United States
Environmental Protection
Agency

Office of
Research and Development
Cincinnati, OH 45268

EPA/540/R-94/510a
August 1995

EPA

SITE Technology Capsule

In Situ Steam Enhanced Recovery Process

Abstract

The SERP technology is designed to treat soils contaminated with VOCs and SVOCs *in situ*. Steam injection and vacuum extraction are used to remove the organic compounds from the soil and concentrate them for disposal or recycling.

A full-scale demonstration of SERP was conducted at the Rainbow Disposal site in Huntington Beach, CA. The technology removed some of the diesel fuel hydrocarbons from the site soil, but did not meet the site cleanup objective of 1,000 mg/kg (ppm) total petroleum hydrocarbons (TPH). Operational problems during treatment may have impacted the treatment effectiveness. A detailed economic analysis of the application of this technology was performed.

The SERP technology was evaluated based on seven criteria used for decision-making in the Superfund Feasibility Study process. Results of the evaluation are summarized in Table 1.

Introduction

This Technology Capsule provides information on the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program Demonstration of the Steam Enhanced Recovery Process (SERP). This technology is designed to remove volatile and semivolatile organic compounds (VOCs and SVOCs) from soils *in situ* and was evaluated during a full-scale remediation of diesel-contaminated soils in Huntington Beach, CA. The SERP treatment occurred between August 1991 and August 1993, with post-treatment soil sampling completed under the SITE Program in September 1993. Information in this capsule describes specific site characteristics and results of the SITE Demonstration. This capsule contains the following information:

- Abstract
- Technology Description
- Technology Applicability and Site Requirements
- Technology Limitations
- Performance Data
- Process Residuals
- Economics
- Technology Status
- SITE Program
- Source for Further Information.

Technology Description

SERP is an *in situ* technology that uses steam injection and vacuum extraction to remove VOCs and SVOCs from soil. Treatment is performed using injection wells and extraction wells that are constructed in the soil.

The steam is introduced into the soil through injection wells and is drawn through the soil towards the extraction wells. A vacuum pump is used to draw a vacuum on the extraction wells, while liquid lift pumps in each well are used to remove the accumulated liquid. The steam heats the soil matrix, causing the more volatile compounds to vaporize. The pressure gradient moves the steam, pore water, and contaminants (in liquid and vapor form) toward the extraction wells.

The application of steam to the contaminated soil provides several potential mechanisms for removal of contaminants.The heat increases the vapor pressure of the less volatile compounds and decreases their viscosity, thus making them easier to desorb from soil particles [1]. The condensation of steam on soil particles provides energy to release adsorbed contaminant molecules. The addition of water in the form of steam dilutes the existing contaminated pore water, causing a

Printed on Recycled Paper

SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

Table 1. Comparison of SERP with Seven of the Feasibility Study Criteria

CRITERIA Overall Protection of Human Health and the Environment	Compliance with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-Term Effectiveness	Implementability	Cost
SERP reduced soil concentrations without excavation. Technology may reduce the mobility of contamination into groundwater after treatment, due to reduced concentrations and free product. Process did not appear to cause lateral or downward migration of contaminants.	Process did not meet soil cleanup criterion, on the average, in this application. Less soil is excavated, thus less soil requires disposal, which avoids land ban restrictions. Permits for drilling, operating, and air and water discharges are required.	A portion of contaminants is permanently removed from the soil. Removed contaminants can be incinerated or recycled. Lower levels of residual contamination present reduced risk.	Treated soil had lower concentrations overall; some areas were cleaned to well below the cleanup criterion. Remaining contaminants may be less mobile since less tightly adhered contaminants were removed. Lower soil concentrations are amenable to natural or enhanced biodegradation. Volume of technology residuals is small compared to the treated soil volume.	Soil is treated below ground so potential air emissions are minimized. Other activities can continue at surface of treatment area with minor disruption. Drilling and treatment may cause noise and dust emissions, which can be mitigated.	Technology uses widely available construction and process equipment. Most regulatory permits are readily acquired for fuel-related cleanups. Treatment of sites with other chemicals may pose additional problems. Operational problems that may delay the remediation can occur. The technology may not be able to meet stringent cleanup requirements, necessitating post-processing such as assisted biodegradation.	Total cost ranged from $29 to $43/yd3 for a large site, depending on the on-line factor. Capital equipment, start-up, and utilities costs are high. Remediation time is the major factor in the costs. Because the process operates in situ, off-site disposal costs are minimized.

soil flushing action that carries dissolved contamination to the extraction wells. [1]

At the Rainbow Disposal site, water used in the treatment process was extracted from an on-site water well. An average of more than 20,000 gal of water was used each day during the 24-hr cycle of operation. The water was softened, chemically conditioned, and preheated in a heat exchanger that simultaneously cooled the liquids removed from the extraction wells. This water was collected in a boiler feed tank and passed to the boiler. High quality steam was then injected into the soil through the injection wells. A schematic of the process is shown in Figure 1.

