# Cost and Performance Report

## Dual Auger Rotary Steam Stripping

## Pinellas Northeast Site

## Largo, Florida

**Innovative Treatment Remediation Demonstration**

**U.S. Department of Energy**

**April 1998**

## 1. SUMMARY

From December 1996 through April 1997, the DOE's Innovative Treatment Remediation Demonstration (ITRD) Program monitored the remediation performance of a dual auger rotary steam stripping technology deployed at the Pinellas STAR Center Northeast Site in Largo, Florida. The system allows in situ treatment of contaminated soil and ground water through the injection of air and/or steam into the subsurface. The objective of this remediation effort was to accelerate the cleanup of a portion of the site that consists of shallow, saturated soil and ground water contaminated with high concentrations (500-5000 ppm) of volatile organic compounds (VOCs). The rotary steam stripping system used during this remediation was developed and operated by In-Situ Fixation, Inc. (ISF), from Chandler, Arizona.

The ISF dual auger system consists of a Caterpillar 245D trackhoe that has been modified to operate two vertical, 35-ft long, hollow kelly bars with 5-ft diameter augers. Air and/or steam is injected through the hollow kellys while the augers drill into the subsurface, liberating VOC contamination during the churning and mixing of the soil. A large shroud covers the auger hole to capture the VOCs removed by this process for treatment. A catalytic oxidation unit and acid-gas scrubber were used to treat the extracted VOCs in this application at Pinellas.

The project provided adequate analytical and operational data to evaluate the performance of the dual auger rotary steam stripping technology. A Treatment Efficiency Characterization (TEC) Study was initially conducted to identify system operational capabilities and issues over the range of contaminant mixtures and concentrations in the planned treatment area. This study identified operational issues, such as mechanical problems, catalyst overheating, and fugitive emissions that required system adjustments and operational changes. These issues slowed the progress of the remediation effort, but the system was overall very effective in liberating large quantities of VOCs from the site soil and ground water. It was observed early in the project that a major limiting factor in the efficiency of the system in the areas of highest contaminant concentration was the off-gas treatment capacity of the catalytic oxidation unit.

During the 3-month operating period, 48 auger holes were drilled to a depth of approximately 32 ft below land surface, resulting in treatment of approximately 2,000 $yd^3$ of the planned 10,000 $yd^3$ treatment volume. Many of the treatment holes had to be treated more slowly than expected to prevent the catalyst in the catalytic oxidation unit from overheating from the large quantities of VOCs liberated by the augers. The treatment rates at this site varied from 1 to 5 holes/day or about 5 to 30 yd/hr, depending on the level of contamination encountered in each hole. Overall, approximately 1,200 lb of VOCs were removed from the soil and ground water in the holes treated in this project.

The cost of this remediation project was $981,251, with most of the costs being equipment operating costs. The on-line time of the ISF system, including the dual augers, off-gas treatment, and the acid gas scrubber components over the entire project averaged approximately 50%, while the on-line time of the system approached 75% after the initial operational problems and issues were addressed and corrected. Based on these on-line percentages, the operational costs of the ISF system at this site ranged from $50/$yd^3$ to $400/$yd^3$ of treated soil and ground water, or about $300/lb to $500/lb of contaminant removed.

Based on the results of this demonstration, the ISF dual auger rotary steam stripping system is an innovative technology capable of providing in situ treatment of VOC-contaminated soil and ground water. During the application of this technology at the Pinellas STAR Center, the ISF system was able to meet many of the performance evaluation criteria; however, the off-gas treatment capacity of the catalytic oxidation unit along with the initial operational problems slowed the system's expected treatment rates for the site. This prevented the system from achieving some of the performance objectives and treatment volumes initially expected in this remediation.

## 2. SITE INFORMATION

### *Identifying Information*

| | |
|---|---|
| *Facility*: | Pinellas STAR Center |
| *OU/SWMU:* | Northeast Site |
| *Location:* | Largo, Pinellas County, Florida |
| *Regulatory Driver:* | RCRA |
| *Type of Action:* | ITRD Remediation/Demonstration |
| *Technology:* | Dual auger rotary steam stripping |
| *Period of operation:* | 12/96 to 4/30/97 |
| *Quantity of saturated soil treated:* | 2,048 $yd^3$ |

### *Site Background*

The Pinellas STAR Center occupies approximately 100 acres in Pinellas County, Florida, which is situated along the west central coastline (Figure 1). The plant site is centrally located within the county; it is bordered on the north by a light industrial area, to the south and east by arterial roads, and to the west by railroad tracks. The topographic elevation of the Pinellas STAR Center site varies only slightly, ranging from 16 ft mean sea level (MSL) in the southeastern corner to 20 ft MSL in the western portion of the site. Pinellas County has a subtropical climate with abundant rainfall, particularly during the summer months.

The Northeast Site includes the East Pond and is located in the northeastern portion of the Pinellas STAR Center site. The Northeast Site is covered with introduced landscaping grass and contains no permanent buildings. The site contains approximately 6 acres and is generally flat, with slight elevation changes near the pond. Access to the Northeast Site is restricted and protected by fencing.

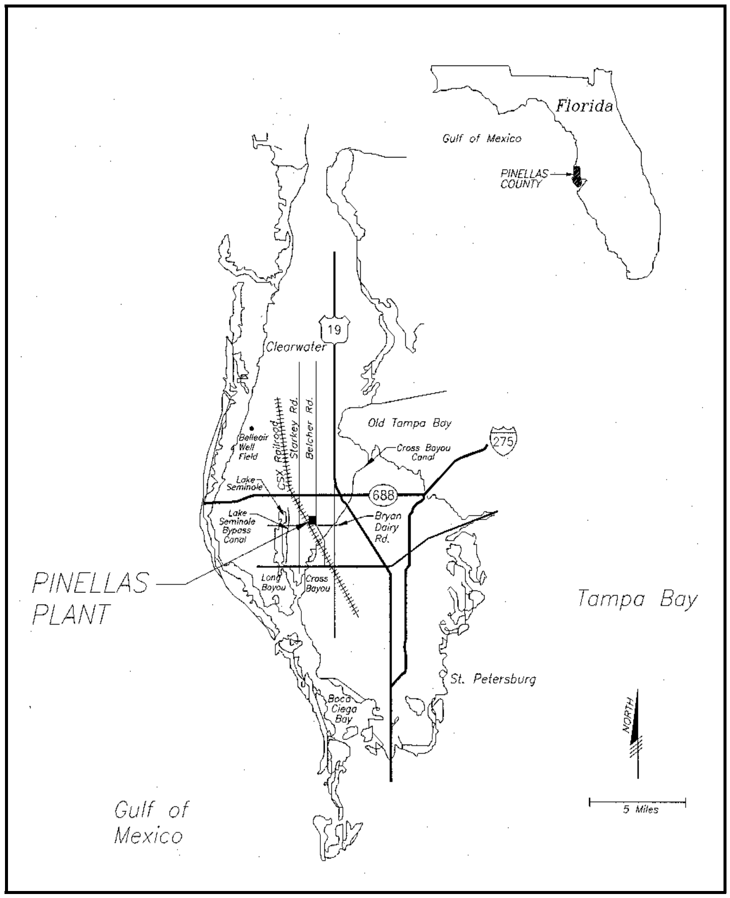


*Figure 1. Pinellas STAR Center location.*

### *Site History*

The Pinellas STAR Center operated from 1956 to 1994, manufacturing neutron generators and other electronic and mechanical components for nuclear weapons under contract to the U.S. Department of Energy (DOE) and its predecessor agencies (SIC Code 9631A-Department of Energy Activities).

The Northeast Site is associated with the location of a former waste solvent staging and storage area. From the late 1950s to the late 1960s, before construction of the East Pond, an existing swampy area at the site was used to dispose drums of waste and construction debris. The East Pond was excavated in

1968 as a borrow pit. In 1986, an expansion of the East Pond was initiated to create additional storm water retention capacity. Excavation activities ceased when contamination was detected directly west of the East Pond.

The Northeast Site was identified as a Solid Waste Management Unit (SWMU) in a Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA)[1] conducted by EPA Region IV. Subsequently, a RCRA Facility Investigation (RFI)[2] was completed and approved in compliance with the facility's Hazardous and Solid Waste Amendments of 1984 (HSWA) permit.[3]

An Interim Corrective Measures (ICM) Study[4,5,6] was developed and submitted to EPA for approval. EPA issued final approval of the ICM in October 1991, and an interim ground water recovery system for the Northeast Site was installed and commenced operation in January 1992. The ICM system now consists of seven ground water recovery wells equipped with pneumatic recovery pumps that transfer ground water for temporary storage in a holding tank before being pumped to a ground water treatment system.

### [redacted] *Release Characteristics*

The Pinellas STAR Center's Northeast Site consists of a shallow ground water aquifer contaminated with a variety of VOCs, including chlorinated solvents such as trichloroethene (TCE), methylene chloride, dichloroethene (DCE), and vinyl chloride. The primary management practice that contributed to contamination was the storage of drums/containers. Because the site was used in the 1950s and 1960s for staging and burying construction debris and drums, some of which contained solvents, contamination at the Northeast Site is believed to be the result of leakage of solvents or resins from those drums. A recent debris removal activity at the site confirmed the presence of multiple buried drums, many of which were empty but contained solvent residue. The ongoing ICM system (pump and treat with air stripping) continues to recover contaminants from the site and has been successful in preventing off-site migration of VOCs.

### [redacted] *Site Contacts*

Site management is provided by the DOE Grand Junction Office (DOE/GJO). The DOE/GJO Environmental Restoration Program Manager is Mr. David Ingle [(813)-541-8943]. The Managing and Operating contractor for this project at the Pinellas STAR Center was Lockheed Martin Specialty Components, Inc. (LMSC). The technical contacts for the Rotary Steam Stripping Project are Mr. Barry Rice [(813) 545-6036], and Mr. Mike Hightower, the ITRD Program Technical Coordinator at Sandia National Laboratories [(505) 844-5499].

## 3. MATRIX AND CONTAMINANT DESCRIPTION

The types of media processed by the rotary stripping system during this application were soil and ground water (in situ). More specifically, this remediation technology focused on treating saturated silty sands (i.e., below the water table) contaminated with high concentrations of VOCs (500 to 5000 ppm).

### *Site Geology/Hydrology*

Based on analyses of soil borings, details of well construction, and environmental studies at the Pinellas STAR Center, the thickness of the surficial deposit below the site ranges from 25 to 35 ft and is composed primarily of silty sand. Soils consist predominantly of saturated beach-type silty sands with permeabilities ranging between $10^{-3}$ to $10^{-5}$ cm/s. A few lenses of more silty materials exist, although no clay lenses occur in the soil being treated. The top of the Hawthorn Group (composed primarily of clay) at the Pinellas STAR Center is encountered at depths approximately 30 ft or greater below ground surface. The thickness of the Hawthorn Group ranges from 60 to 70 ft. The water table at the Pinellas STAR Center is generally 3 to 4 ft below the ground surface. Figure 2 shows the primary geologic units at the site.

