200°F through adjustment of the heat exchanger flow. The scrubber beds were maintained at >220°F to minimize the formation of condensation within the vessels.

The results of post-treatment soil analyses demonstrated attainment of the treatment objective of less than 2 mg/kg. The treatment times of 37 and 6 days for the thermal well and thermal blanket demonstrations respectively, provided the basis for the development of labor and fixed costs for the full scale application of the ISTD technology.

COST OF THE TECHNOLOGY SYSTEM

COST PERFORMANCE

Based on a more recent full-scale in-situ project of 500 tons and a bid received for a 500-ton ex-situ treatability study, the actual construction and operating costs have proven to be quite high, in the range of $750 to over $1000 per ton.

Depending on a number of site-specific and project size factors, the vendor has established an overall cost range of approximately $100 to $250 dollars per ton based on experience with implementation of ISTD at the BADCAT Demonstration, as well as prior ISTD demonstrations and remedial projects. These typical costs are based on a per ton cost for simplicity of the end user, as is a common comparison for disposal costs, even though actual costs may not be closely correlated to tonnage.

Actual construction and operating costs for this project are not available, however example construction and operating costs for implementation of ISTD remediation on a typical 1,000 ton (assume 1.5 tons per yard) thermal well project is provided in Table 7. The table of costs excludes permits, work plans, groundwater controls, and confirmation sampling costs. Larger projects tend to have lower treatment costs**.** Since the treatment time is a direct function of thermal well spacing, primary cost savings are realized from a fixed labor cost during thermal treatment. Variable costs include the increased cost of installation, mobilization and de-mobilization, process equipment, and electric power. Projects with simpler logistics or contaminants with lower boiling points, will likely provide lower labor and energy costs due to shorter treatment times to achieve target treatment temperatures in-situ.

Table 7. Example Construction and Operating Costs for ISTD Remediation of a 1,000 Ton Site

Type of Cost	Technology Cost ($)	Cost for Calculating Unit Cost	1997	1998	1999	2000
1. Capital						
Mobilization/Demobilization	**20,000**					
Site Work and Preparation	**0**					
Site Construction						
Electrical Service Connection	**15,000**					
Well Installation	**24,000**					
Manifold and Piping	**7,000**					
System	**7,500**					
Electrical Control Wiring	**2,000**					
Process Unit installation and Testing	**10,000**					

Type of Cost	Technology Cost ($)	Cost for Calculating Unit Cost	1997	1998	1999	2000
Labor	9,000					
TOTAL	94,500					
Startup and Testing	Not included					
Other						
General Conditions	10,000					
Total Capital Costs		104,500				
2. Operation and Maintenance						
Labor	20,000					
Materials	10,000					
Utilities, Propane and Carbon	32,750					
Equipment ownership, rental	72,000					
Performance testing and Analysis	Not included					
Other Equipment overhead & other direct costs	10,000					
Total Operation & Maintenance Costs		144,750				
3. Other Technology Costs:	0					
Compliance Testing and Analysis	0					
Soil, Sludge, and Debris Excavation, Collection, and Control	0					
Disposal of Residues	0					
4. Other Project Costs	0					
Total Technology Cost	249,250					
Total Cost for Calculating Unit		249,250				
Quantity Treated (1,000 ton example)	1,000 tons					
Calculated Unit Cost	250 per ton					

REGULATORY ISSUES

APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

Prior to the Mare Island Demonstrations, TerraTherm/STVI had obtained a "Draft" TSCA permit for the technology based on designs reviewed in detail by NYSDEC and USEPA Region II.

Other regulators/officials who have become familiar with the technology, including those from the states of Indiana, New York, and Missouri, have readily accepted the technology for a number of reasons:

- The application of heat is fundamentally simple and easily understood.
- The activated carbon, as a redundant treatment step, coupled with backup power and blowers, result in a reliable, robust system.

In order to plan the demonstration and obtain regulatory approval, a number of federal and state regulators/officials were involved. These included:

- USEPA TSCA – Washington, DC
- USEPA Region IX TSCA
- USEPA Region IX Technical Liaison
- USEPA Region IX Quality Assurance
- CalEPA DTSC
- CalEPA Engineering Support
- BAAQMD
- CalEPA

CalEPA took the lead in coordinating the review by the various agencies in order to ensure that regulatory requirements were not either duplicative or conflicting, and to expedite the process.

Of the issues which were raised by regulators/officials, the primary topic of discussion was air quality and whether additional stack testing was necessary. The MU-125 had been tested for PCB and dioxin/furan emissions in May and June of 1997, at the successful demonstration in Missouri. The results were provided to the appropriate regulatory agencies for review as part of the work plan approval process. Based on this review**,** additional stack testing was not required for the Mare Island Demonstrations.

Public participation prior to the demonstration focused largely on the stated demonstration objective of less than 2 mg/kg. Several public commenters were proponents of a cleanup standard of 1 mg/kg PCB or lower. Based on responses at local meetings, the public appeared comfortable with the safety, appearance, and performance of the ISTD equipment.

LESSONS LEARNED

The demonstrations were effective in treating PCB impacted soils at the Mare Island site 11. This innovative technology is applicable to full scale remediation of numerous Navy sites in the Bay Area. The overall process was streamlined despite the large number of individuals involved in the process.

Future projects may no longer have the benefit of being eligible for fast-track permitting. As such, additional project planning will be required to incorporate the approval procedure inherent to CERCLA remedial programs including mandated public comment periods, agency reviews of project work plans, and permitting.

From a technical standpoint, the demonstrations were successful in adding to the level of experience of system operators, while suggesting minor modifications in well heater materials, control and monitoring which will aid in more even soil heating and extend heater life and efficiency. The unusual heater failures experienced on this project were attributable to the use of 316 stainless steel heater strips (rather than 310 stainless steel), and the initially high operating temperature of heaters.

It should be noted, the technology has had limited success in other projects. In these cases, water infiltration from unexpected sources, caused insufficient heating and incomplete removal of the contaminants. Complete understanding of site conditions is of paramount importance to successful operation of the system.

POINTS OF CONTACT

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