Thirty-five injection wells and 38 extraction wells were used at the Rainbow Disposal site. The wells were arranged in an overlapping pattern of alternating injection wells and extraction wells. Over the treatment area of approximately 2.3 acres, the spacing between wells was about 45 ft for wells of the opposite type and 60 ft for wells of the same type. The site layout is shown in Figure 2.

Contaminant vapor and contaminated water were removed from the extraction wells to the above-ground treatment system for further treatment. There, the liquid contaminants were gravimetrically removed from the water by an oil/water separator. The recovered diesel was stored in a large collection tank. The aqueous phase from the separator was passed through a series of 5-micron filters and carbon adsorbers to remove the residual organic contamination. The cleaned water was discharged to an underground storm sewer through a pipe. This treated water stream was sampled and tested every two weeks for TPH and for benzene, toluene, ethylbenzene, and xylenes (BTEX) to fulfill the requirements of a National Pollutant Discharge Elimination System (NPDES) permit.

The vapor phase removed from the extraction wells was passed through a knock-out drum to remove entrained liquids and solids. After steam breakthrough occurred in most of the extraction wells, a simple copper coil condenser was added to the system to lower the temperature of the vapor and increase the condensation of water and contaminant. Most of the removed diesel compounds remained in the vapor phase during treatment. The vapor stream was treated in a thermal oxidizer unit (TOU) that used electrical heating to destroy the organic compounds. The treated gas stream from the TOU was released through a stack to the atmosphere.

The growth of the steam zone in the soil was monitored through use of temperature wells equipped with thermocouples. By using thermocouples to detect the rise in temperature that precedes the steam front, the progress of the steam zone in the soil can be determined. Temperature wells inside the treatment area were used to ensure that the flow of steam and heat was under control. Temperature wells outside the treatment area were monitored to determine whether off-site migration of