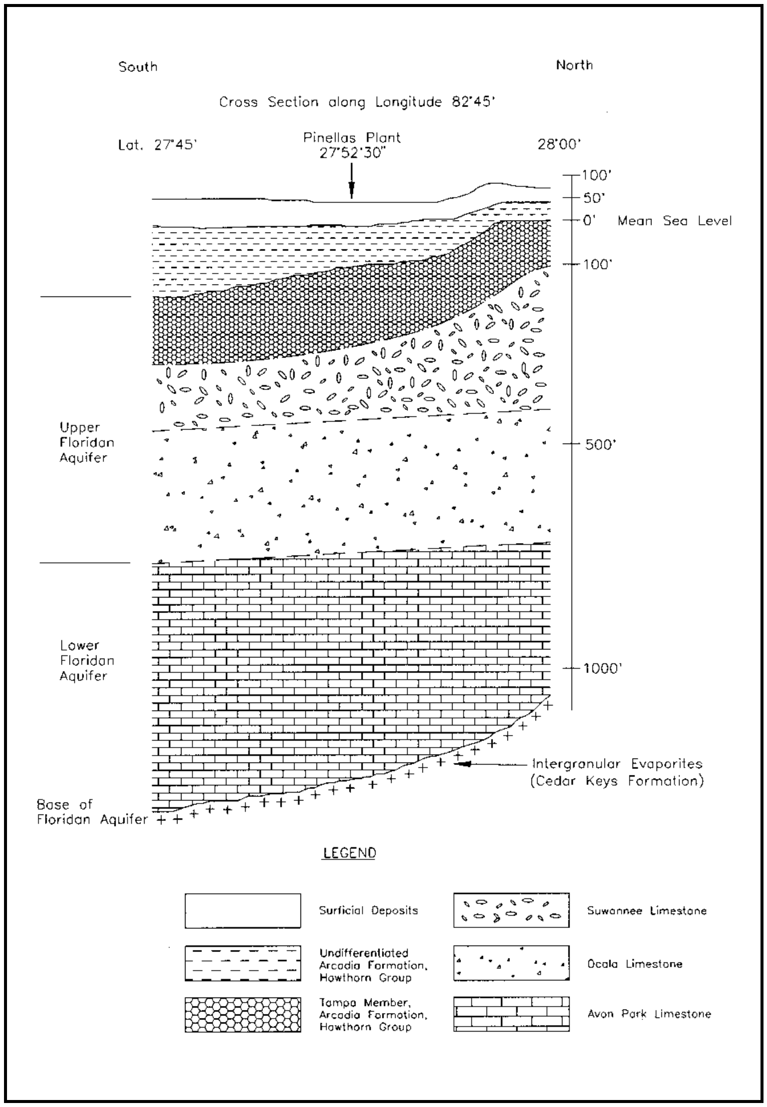


**Figure 2. Geologic section at the Pinellas STAR Center.**

The ground water system at the Pinellas STAR Center is composed of three primary units: (1) an upper unit, the surficial aquifer; (2) an intermediate confining unit, the undifferentiated portion of the Hawthorn Group; and (3) a lower unit, the Floridan aquifer. Undifferentiated sediments lie below the surficial aquifer and above the Floridan aquifer in Pinellas County. Because of the low permeability of these sediments in this region, these upper sediments are not considered part of the intermediate aquifer system and are generally considered to be a confining unit in the area of the Pinellas STAR Center.

### *Nature and Extent of Contamination*

The primary contaminant group that this technology was designed to treat in this application was halogenated VOCs. Contamination at the Northeast Site is limited to ground water in the surficial aquifer. Contaminants of concern (COCs) detected in Northeast Site ground water include 1,1-dichloroethane, 1,1-DCE, benzene, ethylbenzene, 1,2-DCE (cis and trans isomers), methylene chloride, toluene, TCE, tetrachloroethene, methyl tert-butyl ether, vinyl chloride, total xylenes, and chloromethane. The predominant contaminants detected at the site during performance of the demonstration were methylene chloride, 1,2-DCE, and TCE. Other VOCs detected in relatively high concentrations are toluene and vinyl chloride.

Figure 3 shows a contour map of historical total VOC concentrations in the southern groundwater plume at the Northeast Site as established by data collected prior to the rotary steam stripping project. Operation of the rotary steam stripping system was proposed in the areas of highest contaminant concentration (above 200-500 ppm). Table 1 summarizes the pretreatment concentrations of some of the COCs within the planned treatment area.

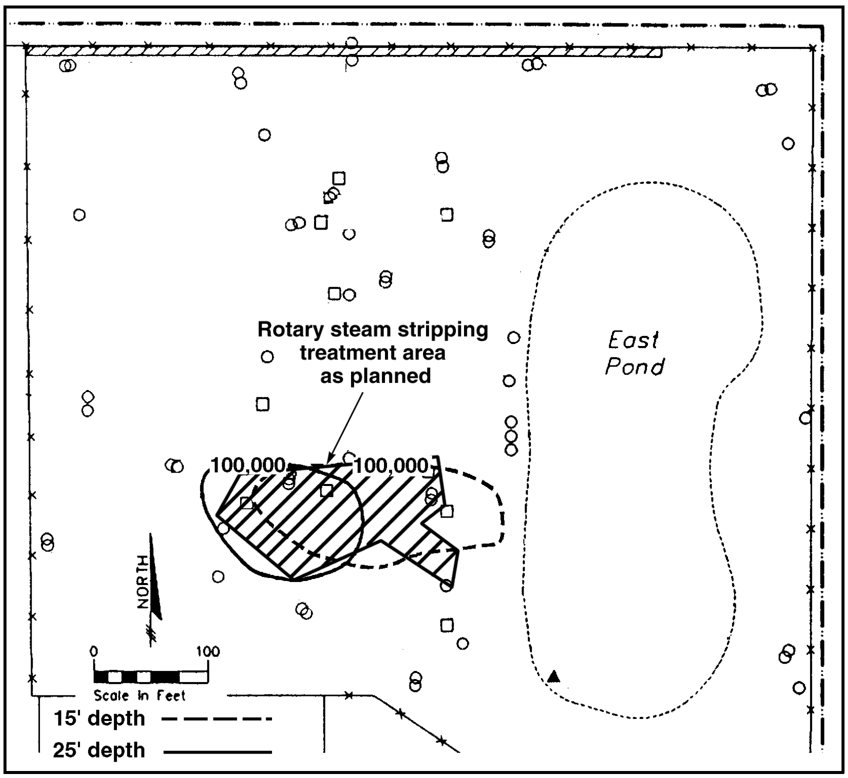


**Figure 3. Total VOC concentrations in ground water (in $\mu$g/L) in the southern plume at the Northeast Site prior to the rotary steam stripping project.**

**Table 1. Pretreatment concentrations of COCs**

| | Ground water | | Soil | |
|---|---|---|---|---|
| **Contaminant** | **Max. conc. ($\mu$g/L)** | **Avg. conc. ($\mu$g/L)** | **Max. conc. ($\mu$g/kg)*** | **Avg. conc. ($\mu$g/kg)*** |
| Methylene chloride | 6,800,000 | 751,000 | 720,000 | 31,100 |
| TCE | 480,000 | 40,300 | 1,200,000 | 35,700 |
| Toluene | 150,000 | 18,600 | 660,000 | 20,600 |
| cis-1,2-DCE | 240,000 | 32,800 | 12,000 | 1,100 |
| Vinyl chloride | 75,000 | 10,000 | 1,700 | 90 |

* dry weight

Based on the pretreatment sampling and analyses and the volume of the treatment area, Table 2 summarizes the estimated mass of contaminants in the subsurface of the planned treatment area for the rotary steam stripping project. Sampling confirmed that the zone of highest contaminant concentrations generally lies in the western portion of the treatment area between 20 ft and 30 ft below the ground surface.

**Table 2. Estimated contaminant mass in the planned treatment area**

| | |
|---|---|
| Methylene chloride | 6,000 lb |
| TCE | 1,900 lb |
| Toluene and other VOCs | 1,100 lb |
| Total | 9,000 lb |

### *Matrix and Contaminant Characteristics Affecting Treatment Cost or Performance*

The Northeast Site includes an ongoing pump-and-treat system of seven ground water recovery wells connected to an air stripper as an Interim Corrective Measure. Because of the high contaminant concentrations of the dense chlorinated solvents in the southern plume at the Northeast Site, the effectiveness of contaminant removal with a pump-and-treat system was a concern. Because of the high volatility of the contaminants of concern and the generally high permeability of the contaminated soils, in-situ stripping technologies were considered likely candidates to help accelerate remediation at the site. The potential benefit of the rotary steam stripping technology was its ability to quickly treat both the soil and ground water, aggressively reducing the source areas of high concentration to levels more consistent with the rest of the site and allowing the site to be more quickly and easily remediated. Table 3 summarizes some of the key matrix and contaminant characteristics at the site as they relate to the performance of an in situ rotary drilling/stripping technology.

The depth of contamination and soil classification were important matrix parameters in considering the application of this technology because shallow, loosely-consolidated, granular soils support faster penetration and enhance contaminant removal. Moisture content was an important matrix parameter because more energy can be required to achieve contaminant removal in saturated soils. Similarly, as TOC in soil increases, VOCs are more strongly adsorbed to soil, requiring more energy for volatilization. In terms of contaminant parameters, the volatility of the specific contaminants of interest is obviously a key characteristic for any type of stripping or heating technology. The heat of combustion of contaminants, including associated chemicals that are not the primary COCs, is important in the selection and design of the off-gas treatment components of the sytem (as discussed in Section 5).

**Table 3. Key matrix and contaminant characteristics**

| Parameter | Value |
|---|---|
| Total depth of treatment | 32 ft |
| Unsaturated thickness | 3-5 ft |
| Saturated thickness | 27 ft |
| Primary zone of contamination | 20-30 ft |
| Soil classification | Silty sand |
| Clay content | Low; approx. 5% |
| Soil hydraulic conductivity | $10^{-3}$ to $10^{-5}$ |
| Moisture content | Saturated |
| Total organic content | Low |
| Contaminant volatility | |
| Vapor pressure | |
| Methylene chloride | 3790 mmHg@20°C |
| TCE | 58 mmHg@20°C |
| Toluene | 22 mmHg@20°C |
| Contaminant heat of combustion | |
| Methylene chloride | 144 kcal/mol |
| TCE | 226 kcal/mol |
| Toluene | 934 kcal/mol |
| Presence of DNAPLs | Highly likely, as indicated by the very high VOC concentrations; believed to occur as an immiscible phase, rather than as a single discrete "pool." |

## 4. TECHNOLOGY DESCRIPTION

The technology evaluated in this field demonstration was rotary steam stripping for the in situ removal of high concentrations of chlorinated organic solvents from soil and ground water. With this technology, a mobile rotary drilling or augering system is used to inject hot air or steam into VOC-contaminated soils to strip the contaminants from the soils and ground water. Several companies have developed mobile treatment technologies based on this process. As stated previously, In-Situ Fixation of Chandler, Arizona, developed and operated the rotary steam stripping equipment selected for this remediation effort.

### *Technology Description*

The rotary steam stripping system is based on rotary drilling technology.[7, 8] As shown in Figure 4, the system consists of a drill tower attached to a mobile platform. In most applications, the drill tower supports one or two drill blades or augers designed to inject hot air or steam into the subsurface soil as the drill blades or augers penetrate below the ground surface. The augers shear and mix the soil while the hot air or steam is being injected, causing stripping and thermal desorption of the organic contaminants from the soil particles and volatilization of the contaminants.[9] The air, steam, and contaminant vapors are carried to the surface by the injected air and steam and are collected by a shroud placed over the soil being treated. The shroud, which is operated under a slight vacuum, rests firmly on the ground so that the gases and vapors released during subsurface treatment are captured.

*Figure 4. Photo of system.*

The contaminant vapors collected in the shroud are sent to an above-ground processing unit for treatment. Depending on the type and concentration removed, contaminants can be treated in various ways: condensation, activated carbon adsorption, or thermal destruction. The treated air and steam can be reinjected for further soil treatment.

These systems can be used to treat both the vadose and saturated soils in a batch process. To fully treat an area, a grid of overlapping treatment zones is used. After one treatment zone is completed, the rotary drilling system is moved to the next zone for treatment. Depending on the contaminant types and concentrations, treatment rates of 4 to 20 yds/hr are possible with these systems. The number of passes made up and down through the soil column by the drilling system is varied as needed to reduce the contaminants to the desired treatment levels, thereby often obtaining contaminant removal efficiencies ranging from 85% to 99%.[10]

A patent on certain aspects of the steam stripping technology exists, and the patent holder has pursued what was interpreted to be patent infringements in the past. The exact details of this patent are not known by the ITRD Program. According to In-Situ Fixation, Inc., no patent infringements occurred during the Pinellas Project. Anyone wishing to place contracts for the use of this technology should be aware of the potential for patent-related issues.

## *Technology Advantages*

The treatment of VOC-contaminated soils and ground water using this type of system offers the following advantages:

- treats the contaminated soils and ground water in situ without excavation while capturing air emissions;
- provides thorough mixing and homogenization of the treated soil, resulting in effective contact between the treatment agents and the contaminants;
- can operate in bedded soils of varying permeability, such as clays and sands;
- can operate in both vadose and saturated soils; and
- can be used to focus remediation at specific contaminated strata.

## *Technology Limitations*

This technology has the following limitations:

- Contaminant removal rates can be limited by the size and operational capabilities of the required off-gas treatment system.
- Treatment is generally limited to contaminated soils less than 40 ft deep.
- Removal effectiveness and efficiency are dependent on the contaminant volatility and concentrations and soil types.
- The intended treatment area must be cleared of underground obstructions.

## *In-Situ Fixation System Description*

The ISF treatment system uses a dual-auger steam injection system. An integral drill tower containing the dual augers and collection shroud are mounted on a Caterpillar trackhoe chassis. The dual augers (Figure 5) operate in a counter-rotating mode to provide balanced forces and stability of the drill tower. The dual 5-ft-diam augers overlap slightly, providing a treatment area of about 4.5 ft by 7.5 ft, or about 35 $ft^2$. The current fixed-tower design allows soil treatment to a depth of about 35 ft. By being mounted on the trackhoe chassis, the drill tower and augers can be moved easily from one treatment zone to another.

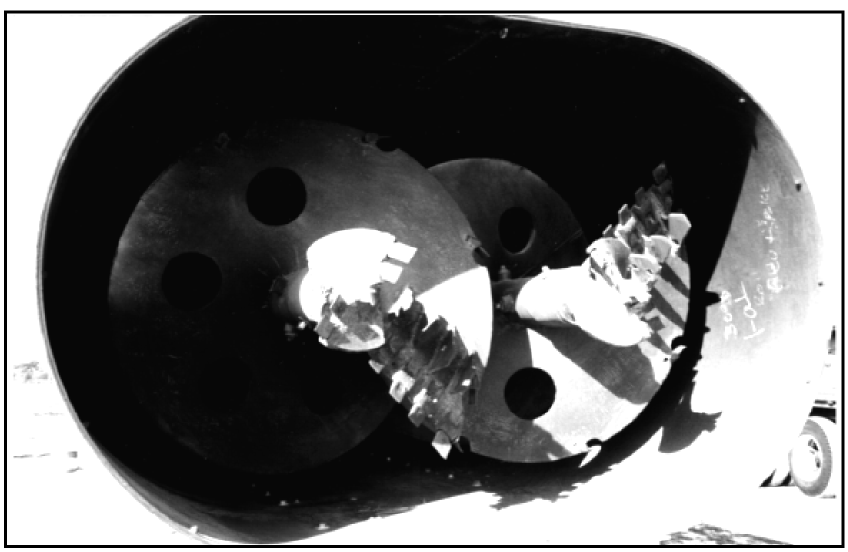

**Figure 5. ISF dual auger bits and shroud.**

For application at the Northeast Site, the dual auger system was connected to a steam plant and air compressor to provide both air and steam as the injection fluids for stripping the VOCs from the soil and ground water.  The shroud used to collect the stripped VOCs was connected to a catalytic oxidation (CATOX) system (Figure 6) for destruction of the organic contaminants.  The oxidation system was connected to an acid-gas scrubber (Figure 7) to neutralize air emissions.

**Figure 6.  Off-gas treatment system prior to completed assembly, showing (from right to left)  knock-out tank, vacuum extraction unit, and CATOX.**

**Figure 7.   Acid-gas scrubber tower prior to assembly with quench unit and CATOX.**

## *Treatment System Schematic and Operation*

Figure 8 is a schematic of the ISF treatment system operated at the Pinellas STAR Center. The treatment system process flow was as follows:

- The rotary steam stripping system was moved to the area to be treated, and the shroud was lowered to the ground surface and placed under negative pressure.
- The rotating augers began penetration into the contaminated soil, continuously injecting either air and/or steam through the drilling kelly bars into the contaminated soil and ground water.
- Depending on the contaminant removal rates and the amount of contaminants removed, the augers made a series of passes up and down through the soil column.
- The contaminant vapors collected with the shroud were directed first to a water knock-out tank and then to a catalytic thermal oxidizer, where the VOCs were destroyed.
- The emissions from the catalytic oxidation system were passed through an acid-gas scrubber to remove hydrochloric acid (generated during the destruction of the chlorinated VOCs) before discharge into the atmosphere.

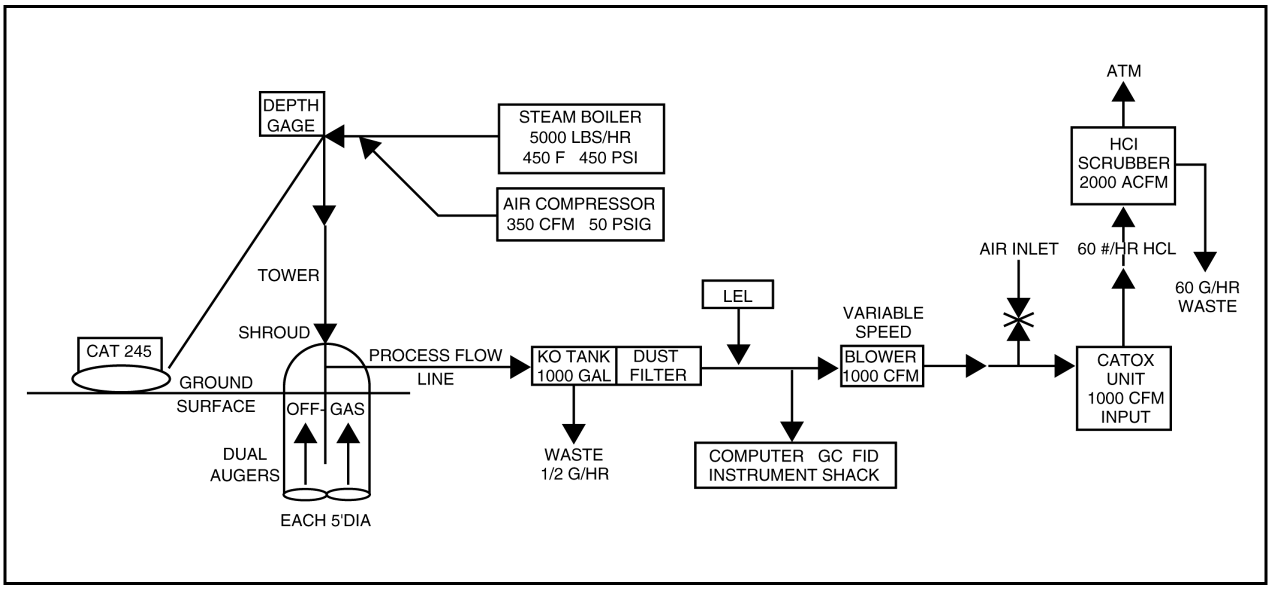


**Figure 8. Process schematic.**

Health and safety requirements for the operation of the system required continuous monitoring of the following: the areas around the shroud for leakage of contaminant vapors, the concentration of contaminants entering the catalytic thermal oxidation system, and the air emissions from the off-gas treatment system. Figure 9 is an aerial view of the entire treatment system in operation at the Pinellas STAR Center.

## *Key Design Criteria*

In situ anaerobic bioremediation is being considered as a potential remediation technology for the Pinellas STAR Center's Northeast Site. The application of the rotary steam stripping technology at this site was initiated to reduce the areas of very high levels of chlorinated solvents to levels more consistent with the rest of the site and more compatible with bioremediation. This goal required the reduction of the identified contaminants in the areas of high concentration from levels of 500 to 5000 ppm to levels of 100 to 200 ppm.

**Figure 9. Aerial view of the dual auger rotary steam stripping and off-gas treatment system.**

Based on the areal extent and depth of the contamination at Pinellas, it was expected that approximately 10,000 cubic yards of soil could require treatment to a depth of approximately 30 ft. Based on the Florida Department of Environmental Protection (FDEP) guidelines, the removal of these high concentrations of VOCs from this volume of material would require air emission treatment. Initial estimates suggested that the use of thermal treatment technologies would be more cost effective than other air emission control devices, such as activated carbon. Based on the volume of contaminants to be treated, the largest easily portable catalytic oxidation system was selected for use with the rotary steam system. Because the VOCs being treated at the Northeast Site are predominately chlorinated solvents, an acid-gas scrubber was also required to meet the FDEP's air discharge requirements.

ISF proposed a CATOX system design that would treat 60 lb/hr of methylene chloride, the major site contaminant. The scrubber capacity (60 lb/hr HCl) was sized slightly larger to account for the presence of TCE. It was anticipated that only in the most concentrated areas would the removal rate exceed 60 lb/hr. In these cases, process controls would be initiated to limit the VOC throughput to the off-gas destruction system. The critical factors that determined the selection of the 60 lb/hr capability of the off-gas treatment system were (1) the combined cost of the scrubber, catalyst and CATOX; (2) the pretreatment site characterization chemical data; and (3) the delivery schedule of the scrubber and CATOX.

Based on the site pretreatment chemical data, the presence of toluene was noted as significant in one area of the site. As indicated in Section 3, toluene has a much higher (approx. 7 times) heat of combustion than methylene chloride. If toluene occurred in even moderate amounts, its destruction would release enough heat to limit off-gas throughput by causing catalyst overheating. It was difficult to evaluate the extent of this potential problem prior to the remediation.

### *Operating Parameters*

The operating parameters (Table 4) of the rotary steam stripping system can be adjusted depending on the effluent concentrations of the contaminants being treated, the capacity of the off-gas treatment system, air emission requirements, and the type of soil being treated. Because the levels of contaminants varied across the site to be treated, it was expected that different combinations of air/steam, injection pressures, penetration rates, etc., would be varied to cost effectively reduce the contaminant concentration levels across the site. For this application, two major areas of contaminated soil/ground water treatment were addressed—one area had VOC concentration levels in excess of 5000 ppm, and the other area had VOC concentration levels of about 500 ppm. Because of the flexibility of the treatment system, each area was treated differently to optimize the treatment performance.