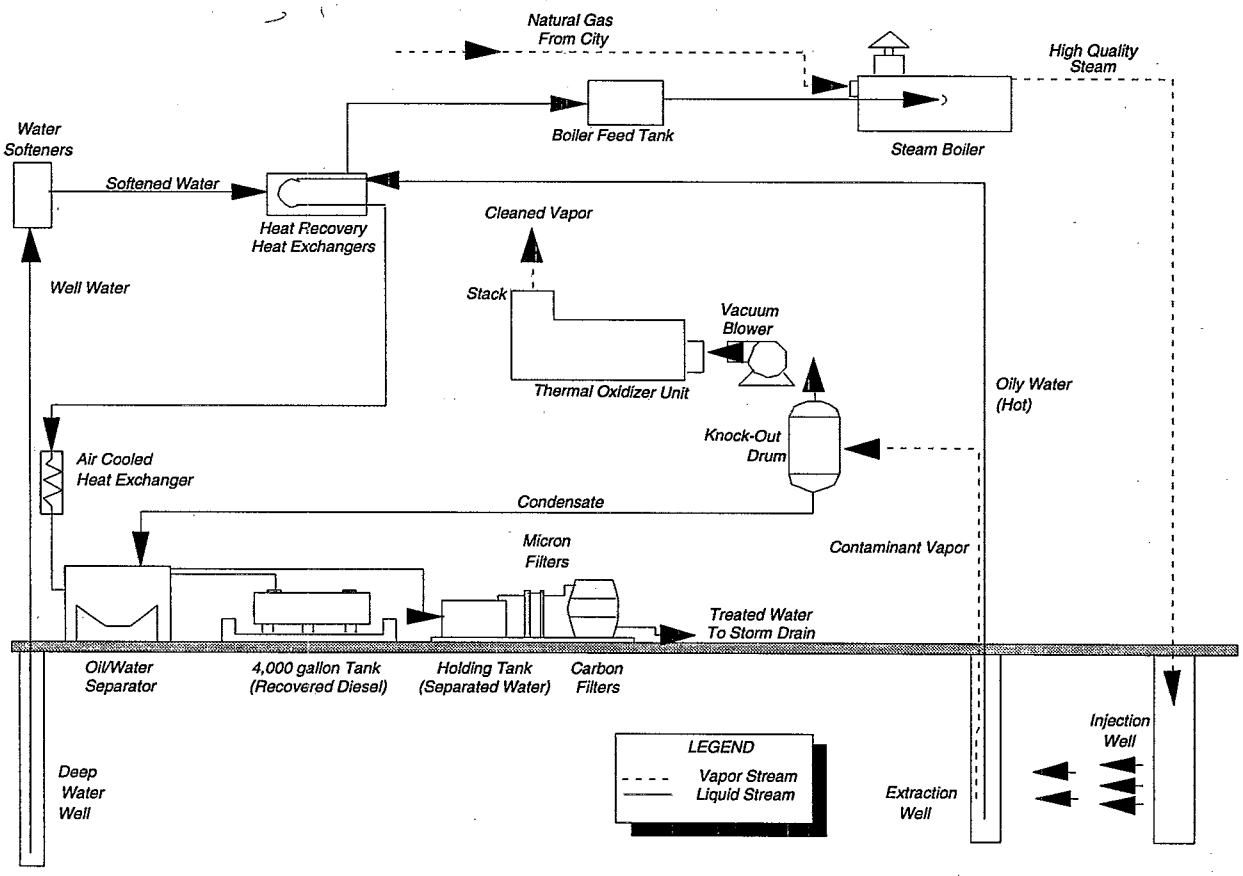

Figure 1. *Schematic of the SERP process.*

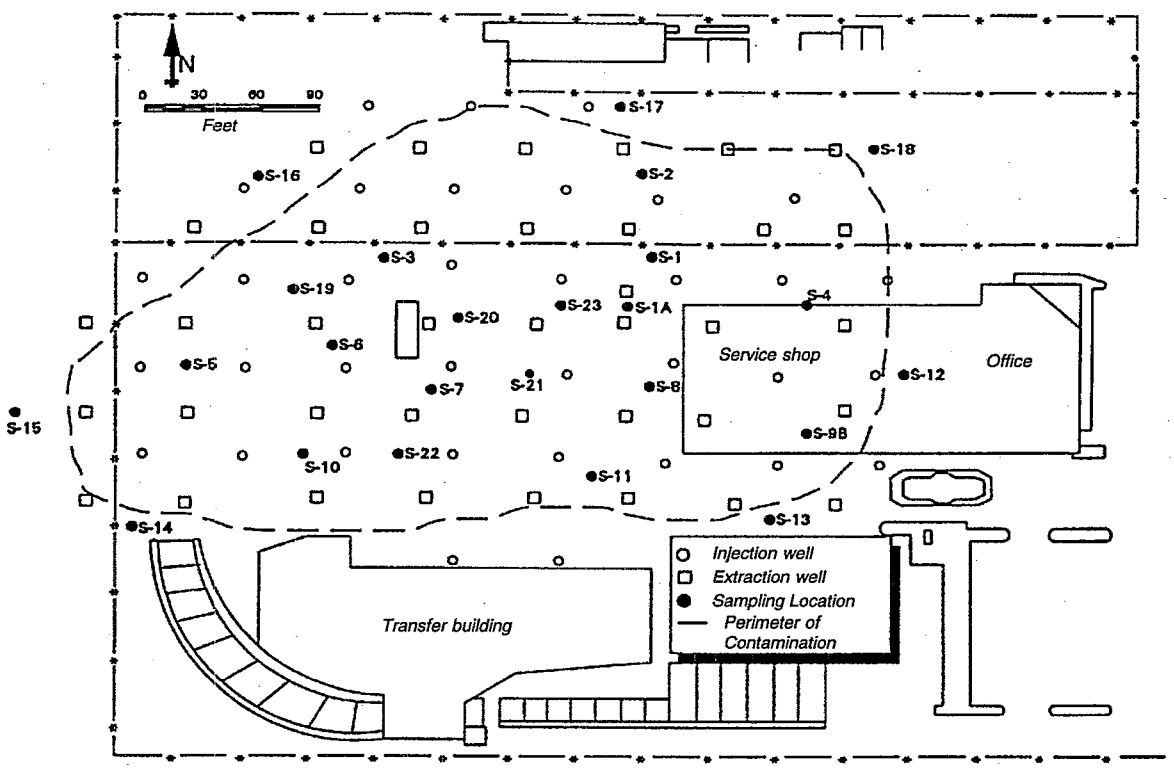

Figure 2. *The layout of SERP wells and soil sampling locations at the Rainbow Disposal site.*

the steam was occurring. If an increase in perimeter soil temperature had been detected, process conditions could have been changed to regain control of the steam zone.