At the Northeast Site, treatment operations were generally conducted 8 to 10 hrs/day, 5 days/week. ISF typically had five people involved in operations: a site supervisor, a health and safety officer [who doubled as a sampler and gas chromatograph (GC) operator], a trackhoe operator, a boiler operator, and a general laborer. Oversight by LMSC typically involved a project manager, and an individual from the LMSC Industrial Hygiene/Safety Department routinely visited the site during operations.

Operation of the rotary steam stripping system was controlled and adjusted based on the VOC levels coming out of the shroud, which were continuously monitored with an in-line flame ionization detector (FID). Treatment parameters (depth, FID, process temperature, air injection rate, steam injection rate, and process flow rate) were continuously monitored with a digital display, strip chart recorder, flowline meters, and pressure gauges located throughout the system. A remote FID and depth display was mounted in the CAT245 cab for the operator. The operator observed and used these data to adjust the penetration rates and treatment times in each of the treatment holes. This continuous monitoring during drilling reduced the chance of exceeding the catalyst temperature threshold in the CATOX system and assisted in directing treatment to the appropriate horizons in each hole.

**Table 4. Typical operating parameters**

| Parameter | Value |
|---|---|
| System equipment base/mover | Caterpillar 245D trackhoe |
| Stripping system | Dual counter-rotating, 5 ft-diam augers |
| Support equipment | Backhoe, welder, off-gas treatment system, compressor, boiler, generator, parts trailer |
| Treatment area per hole | 35 $ft^2$ |
| Auger rotation rate | 12 rpm |
| Auger penetration rate | 1 ft/min avg |
| Air injection rate/pressure | 200-300 scfm avg @ 125 psi |
| Steam injection capacity/ temperature | 2,000-4,000 lbs/hr @ 450°F @ 550 psi |
| Vacuum on shroud | 5-10 in. water |
| CATOX capacity/throughput | 60 lb/hr (based on methylene chloride) |
| CATOX operating temperature | approx. 1000-1100°F |

# 5. ROTARY STEAM STRIPPING SYSTEM PERFORMANCE

ISF treated an area within the Pinellas STAR Center Northeast Site from January through April 1997. The following sections of this report present a summary of the system's performance.

## *Remediation Objectives and Approach*

The remediation was coordinated by LMSC, the DOE's site contractor for the Pinellas STAR Center, in cooperation with the ITRD Program. The primary objective of the rotary steam stripping project was to quickly remediate areas of high concentrations of contaminants within the designated treatment area of the Northeast Site. Through the remediation of these areas of high concentration, the Northeast Site would then have more moderate contaminant levels that could be more easily treated with a proposed in situ bioremediation effort.

The approach to the remediation focused on four supporting objectives:

1. optimize system operating parameters through an initial Treatment Efficiency Characterization (TEC) study,
2. evaluate overall system performance in treating VOC-contaminated soil and ground water,
3. evaluate system operation effects on the surrounding environment, and
4. quantify site-specific unit treatment costs.

## *Performance Evaluation Criteria*

Performance criteria considered in the evaluation of the rotary steam stripping technology included the following:

- ability of the system to remove VOCs in the soil and ground water to a level of 100 to 200 ppm in an approximate 10,000-$yd^3$ treatment volume,
- recovery and treatment of volatilized contaminants to air emission levels specified in the FDEP's Notice of Authorization[10,11] to conduct the rotary steam stripping project,
- absence of fugitive hazardous emissions from the treatment system, and
- absence of migration of contaminants outside the treatment area.

The methods used to assess performance were:

1. To gain further insight into the rotary steam stripping technology and to establish efficient operating parameters to remediate the treatment area, a TEC was conducted immediately after system setup.
2. To verify VOC removal and determine final contaminant levels, pre- and post-treatment soil and ground water sampling and analyses were performed. The ITRD group established a sampling grid (Figure 10) to characterize the planned treatment area and its perimeter.
3. To verify the level of recovery and treatment of volatilized contaminants, air samples were collected daily during operations from the CATOX influent, the CATOX effluent, and the scrubber effluent.
4. To verify the absence of any fugitive emissions from around the treatment system, monitoring was performed with a hand-held FID vapor analyzer during operations.
5. To verify the absence of migration of contaminants outside the treatment area, soil and ground water sampling points were established around the treatment area perimeter, and monitoring wells around the perimeter were sampled before and after treatment operations.

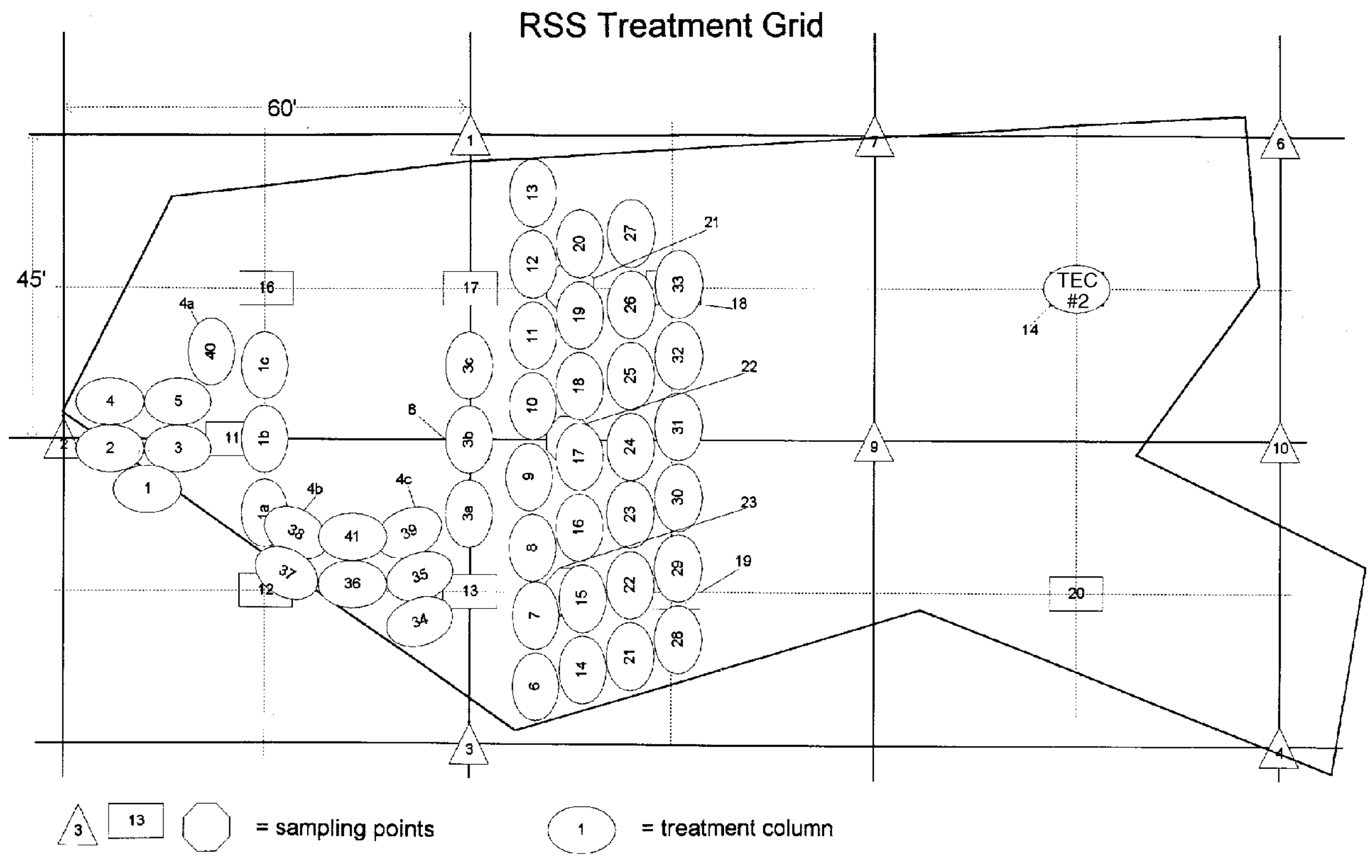


**Figure 10. Sampling grid with overlay of treatment holes.**

## *Operational Summary*

### Mobilization Phase

Equipment and materials were transported to the Pinellas STAR Center's Northeast Site from approximately September 25 through December 24, 1996. The original estimate for completion of transport of equipment was mid-November, with a completion of assembly by the end of November. Several issues resulted in the delay of completion of the mobilization phase until January 20, 1997. One significant issue was that an available CAT 245D trackhoe (this specific model was required to mate with the ISF dual auger system components) rental unit was not able to be located in the southeastern United States, necessitating the transport of one from Phoenix, Arizona.

After assembly, the drilling of two practice holes demonstrated that the dual-auger system was able to penetrate the soils at the Northeast Site without any significant resistance and that the air and steam injection through the soil and ground water, along with the resultant recovery of vapors, appeared to be functioning as expected. However, hydraulic problems (a broken fitting and incorrectly connected hydraulic lines) encountered on the first practice hole resulted in a one-week delay in beginning operations.

### Treatment Efficiency Characterization Phase

A Treatment Efficiency Characterization (TEC) Study was conducted to identify system operational capabilities and issues over the range of contaminant mixtures and concentrations in the treatment area. The ITRD group chose three specific areas based on contaminant levels and characteristics. Figure 10 shows the locations of not only these areas, but also sampling points and later treatment holes. The 1A, B, and C holes were located in an area of very high VOC contamination in the ground water (up to 5,000,000 $\mu$g/L total VOCs). TEC No. 2 hole was located in an area of moderate VOC contamination in the ground water (approx. 250,000 $\mu$g/L total VOCs). The 3A, B, and C holes were located in an area with the highest levels of total VOCs in the soil (approx. 400,000 $\mu$g/kg total VOCs).

The TEC phase began on January 21 and continued through February 11. During the treatment of these areas, air only was injected into the 1A and 3A holes, air and steam was injected into the 1B and 3B holes, and air was injected in the first pass then steam for the remaining passes for the 1C and 3C holes. The results were monitored to develop optimal treatment settings for the rest of the treatment area. Sampling of soil and ground water was performed before and after treatment of the TEC locations, and an in-line FID was used during operations to collect continuous total VOC removal quantities. Several initial operational issues with the system were identified during the TEC and are listed in Table 5.

**Table 5. Operational issues and delays during the TEC**

| Issue | Result and extent of delay |
|---|---|
| Field GC was not operating properly for approx. 2 weeks, necessitating the use of the LMSC Analytical Laboratory. | Delayed receipt of analytical results at least 1 day. |
| Destruction efficiency of the off-gas treatment system dropped below the permit-required 90% destruction. | Repaired CATOX unit and catalyst (2 days). |
| Because of efficiency problems of the off-gas treatment system, operations were limited to treating one hole and then ceasing operations until it was confirmed that the off-gas treatment system was effectively destroying the contaminant vapors in accordance with the air emissions permit requirements. | Resulted in the loss of approximately ½ to 1 day of operations after treating each hole. |
| Packing in the scrubber tower melted due to a loss of cooling water caused by a plant-wide water shutoff. | Removed and replaced with new packing (2 days). |
| Fugitive emissions were detected outside of the dual auger system shroud. Some of the fugitive emissions exceeded the Permissible Exposure Limits (PELs) in the breathing zone for the project. | Variable extent; this continued to occur throughout the project; however, the frequency of occurrence was decreased by limiting the air injection rate, creating an exclusion zone around the shroud and placing a large sheet of plastic around the shroud to limit fugitive emissions. |
| Automatic alarm shutdowns of the CATOX unit and the vacuum extraction unit occurred when the mass of VOCs being fed to the CATOX was large enough to raise the temperature of the catalyst beyond its operating limits. | Variable extent; this problem continued to occur throughout the project; however, it was limited by increasing the catalyst's operating temperature limits and implementing procedures to limit the mass of VOCs being fed to the CATOX. |
| During periods of recovery and treatment of large masses of VOCs, the acid-gas scrubber was incapable of controlling the pH of the air emissions. | Variable extent; further inspection revealed an undersized caustic-addition pump intake line. When the size of the intake line was increased, the scrubber was able to neutralize the air emissions at all times. |

At the end of the TEC phase, the following operational characteristics of the rotary steam stripping system became apparent:

- The mass of VOCs (especially any VOC with a high heat of combustion) being fed to the CATOX had to be limited; otherwise, the catalyst could be overheated.
- Catalyst overheating protection shutdowns frequently occurred when air and steam were being injected.
- The dual-auger system was capable of removing more contaminants than the design capacity of the off-gas treatment system.
- Fugitive emissions were able to escape outside the shroud and could exceed PELs.
- Because of the FDEP's air emissions limitations, timely and accurate gas sample analysis was critical.
- Sampling of the TEC holes where only air injection was used (1A & 3A) showed mixed results, with negative removal (i.e., contaminant redistribution) of VOCs in the soil and groundwater at 20 ft below land surface (bls), and good removal of VOCs from the ground water at 30 ft bls.
- Sampling of the TEC holes where steam and air injection was used (1C, 2, 3B, 3C, & 4A-C) showed generally better results, with more limited occurrences of redistribution of VOCs in the soil and groundwater at 20 ft bls, and good removal of VOCs from the ground water at 30 ft bls.

**Remediation Phase**

As discussed in Section 3 and shown in Figure 3, the contaminants at the site in the area treated with the dual-auger system were mainly between 16 and 30 feet below the surface. Additionally, the highest levels of contamination occurred on the west end of the treatment area and decreased quickly to the east. Because of these relative levels of contamination, it was decided to begin treatment in the areas of highest contaminant concentration. From Figure 10, this included treatment holes 1-5. After beginning treatment of production hole No. 1 on February 12, the off-gas treatment system continued to experience problems with catalyst high temperature shut-downs. On February 18, the dual auger system sheared bolts that attach the kelly bars to the drive unit and was inoperable until February 25. Further problems with the off-gas treatment system resulted in only three holes being treated during this phase in February. (Two holes were treated in the TEC phase during February.)

March operations in the western portion of the treatment area continued to have problems with fugitive emissions and catalyst high-temperature shutdowns until March 4, when LMSC personnel decided that the rotary steam stripping system was not able to operate effectively at this elevated level of contamination, and no further knowledge of the technology's application at this site was being gained . On March 5, the system was moved to the central portion of the treatment area, where contamination levels were significantly lower. This included treatment holes 6-33. Holes 6-11 were quickly treated in two days. On March 7, the system was unable to back out of hole No. 11 due to a failed drive chain in the main gearbox. Repairs of the system lasted through March 18. Operations resumed on March 19, after which 26 holes were treated in 6 days, and progressively lower levels of contamination were being encountered as treatment progressed eastward.

On March 24, after finishing hole number 33, the system was moved back to the area of higher contaminant concentration because LMSC personnel felt that the knowledge and experience of system operations on-site had improved to a point where effective treatment could be accomplished in the higher concentration areas. The system remained in this area for the remainder of the remediation phase, treating holes 34-41. Because of the higher contaminant concentrations in this area, several passes were required in each hole, and operations were slowed to keep from overheating the catalyst. On March 27, clay buildup on the dual auger's cutting teeth was slowing penetration rates enough that the clay had to be removed, and it was discovered that the boiler had to be descaled. Operations once again resumed on March 31 and continued through April 2, at which time the funding for the time-and-materials phase of the subcontract was depleted, and the project was terminated.

## System Performance and Treatment Results

Contaminant removal by the dual auger system from each of the treatment holes was monitored with an FID located on the dual auger shroud. This provided a continuous display of the amount of contaminants being removed by the system. It also allowed the operator to concentrate treatment in each borehole in the zone of highest contaminant concentration. The FID was calibrated with a GC throughout the remediation so that, along with the continuous monitoring of the air and steam flow rate through the shroud, the amount of contaminants removed from each treatment hole could be measured (Table 6). Based on this data, approximately 1200 lbs of contaminants were removed by the dual auger system. These results compare well with the results obtained from monitoring of the CATOX system and comparisons with pre- and post- treatment sampling of the soil and ground water.

**Table 6. Examples of contaminant removal for several treatment holes based on calibrated FID data**

| Treatment hole no. | Air or steam | Time treated (hrs) | Contaminant removed (lbs) |
|---|---|---|---|
| 1A | air | 4 | 19 |
| 1B | air & steam | 5 | 28 |
| 1C | air, then steam | 3 | 17 |
| 3A | air | 2 | 6 |
| 3B | air, then steam | 3 | 7 |
| 3C | air & steam | 3 | 10 |
| 2 | air, then air & steam | 6 | 92 |
| 5 | air | 3 | 50 |
| 6 | air | 3 | 3 |
| 7 | air | 1 | 2 |
| 8 | air | 1 | 2 |
| 9 | air | 1 | 2 |
| 10 | air | 1 | 4 |
| 11 | air | 1 | 1 |
| 37 | air & steam | 2.5 | 14 |
| 38 | air & steam | 5 | 42 |
| 39 | air & steam | 4 | 34 |
| 40 | air & steam | 4 | 47 |

Based on the historical VOC concentration data previously discussed and shown in Figure 3, several sets of soil and ground water samples were collected to assess system performance and system operational effects on the surrounding environment. As shown in Figure 10, about 20 different locations were selected on a defined grid pattern to collect soil and ground water samples inside and around the edges of the expected treatment zone. Soil and ground water samples were collected at these locations both before and after treatment. Because the existing historical data showed that most of the contamination in the treatment area was at depths between 15 and 30 feet deep, at the identified locations ground water samples were collected at depths of 15 and 25 feet, while soil samples were collected at depths of 10, 20, and 30 feet or depths of 15, 20, and 25 feet. All samples were collected using direct push sampling techniques and were analyzed using EPA Methods SW846 8240A for soils and 8260A for ground water.

As can be seen in Figure 10, several of the treatment holes were oriented to coincide with the identified monitoring locations. Additionally, many of the Treatment Efficiency Characterization treatment holes were sampled before and after treatment. At these locations, the soil was sampled continuously before treatment and the VOC distribution assessed using a PID detector. At the location of the highest PID reading, a soil sample was taken for analysis. After treatment, the soil was sampled at the same location for comparison. These are the maximum soil contamination values pre and post-treatment identified in Table 7. The results in Table 7 cover a wide range of soil and ground water contaminant concentration ranges and should be representative of the overall effectiveness of the rotary steam stripping system.

As can be seen from the results presented in Table 7, the overall removal efficiencies commonly vary from 69-95%. The percent removals were calculated from total contaminant estimates before and after treatment and from the GC-calibrated FID data collected during treatment. With a few exceptions, these results track with the general percent reduction in the levels in the maximum contaminant concentrations. The sampling data show that the contaminants of concern at the site, methylene chloride, TCE, DCE, vinyl chloride, and toluene are all removed equally well. None of the contaminants showed consistently lower removal rates than the other contaminants. In some cases, post-treatment sampling revealed higher VOC concentrations at some horizons than were detected pretreatment; this is believed to be caused by the liberation and vertical mixing of contaminants as the dual augers are rotated up and down the treatment hole. Still, the FID data indicated that, overall, many pounds of VOCs were removed from each hole.

**Table 7. Pretreatment and post-treatment soil and ground water concentrations**

| Treatment hole/ monitoring point # | Pretreatment concentrations (ppm) | | Post-treatment concentrations (ppm) | | Percent reduction in observed maximum (%) | Percent removal based on FID data (%) | Air or steam | Treatment time |
|---|---|---|---|---|---|---|---|---|
| | Max. soil ($\mu$g/g) | Ground water (mg/L) | Max. soil ($\mu$g/g) | Ground water (mg/L) | | | | |
| Hole 1A | <1 | 5170 | 120 | 1484 | 69 | 93 | Air only | 4 passes, 4 hrs |
| Hole 1C | 1860 | 2480 | 106 | 724 | 81 | 55 | Air, then steam | 4 passes, 3 hrs |
| Hole 3A | 20 | 1426 | 325 | 1019 | 7 | 95 | Air only | 2 passes, 2 hrs |
| Hole 3B | 7 | 6952 | 11 | 1135 | 84 | 30 | Air, then steam | 3 passes, 3 hrs |
| Hole 3C | 82 | 1860 | 29 | 341 | 81 | 95 | Air and steam | 4 passes, 3 hrs |
| Hole 4A | 28 | NA | 143 | NA | -- | 90 | Air and steam | 3 passes, 4 hrs |
| Hole 4B | 900 | NA | 26 | NA | 97 | 95 | Air and steam | Many passes, 5 hrs |
| Hole 4C | 204 | NA | 158 | NA | 23 | 95 | Air and steam | 1.5 passes, 4 hrs |
| MP 14 | 19 | 251 | <1 | 2 | 99 | no data | Air and steam | 2.6 passes,1 hr |
| MP 18 | <1 | 1290 | 2 | 198 | 85 | 75 | Air and steam | 1 pass, 1 hr |
| MP 19 | <1 | 1364 | 6 | 198 | 85 | 45 | Air and steam | 1 pass, 1 hr |

NA = not analyzed

While the percent removal data is impressive, an important evaluation criterion is also the level to which the contaminant concentrations can be reduced. As shown in Table 7, even after several passes with the rotary steam stripping system, areas with the highest contaminant concentrations often still require additional treatment to reduce contaminant concentrations below 100 or 200 ppm, levels considered most compatible with a proposed in situ anaerobic bioremediation system. This, of course, would increase the total cost of a remediation effort using this technology.

Based on the results of the TEC study, a general understanding of the contaminant removal rates obtained by the dual-auger system and effectively handled by the off-gas treatment system was determined for various operating conditions and contaminant levels. Figure 11 shows the relationship at this site for the expected contaminant removal rates for various operating conditions. The amount of total VOC contaminants in each treatment hole was estimated based on the extensive soil and ground water sampling data generated for this remediation effort through the TEC study. As the dual-auger system made passes up and down through each treatment hole, the volume of VOCs removed was recorded continuously with a GC-calibrated FID. The results in this figure are based on the removal data from more than 100 separate treatment passes of the dual-auger system.