The process configuration at any site must be determined by site-specific characteristics. The equipment used for SERP treatment consists of standard, available components.

Technology Applicability and Site Requirements

Because SERP operates on soils *in situ*, specific contaminant and site characteristics are required for the technology to be effective. The following are site requirements for the use of SERP:

- The contamination must consist of VOCs, SVOCs, or a combination of both.
- Maximum concentrations of 200 to 1,000 mg/kg are typical limits for compounds with a liquid phase that is heavier than water, based on the characteristics of the contaminant. If higher concentrations are present, there is a potential for downward migration when these compounds are concentrated by the process [2].
- The area of soil to be treated must have a confining layer below the treatment zone to prevent downward contaminant migration. This confining layer could be a water table, a zone with permeabilities two or more orders of magnitude less than the overlying treatment zone, bedrock, or an artificial boundary. It is possible that a much more permeable zone can act as a confining layer if a flow of steam can be maintained in this zone [2].
- If the treatment zone is close to the soil surface, a confining layer above the area of soil to be treated is required to prevent short-circuiting of the steam to the surface. If the site geology does not have such a layer, a temporary concrete or asphalt cap can be installed before treatment is started.

The SERP technology is most economical and technically effective on a large volume of moderately contaminated soil. Soils with low levels of contamination (e.g., less than twice the cleanup level) would require a high expenditure of time and energy for a small gain. Extremely high levels of compounds that form denser-than-water liquid phases might increase the potential for downward contaminant migration.Small volumes of soil might be better treated with an *ex situ* technology. For very large or stratified sites, separate applications of the technology could be made, either concurrently or sequentially to provide better process control.

SERP can effectively treat in both the vadose (unsaturated) zone and saturated soils. Greater amounts of energy would be required to heat saturated soil, and water recovery would be much higher. However, treatment effectiveness is expected to be as good as or better than that for unsaturated soils.

The technology is capable of treating soils to a significant depth, up to 100 ft or more. Use of SERP is especially practical and cost-effective for deep contamination because the wells permit deep access to the treatment area at low cost. Other site requirements for use of SERP include utilities (water, fuel, and electricity), accessible roads for personnel and equipment, and room to install wells and processing equipment.

The remediation at the Rainbow Disposal site utilized one of the more unusual aspects of the SERP technology—the claimed ability to treat soil under and around existing structures. This site is an active trash transfer facility consisting of a covered transfer bay, a truck service shop, and a truck wash facility. Activities at the transfer facility could not be halted during remediation. The technology was used to treat soil underneath the structures, as well as around some empty underground tanks, underground utilities, and other underground and aboveground obstructions.

Technology Limitations

The SERP technology is not applicable for treatment in nonpermeable or low permeability strata such as rock or thick clay layers. Fractured rock formations and geological structures with high permeability "tunnels" within them would cause preferential steam flow and would not allow most areas of soil to be appropriately treated by the technology.

The less volatile the contaminants, the more difficult they are to remove from the soil. This condition would lead to longer treatment times, less complete removal efficiencies, and higher costs overall for treatment.

Shallow contamination, or very narrow depth intervals of contamination, would not be appropriate to treat due to the difficulty of controlling the steam zone to a narrow range and the high costs per cubic yard based on the area of the site. Capital and mobilization costs for the technology are high enough that only large volumes of soil are economical for treatment.

Performance Data

The SITE Demonstration at the Rainbow Disposal site focused on the condition of the soil after treatment with SERP. The primary objective of the Demonstration was to determine whether the technology could meet the remediation goals for the site. The California Regional Water Quality Control Board had set a limit of 1,000 mg/kg of TPH [diesel fraction by the California Leaking Underground Fuel Tank (LUFT) method] in soil.

Pre-treatment soil data were collected by the technology developer and the site owner with oversight by EPA. However, this was not conducted under a SITE Program Quality Assurance Project Plan (QAPP) and, therefore, these data cannot be directly compared with the post-treatment data as a critical objective. These data have been used as an informational comparison of pre- and post-treatment soil conditions. During pre-treatment sampling, 12 boreholes were drilled and a total of 23 soil samples were collected from discrete depths in these boreholes. The pre-treatment samples were analyzed for TPH and BTEX. All samples collected before treatment were from inside the treatment area (perimeter of contamination). Post-treatment soil data were collected from both inside and outside the treatment area by EPA according to a site-specific QAPP.