Based on the information presented in Figure 11, a few general observations can be made. First, higher air-flow rates provide higher contaminant-removal rates. In areas with low contaminant levels, the differences are less pronounced. The large contaminant-removal rates available with the dual auger system suggest that the selection of an appropriate off-gas treatment system is important, because it can become the rate-limiting factor in treating areas with high contaminant concentrations. In fact, this limitation occurred in the Northeast Site application in the area of high contaminant concentration where the catalytic oxidation system could not handle the amount of contaminants being produced by the dual auger system, forcing the operator to reduce the penetration rate and/or steam injection rate in order to limit the contaminant removal rate.

In addition, some areas contained TCE and toluene, compounds with much higher heats of combustion, in approximate concentrations of 350 ppm and 100 ppm, respectively. It was observed that during treatment in the areas with these compounds, the maximum temperature allowable for the catalyst (approx. 1,100° to 1,200°F) could be reached very quickly, resulting in an automatic over-temperature system shut-down. Further elevation of the catalyst temperature could result in irreversible physical damage to the catalyst. It is believed that the TCE and toluene quickly elevated the temperature of the catalyst when they were combusted. Slowing the auger penetration rate by 75% to 90% and decreasing or stopping steam injection helped to control the catalyst temperature. As discussed in Sect. 4, the design of the off-gas treatment system was based on the high concentration of methylene chloride in the western portion of the treatment area, and the potential impact of the high TCE and toluene concentrations on off-gas treatment was not fully understood.

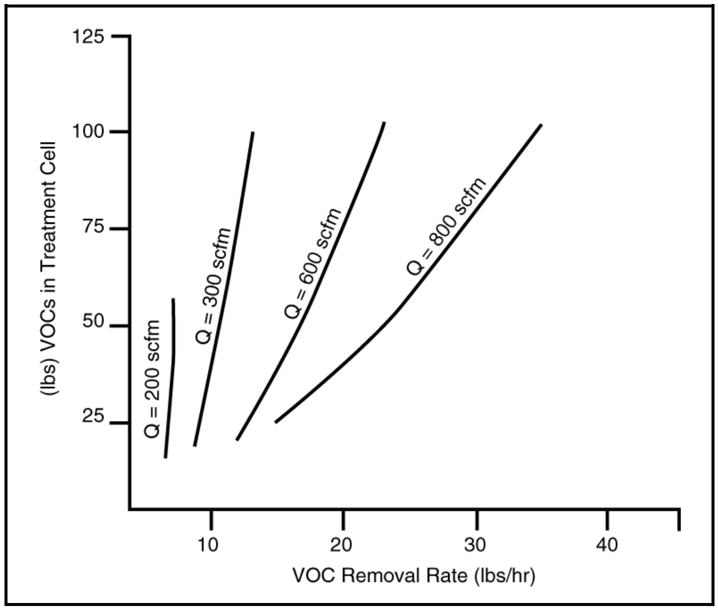


**Figure 11. VOC removal rates compared to estimated original quantities of VOCs in treatment hole**
**(Q = extraction flow rate in standard cubic ft/min).**

Another observation is that contaminant removal rates generally decrease as contaminant levels decrease, suggesting that a practical limit probably exists for the level to which the contaminant concentrations can be reduced cost effectively. For this remediation effort, the goal was to reduce the contaminant concentrations to levels approaching 100 to 200 ppm to be compatible with the rest of the site and a proposed in situ anaerobic bioremediation effort. In the areas of low contaminant concentration, contaminant levels were easily reduced from approximately 100 ppm to 1 to 10 ppm for both soil and ground water. Whether these levels could be attained cost effectively in areas of high contaminant concentration was not fully investigated at this site.

Part of the system performance evaluation included looking at the effects of the system operation on the surrounding environment. Major concerns were fugitive emissions and the possible migration of contaminants outside the treatment area. As previously discussed, fugitive emissions were detected above permissible exposure limits during some operations. These were minimized by limiting air injection rates, creating an exclusion zone around the shroud, and by placing plastic around the shroud. Post-treatment soil and ground water sampling around the perimeter of the treatment areas did not show any contaminant migration from the treatment areas into the adjacent untreated areas. During sampling of some post-treatment holes, it was discovered that it was difficult to obtain some water samples using direct push technology. This suggests that the permeability in the treated soils may have been reduced.

However, sufficient post treatment testing has not been conducted to determine if any long term reduction in the soil permeability has occured. This does suggest though that, if rotary steam stripping is to be used in conjunction with another technology, such as air sparging/soil vapor extraction, consideration should be given to determine whether rotary stripping operations would negatively affect the performance of a follow-on technology.

As discussed in the previous project chronology, system downtime affected the performance of the rotary steam stripping system. Figure 12 shows the operating time for the system, which averaged approximately 50% for the entire project. Figure 13 shows the downtime as a percent of available operating time per week, identified with the general cause of the downtime. The operating time for the system over the last half of the project increased continuously and averaged approximately 80% during the last three weeks of operation.

A summary of the performance of the rotary steam stripping system is provided in Table 8 relative to the performance measures of the remediation effort. After some initial operational problems, the system met many of the identified goals. However, problems with the capacity and operation of the off-gas treatment component did significantly reduce the treatment rate and overall system performance.

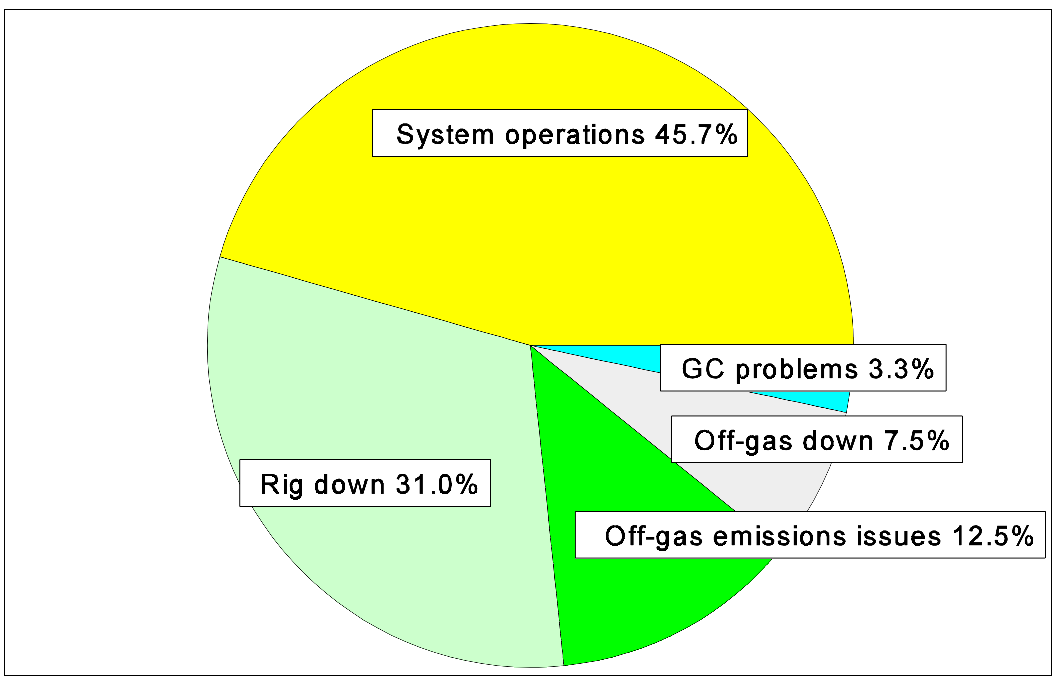


**Figure 12. Summary of system operations vs downtime.**

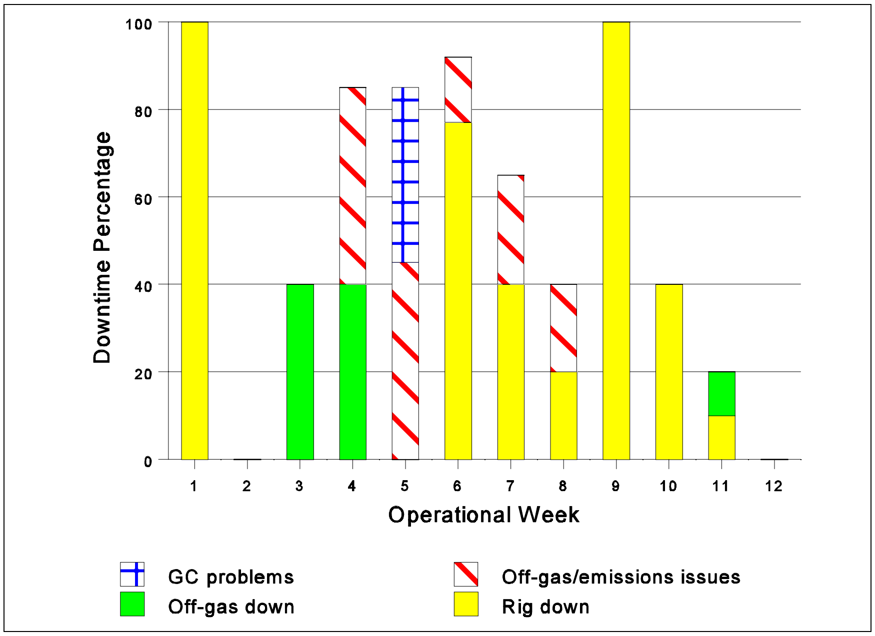


**Figure 13. Percent downtime of operations (by week).**

**Table 8. Pinellas rotary stripping system performance summary**

| Performance Measure | Value/ Result |
|---|---|
| Quantity of soil/area treated<br>• Planned<br>• Actual | <br>10,000 $yd^3$<br>2,043 $yd^3$ |
| Mass of contaminants<br>• Estimate (pretreatment) in planned treatment area<br>• Estimate (pretreatment) in actual treatment area<br>• Estimated mass removed | <br>9,000 lbs<br>1,300-1,400 lbs<br>1,200 lbs |
| Remediation goals<br>• Optimize parameters through a Treatment Efficiency Characterization<br>• Removal of VOCs in the soil and ground water to approx. 100-200 ppm<br>• Absence of fugitive emissions<br>• Absence of contaminant migration | • A TEC was performed, although multiple equipment problems limited the information obtained.<br>• Some areas were reduced to below 100 ppm; however, time and funds available prevented reduction below 200 ppm in other areas.<br>• Monitoring revealed fugitive emissions; these were reduced by limiting the drilling/injection rate and by covering the surrounding soil with plastic sheeting.<br>• Sampling and analyses verified that contaminants did not migrate outside the treatment area. |
| Compliance Goals:<br>Recovery and treatment of volatilized contaminants to FDEP's limits | Initial discharge from the off-gas treatment system exceeded the FDEP's limits; however, after repair, limits were not exceeded. |
| Residuals | Used hydraulic oil<br>Scrubber, boiler, and knock-out tank effluent water |
| Quantity of material disposed | Approx. 100 gal. of used hydraulic oil<br>Effluent water quantity unknown (approx. 5 gpm); routed to site wastewater system |

# 6. ROTARY STEAM STRIPPING SYSTEM COST

The Rotary Steam Stripping project was subcontracted by LMSC to ISF with a fixed price for the mobilization and demobilization phases, and a time-and-materials reimbursement (with a not-to-exceed amount) for the treatment operations phase. The mobilization fixed amount was all-inclusive, including moving the equipment, personnel, supplies, materials, and any other necessary items to the job site prior to start. The demobilization fixed amount was all-inclusive, including moving the equipment, personnel, and any remaining items to ISF's next destination after completion of the project.

Under the subcontract, ISF agreed to the following financial terms:

| | |
|---|---|
| Mobilization | $ 95,000.00 |
| Demobilization | $ 51,000.00 |
| Time and materials not to exceed | $773,651.08 |
| Total subcontract established amount | $919,651.08 |

ISF was to perform all work according to the Scope of Work, dated April 17, 1996, and the subsequent clarifications. This not-to-exceed, time-and-materials type contract was based on crew-days on-site and did not specify the volume of soil and ground water to be treated.

Table 9 shows the breakdown of project costs in accordance with accepted Federal Remediation Technologies Roundtable[13] cost elements. Based on the nature of equipment used on such a project, equipment operating rates can be quite high and were the largest component of cost. In addition, standby rates were established for this project in case LMSC stopped the ISF operations and equipment was sitting idle. With this arrangement, full equipment operating costs were not incurred; instead, a minimal rate to cover the equipment rental rate was incurred.

Unit treatment costs are often calculated based on the volume of contaminants removed or the volume of soil treated. Either method must be used carefully because of the variation in treatment inherent at any site. For example, providing unit costs based on the volume of soil treated will vary based on the relative contamination level of the soils being treated, with soils having higher contaminant levels requiring longer treatment. On the other hand, providing unit costs based on the volume of contaminants removed will also vary based on the relative contaminant levels of the soil being treated. As discussed in Section 5, fewer pounds per hour of contaminant are removed in soils with lower contaminant levels. Therefore, in using either method, consideration should be given to both the contaminant level of the soil to be treated and the desired target treatment level.

Another complicating factor is that the rotary steam stripping system consists of several subsystems, each of which has a substantial impact on overall system performance and cost. In the application at the Pinellas STAR Center's Northeast Site, the off-gas treatment system was a major contribution to the unit treatment costs that may or may not be required or could be modified at a different site. Additionally, each of these systems has its own associated downtime that affects the overall system performance and cost.

Therefore, unit treatment costs as a function of the volume of soil treated, the initial contaminant levels in each treatment hole, and the required treatment levels were chosen as identifying factors. Based on the data provided in Table 9, general estimates of the costs per day for the dual auger and the off-gas treatment systems can be defined. Based on the results shown in Table 7 and Figure 11, the time required to reduce the various treatment hole contaminant levels to levels of approximately 200 to 300 ppm was used to calculate the unit removal and treatment costs.

**Table 9. Pinellas Rotary Steam Stripping Project cost by interagency work breakdown structure (WBS)**

| Cost element (with interagency WBS Level 2 code[14]) | Description | Costs ($) | Subtotals ($) |
|---|---|---|---|
| Preproject operations visit | Visit to similar project | $ 2,400 | $ 2,400 |
| Mobilization and preparatory work (331 01) | CAT 245D transport to Pinellas | $ 10,000 | $ 95,000 |
| | Dual auger transport to Pinellas | $ 15,000 | |
| | Parts trailer transport to Pinellas | $ 11,000 | |
| | Trucks and dual auger hood transport | $ 11,000 | |
| | Steam processing equipment transport | $ 19,400 | |
| | Personnel & equipment load out | $ 6,600 | |
| | Personnel & equipment unload & assemble | $ 12,000 | |
| | Operational precheck | $ 10,000 | |
| Monitoring, sampling, testing, and analysis (331 02) | Pretreatment sampling and analysis | $ 23,000 | $ 59,000 |
| | Pre-TEC sampling and analysis | $ 9,000 | |
| | Post-TEC sampling and analysis | $ 9,000 | |
| | Post-treatment sampling and analysis | $ 18,000 | |
| Physical treatment (331 13) | Equipment<br>CAT 245D $ 76,586<br>Dual auger system $ 53,211<br>Backhoe $ 11,643<br>Air compressor $ 8,853<br>Generator $ 14,889<br>Support equipment $ 29,054<br>Boiler $ 42,957<br>Gas chromatograph $ 15,417<br>Off-gas treatment equip. $ 215,657 | $ 468,267 | $ 773,651 |
| | Labor (incl. travel & per diem) | $ 259,097 | |
| | Supplies & Materials | $ 25,250 | |
| | Fuel | $ 21,037 | |
| Disposal [other than commercial (331 18)] | Hydraulic oil | $ 200 | $ 200 |
| Demobilization (331 21) | CAT 245D | $ 5,000 | $ 51,000 |
| | Dual auger system | $ 7,000 | |
| | Parts trailer | $ 6,000 | |
| | Trucks and dual auger hood | $ 6,000 | |
| | Steam processing equipment | $ 12,400 | |
| | Personnel & equipment disassemble & load | $ 8,000 | |
| | Personnel & equipment off-load | $ 6,600 | |
| | | **TOTAL:** | $ 981,251 |

As previously discussed, the operation of the rotary steam stripping treatment at Pinellas was affected by a number of operational issues and design limitations that caused great variations in the observed treatment rates. Contaminant mixtures and concentrations also affected the rate of treatment, particularly in the western portion of the treatment area. Because of these operational variations, the unit treatment costs for this project are more accurately represented by a range rather than a discrete value (Table 10).

Based on the time-and-materials contract used at this site, the operating costs of the rotary steam stripping system were approximately $13,000/day. In areas of low contaminant concentration, as many as 5 to 6 holes could be treated in one day, while in the areas of high contaminant concentration, often only one hole could be treated in one day. Based on this data, the operating costs of the system varied from approximately \$50-\$400/$yd^3$ of treated soil, depending on the contaminant levels.

**Table 10. Range of observed unit treatment costs in the Pinellas rotary steam stripping project**

| Holes per day | Volume per day ($yd^3$) | Volume treated at this rate in 60 days ($yd^3$) | Operating Cost, based on \$13,000 per crew-day (\$/$yd^3$) | Mob./Demob. Cost, based on 60 day treatment period(\$2433/day) (\$/$yd^3$) | **Total Cost** (\$/$yd^3$) |
|---|---|---|---|---|---|
| 1 | 40 | 2,400 | $325 | $62 | **$387** |
| 2 | 80 | 4,800 | $163 | $31 | **$194** |
| 3 | 120 | 7,200 | $108 | $21 | **$129** |
| 4 | 160 | 9,600 | $81 | $16 | **$97** |
| 5 | 200 | 12,000 | $65 | $12 | **$77** |
| 6 | 240 | 14,400 | $54 | $10 | **$64** |

The operating costs can also be viewed from the standpoint of costs per pound of contaminant treated. This method of assessing costs is often presented because it can more easily address the differences in contaminant levels in the treatment holes. Calculating operating costs based on this method, we determined that the unit operating costs for the system varied from $300-$500/lb of contaminant removed.

Key factors that affect overall treatment costs are the on-line time of the entire system, the level of contaminants in the treatment holes, and the target concentration levels one would like to achieve. These factors need to be considered and evaluated critically when trying to assess the expected treatment costs at other sites. Additionally, site-specific costs for mobilization/demobilization, technology performance monitoring, and environmental safety and health monitoring should be considered and included to determine the overall implementation cost of this technology at a specific site.

## 7. REGULATORY/INSTITUTIONAL ISSUES

In July 1993, DOE, EPA, FDEP, and LMSC entered into an agreement with the ITRD Program to evaluate innovative technologies to remediate ground water contamination at the Pinellas STAR Center Northeast Site effectively and expeditiously.

Under Section II.D.1 of the Pinellas STAR Center's HSWA Permit, interim measures may be conducted at SWMUs after EPA approval. Section II.D.3 requires the permittee to notify the EPA's Regional Administrator as soon as possible of any planned changes, reductions, or additions to the interim measures. The proposed rotary steam stripping project would temporarily interrupt the operation of the existing interim measures (pump and treat with air stripping); therefore, the Pinellas STAR Center ER's Program provided notice to the EPA and FDEP of a planned change (the implementation of ITRD field activities) to the approved interim measures and proposed implementation schedule for concurrence in August 1996. Authorization for implementation of the activities was received in August 1996.

In addition to the HSWA permit issues, FDEP required notification and authorization for air emissions from the rotary steam stripping project. In July 1996, DOE/PAO requested authorization to conduct the rotary steam stripping project. The PAO received authorization in August 1996[9]. Two further amendments to the August authorization were received based on changes in equipment and the end date of the project[10]. The FDEP authorization specifically identified each component of the off-gas treatment system and required the use of that model or its equivalent during the project and a Professional Engineer's certification that the system will comply with FDEP's standards. Additional stipulations were as follows:

- The operating time of the air treatment system would not exceed 8 hrs/day and 90 operating days.
- The air treatment system would reduce VOC emissions by at least 90%.
- The maximum allowable air emissions from the air treatment system were as follows.

| Pollutant | lbs/hr | lbs/day | Total project (lbs) |
|---|---|---|---|
| Methylene chloride | 2.01 | 16.06 | 1447 |
| Other VOCs | 1.15 | 9.2 | 828 |

- Continuous monitoring of the inlet process stream would be performed with an FID organic vapor analyzer (HNU Model PI201 or equivalent), real-time analysis of the CATOX inlet, CATOX outlet, and scrubber outlet process stream by syringe sampling of the process stream and direct injection into an on-site FID/GC.
- Daily summary logs would be completed.
- If system operations or equipment indicated that the project was not operating according to the above requirements, the project would cease operation until the problems were corrected.

Local fire authorities required a permit for use of the propane tank that fueled the CATOX unit. Minimum distances to vegetation and ignition sources were conditional to issuance of the permit. Any future users of the steam stripping technology that involves fuel tanks should check with their local authorities for any necessary permitting.

Upon start-up of the rotary steam stripping operations, compliance with the FDEP air emissions authorization became a very significant part of the project. Initially, the field GC was not operational and necessitated the use of the LMSC Analytical Laboratory. This led to an approximate 1-day delay in receiving analytical results. When the CATOX efficiency was found to be below the FDEP's limits, DOE/PAO limited operations to treating one hole at a time and not proceeding to the next hole until analytical results confirmed that emissions were within the FDEP's limits. Confirmation of continual operations within FDEP's limits allowed the one-hole-at-a-time restriction to eventually be eliminated; however, duplicate sampling and analyses continued throughout the remainder of the project to ensure compliance.