To characterize the site soil after treatment, a total of 72 soil samples were collected from 24 boreholes. All of the samples were analyzed for TPH, Total Recoverable Petroleum Hydrocarbons (TRPH), and BTEX. (TRPH analysis provides information similar to TPH analysis, but is performed using an EPA-approved method. Although the TPH method is widely used, it is not an EPA-approved method.) Twelve of the borehole locations were selected to correspond with the pre-treatment boreholes (approximately four feet away), and samples were collected from the same depths in these boreholes as were collected before treatment to improve comparability between the pre- and post-treatment data sets. Six of the post-treatment boreholes were drilled and sampled outside the

treatment area in order to determine whether treatment caused any lateral migration to occur. The locations for pre- and post-treatment soil sampling are shown on Figure 2. Pre- and post-treatment sampling boreholes refer to the same numbered location.

Table 2 presents the post-treatment soil sampling results for TPH and TRPH. Based on analysis of the post-treatment TPH and TRPH data, removal of contamination by the SERP technology was less complete than expected. Forty-five percent of the post-treatment soil sample results inside the treatment area were above the cleanup criterion of 1,000 mg/kg TPH. Seven percent of samples had TPH levels in excess of 10,000 mg/kg.

BTEX was not detected in any of the post-treatment samples. The analytical detection limit was 6 µg/kg (ppb). This may be an indication that the SERP technology was effective in removing these compounds because BTEX compounds were found at low mg/kg levels in a few pre-treatment soil samples. However, this finding is not conclusive. There were no cleanup criteria established for BTEX compounds in soil.

As a part of the post-treatment demonstration sampling, triplicate samples of soil were collected at pre-determined sampling locations to evaluate *in situ* soil contaminant variability. Three samples of soil were collected vertically from the same 18-in. split-spoon sampler in separate 3-in. brass sleeves and were analyzed separately at the laboratory. Results of the analysis of triplicate samples were highly variable, showing that the site contamination was heterogeneous, even over small vertical distances (approximately 3 in.). Table 3 presents the triplicate sample results and associated statistics.

A geostatistical analysis of the post-treatment soil data was conducted using a "nearest neighbor" approach on a computerized model to assess the spatial variability of soil contamination and to determine a weighted average of the soil results. The use of this geostatistical approach results in the calculation of a more "unbiased" estimate of the true average level of contamination for a site, based on a subset of data for all soil parcels within a site and where there is no pattern of spatial correlation (i.e., high spatial variability) for soil contamination, as was the case at the Rainbow Disposal site [3]. Based on the geostatistical analysis, the post-treatment weighted average soil TPH concentration is 2,290 mg/kg, with a standard error of 784 mg/kg. Based on an approximate normal distribution for the weighted average, the 90 percent confidence interval for TPH concentration is 996 mg/kg to 3,570 mg/kg. This large interval is because of the heterogeneity of the *in situ* soil contamination as seen by the variability of site soil sampling results; analytical variability was within established quality control limits and contributed little to overall data variability. According to this analysis, at 90 percent confidence, the true average may be below the cleanup criterion of 1,000 mg/kg, but this represents a small probability. Therefore, with almost 90 percent confidence, the average concentration of the site soil after treatment with SERP is above the cleanup criterion.

The geostatistical analysis results for TRPH yielded a weighted average concentration of 1,680 mg/kg, with a standard error of 608 mg/kg. The 90 percent confidence interval for the weighted average for TRPH is 676 to 2,680 mg/kg. The calculated weighted average and confidence interval for TRPH are lower in magnitude than for TPH. No TRPH cleanup criteria were set for the Rainbow Disposal site.

The treatment area was based on a perimeter of contamination that had been determined using the available site characterization data at the time the SERP system was installed. The perimeter encompassed all soil on the site with TPH levels higher than 1,000 mg/kg. After treatment, two samples in each of six boreholes were collected outside of this perimeter in areas known to be clean or to have levels of contamination less than 200 mg/kg of TPH, based on site characterization data, to assess whether the treatment was causing any lateral migration of the contamination. These samples were analyzed for TPH, TRPH, and BTEX. Only one of the 12 samples collected had TPH levels higher than 200 mg/kg, the limit set to determine whether lateral migration had occurred. Since this one sample was less than twice the limit and the variability found in samples from the site was so great, this result is not felt to indicate that any significant lateral migration had occurred. Additionally, of the remaining perimeter samples, only two contained greater than 10 mg/kg TPH, and many contained levels less than 5 mg/kg, which would have been undetectable at the detection limit achieved in the original site survey. TRPH results were similar to TPH results.