## 8. SCHEDULE

Figure 14 shows the associated tasks and schedule for the demonstration and evaluation of the rotary steam stripping system at the Pinellas STAR Center.

| ID | Task Name | Start | Finish |
|---|---|---|---|
| 1 | **Procurement Process** | **4/19/96** | **8/20/96** |
| 11 | **Planning & documents** | **8/23/96** | **1/3/97** |
| 12 | **Mobilization** | **12/2/96** | **1/10/97** |
| 15 | **Repair CAT 245D** | **1/13/97** | **1/17/97** |
| 16 | **TEC** | **1/20/97** | **2/11/97** |
| 17 | Treatment Ops | 1/20/97 | 1/29/97 |
| 18 | Repair Catox | 1/30/97 | 1/31/97 |
| 19 | Fugutive emissions | 2/3/97 | 2/4/97 |
| 20 | Repair Scrubber | 2/5/97 | 2/6/97 |
| 21 | Treatment Ops | 2/7/97 | 2/10/97 |
| 22 | A/W gas analysis | 2/11/97 | 2/11/97 |
| 23 | **Treatment Operations** | **2/12/97** | **4/2/97** |
| 24 | Treatment Ops | 2/12/97 | 2/12/97 |
| 25 | GC discrepancy | 2/13/97 | 2/14/97 |
| 26 | Treatment Ops | 2/17/97 | 2/17/97 |
| 27 | Repair augers | 2/18/97 | 2/24/97 |
| 28 | Treatment Ops | 2/25/97 | 3/6/97 |
| 29 | Repair drive table | 3/7/97 | 3/18/97 |
| 30 | Treatment Ops | 3/19/97 | 3/26/97 |
| 31 | Repair boiler/augers | 3/27/97 | 3/28/97 |
| 32 | Treatment Ops | 3/31/97 | 4/2/97 |
| 33 | **Demob. & Cleanup** | **4/3/97** | **4/11/97** |
| 36 | **Project Completion** | **4/14/97** | **4/30/97** |
| 37 | Project summary report | 4/14/97 | 4/30/97 |
| 38 | Final Invoice | 4/30/97 | 4/30/97 |

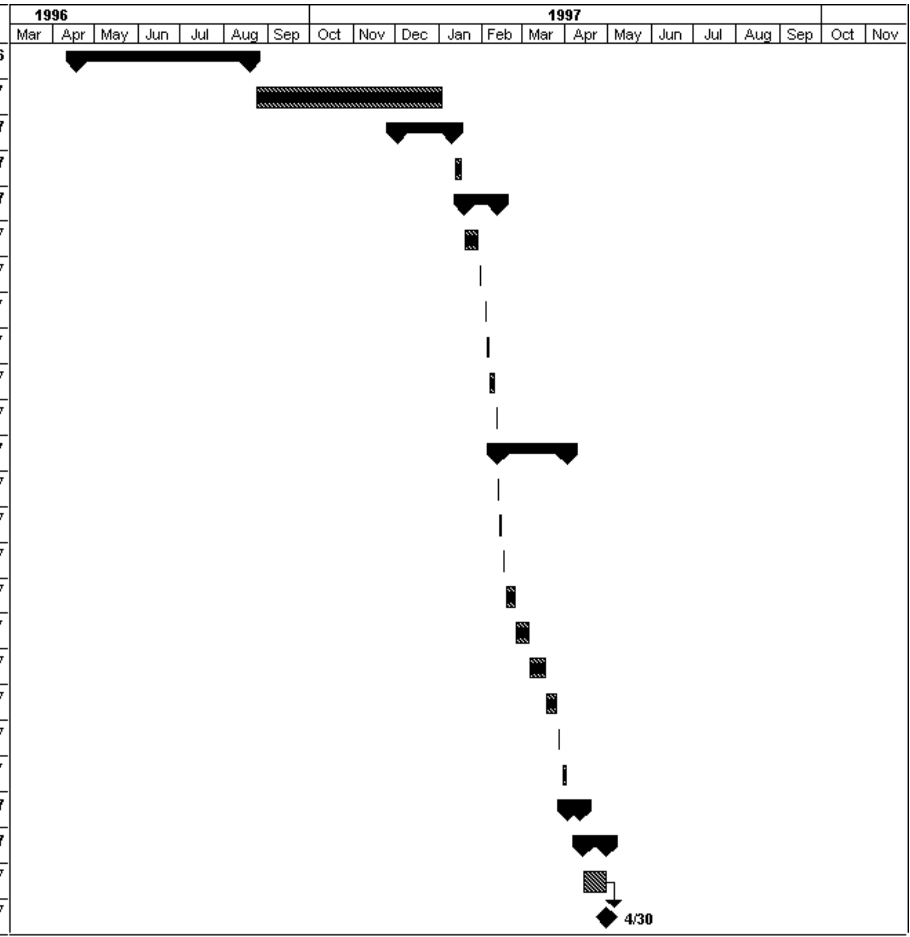


**Figure 14. Project schedule.**

## 9. OBSERVATIONS AND LESSONS LEARNED

### *Cost Observations and Lessons Learned*

The rotary steam stripping system deployed at the Pinellas STAR Center's Northeast Site consisted of a dual-auger rotary drill tower for contaminant removal, a CATOX system for VOC vapor treatment, and an acid-gas scrubber for off-gas treatment. Although each subsystem consists of standard equipment, operating the entire system efficiently and reliably is demanding. Mechanical and operational problems are a given for this type of heavy equipment operation, and provisions should be made in the contracting to minimize costs during system downtime. VOC vapor and off-gas treatment can be significant portions of the overall treatment costs for this type of system. Accurate design and operation of these subsystems is crucial for the cost effective application of this technology at a site.

Other project cost observations include:

- The major cost items (74% of the entire project cost) were equipment and operating costs.
- The inability of the off-gas treatment system to process all of the contaminant vapors removed by the dual-auger system was a shortfall in the design process that severely affected the subsurface VOC removal rate and the cost per cubic yard of soil and ground water treated and the overall cost-effectiveness of the system.

### *Performance Observations and Lessons Learned*

The ISF dual auger system deployed at the Pinellas STAR Center demonstrated the following performance characteristics.

- The ISF dual augers demonstrated the ability to remove large amounts of contaminants from the soil and ground water in a treatment column.
- For the columns that were sampled before and after treatment, the rotary steam stripping system removed an average of 77% of the VOCs in the ground water and soil, and reduced the maximum contaminant concentrations by an average of 71% (Table 7).
- The system did not consistently remove VOCs from the site's soil and ground water to a level of 200 ppm or less, especially in the areas of high initial concentrations.
- The only effects of the rotary steam stripping system on the surrounding environment was the escape of air outside the bore hole, which seemed to be limited to a radius approximately 6 ft from the shroud.
- The injection of only air appears to have produced a removal rate similar to that when air and steam are used; however, the ability of air by itself to quickly reduce contaminant levels of VOCs to very low final concentration is questionable, and the injection of only air appears to leave more contaminants deposited at shallower depths than when air and steam are injected.
- The higher the flow rate of air and/or steam, the better the removal of contaminants.

The project provided the following lessons learned on performance:

- Preproject discussions with regulatory agency personnel are essential. A cooperative relationship with the regulators, including full disclosure of all issues and problems that arise during a project, will minimize delays in obtaining authorizations and can facilitate the use of alternative emissions control methods and associated equipment.
- Any necessary permits, such as air emissions, should have long enough periods of performance to allow for potential delays in system mobilization and operation..

- The location, availability, and transport of all necessary equipment should be thoroughly evaluated for any impact on the project schedule.
- Evaluators of rotary steam stripping technologies should research the average downtime that a vendor experienced during past projects as a result of equipment failures and repairs.
- The impact of fugitive emissions on a project should be evaluated and planned for in case emissions are detected.
- Off-gas treatment systems should be evaluated for proper capabilities based on contaminant mass and combustion characteristics. The ability to increase treatment capability quickly, if needed, should be evaluated.
- Soil and ground water sampling after rotary steam stripping is performed can be delayed up to 2 to 3 weeks after treatment because of the inability of sampling vehicles to traverse the soft, loosened soil of each borehole.
- All site geology/hydrology characteristics may be changed following rotary steam stripping treatment, possibly affecting the ability to collect post-treatment samples (i.e., hydraulic conductivity, relatively firm soil, etc.).
- Patent issues, though not a factor in this application, should be thoroughly researched and evaluated and considered part of the bid review process for this technology.
- Utility supplies vital to project operations should have back-up supplies in the event of loss of that utility.
- Fuel storage regulations should be researched with local authorities; permits may need to be secured.

## ***Summary***

Based on the results of this demonstration, the ISF dual auger rotary steam stripping system is an innovative technology capable of providing in situ treatment of VOC-contaminated soil and ground water. During the demonstration of this technology at the Pinellas STAR Center, the ISF system was very effective in liberating large quantities of VOCs from the site soil and ground water. During the operating period, 48 treatment holes were drilled to a depth of approximately 32 feet, resulting in the treatment of over 2,000 $yd^3$ of soil and ground water and the removal of approximately 1,200 pounds of VOCs.

Initially, many operational problems were encountered with the system, especially with the off-gas treatment component because of high contaminant loading. As the project progressed, these problems were reduced through operational adjustments. The off-gas treatment capacity of the catalytic oxidation unit, initial operational problems, and mechanical breakdowns slowed the expected treatment rates for the system at the site. This prevented the system from meeting some of the performance objectives and treatment volumes initially expected in this remediation.

## 10. REFERENCES


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14. *HTRW Remedial Action Work Breakdown Structure*, Hazardous, Toxic, Radioactive Waste Interagency Cost Engineering Group, February 1996. (downloadable at http://globe.lmi.org/lmi_hcas/wbs.htm)

## 11. VALIDATION

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

10-22-97

David S. Ingle, Pinellas Area Office
U.S. Department of Energy

Mike Hightower, Technical Coordinator
Innovative Treatment Remediation Demonstration Program
Sandia National Laboratories

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
100 ALABAMA STREET, S.W.
ATLANTA, GEORGIA 30303-3104

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OCT 1 6 1997

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

The United States Department of Energy
Pinellas Plant
Attn: Mr. David Ingle
P.O. Box 2900
Largo, FL 34649

SUBJ: Cost and Performance Reports for the:
1) Dual Auger Rotary Steam Stripping Technology, and
2) Pervap Membrane Separation Technology
Demonstrations at the Northeast Site
DOE Pinellas Plant, FL
EPA I.D. Number FL6 890 090 008

Dear Mr. Ingle:

The Environmental Protection Agency (EPA), Region 4, has completed our review of the above referenced documents. Both of these reports appear to accurately convey information gathered by the Innovative Treatment Remediation Demonstration (ITRD) Team for the two different technologies that were demonstrated on the small scale at the Northeast site.

The activities associated with the Northeast Site under the direction of the ITRD have been very important to the Agency because the successful demonstration of the various technologies would ultimately lead to a remedy selection for this solid waste management unit. Additionally, the information gained from these activities is valuable in determining the cost/benefit of using these innovative technologies at other sites. EPA remains committed to working with the Department of Energy (DOE) at the former Pinellas Plant to document the success of these technology demonstrations, for a final remedy selection at this site, and eventually facility restoration.

If you have any questions regarding the ITRD at the Northeast Site then please contact me at (404) 562-8550.

Sincerely,

Carl R. Froede Jr.

Carl R. Froede Jr., P.G.
DOE Remedial Section
Federal Facilities Branch
Waste Management Division

cc: Eric Nuzie, FDEP
Jim Crane, FDEP

# Department of Environmental Protection

Lawton Chiles
Governor

Twin Towers Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Virginia B. Wetherell
Secretary

February 5, 1998

Mr. David Ingle
United States Department of Energy
7887 Brian Dairy Road
Suite 260
Largo, Florida 33777

Dear Mr. Ingle:

I have reviewed the *Cost and Performance Report, Dual Auger Rotary Steam Stripping, Pinellas Northeast Site, Largo, Florida*, dated December 1997, and find it acceptable. If you should have any questions please feel free to contact me.

If I can be of any further assistance please feel free to contact me at (850) 921 9983.

Sincerely,

John R. Armstrong P.G.
Remedial Project Manager

2/5/1998
Date

CC: Cheryl Walker-Smith, USEPA Atlanta
Satish Kastury, FDEP

JJC ESN for ESN

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