A secondary (non-critical) objective of the demonstration was to determine a removal efficiency (or percent removal) by comparing pre- and post-treatment sample analysis data. Percent removal was calculated for TPH only, since no pre-treatment TRPH data exist and only three of the pre-treatment samples contained detectable amounts of BTEX.

Due to the high spatial variability of the *in situ* soil contamination at this site, the pre- and post-treatment data sets were pooled to compare the two. To accomplish this, weighted average concentrations of TPH in the soil before and after treatment were compared. A weighted average TPH concentration in the soil before treatment was calculated using geostatistical modeling (nearest neighbor approach), as was done for the post-treatment data. The weighted average pre-treatment concentration was calculated to be 3,790 mg/kg with a standard error of 2,340 mg/kg. Since the distribution of the pre-treatment weighted average did not conform to a normal distribution, the confidence interval on this average was calculated using a computerized "resampling" technique. This technique is often used to more accurately estimate confidence intervals for statistics with non-standard and non-normal distributions [4]. At 90 percent confidence, the calculated interval on this weighted average is 1,390 to 7,290 mg/kg. This large range is due to the small number of pre-treatment samples collected and to the variability in the data set.

Comparing the pre-treatment soil TPH weighted average to the post-treatment soil TPH weighted average, the overall removal efficiency was calculated to be about 40 percent. Using the resampling technique to calculate the confidence interval, at 90 percent confidence, the percent removal could be significantly higher or lower. This large removal efficiency confidence interval is due primarily to the lack of sufficient pre-treatment sample measurements, and the resultant data set variability. According to process data, however, it is known that some diesel contamination was removed from the soil during treatment.

The amount of diesel recovered in the storage tank during treatment was measured and totalled approximately 700 gal at the end of the project. This is much less than the amount anticipated when the system was designed and installed, because a larger percentage of the recovered diesel remained in the vapor phase and was oxidized in the TOU. This was also due to inadequate vapor stream condenser design. More diesel was removed through the vapor treatment system and oxidized in the TOU than was collected in the storage tank. Vapor concentration measurements taken at the inlet of the

Table 2. *Summary of Post-Treatment Analytical Results for Samples Inside the Treatment Area*

Boring	Depth	TPH (mg/kg)	TRPH (mg/kg)	Boring	Depth	TPH (mg/kg)	TRPH (mg/kg)
1	16.5	21	60	9B	25	2.6	43
1	26.5	31,000	12,000	9B	32	3.4	<20
1	30	5,600	1,400	9B	37	8.5	<20
1	35	3,500	1,100	10	30	69*	<20*
1A	15	4.3	<20	10	37	1,400	760
1A	25	340	110	10	40	3,300	590
1A	30	6,100	5,600	11	30	1,900	350
1A	35	2,300	4,600	11	35	810	140
2	32	670*	190*	19	28	41	210
2	35	960	380	19	32	350	690
3	32	390	190	19	38	230	230
3	38	4.2	<20	20	30	190	1,600
4	30	6,800*	2,000*	20	34	22,000	1,700
4	38	1,800	600	20	41	2.8	310
5	30	11	<20	21	30	11,000	25,000
5	35	5,200	110	21	35	9,100	9,700
5	38	7,900	860	21	40	1,000	950
6	32	1,100	540	22	31	14	150
6	40	1,700*	1,400*	22	37	18	96
7	25	8.3	<20	22	42	630	290
7	35	9,300	13,000	23	20	5.5	<20
8	31	3,400	2,000	23	30	6,100*	6,100*
8	43	15	160	23	38	440	770

* Average of Triplicate Results

Table 3. *Post-Treatment Triplicate Sample Analytical Results*

Borehole Number	Depth (ft) and Designation	TPH Results (mg/kg)	TRPH Results (mg/kg)	Standard Deviation of TPH Results (mg/kg)	Standard Deviation of TRPH Results (mg/kg)
2	32 primary	670	80	230	100
	duplicate	120	160		
	triplicate	310	320		
4	30 primary	12,000	1,400	5,000	2,400
	duplicate	240	260		
	triplicate	7,700	5,800		
6	40 primary	590	1,100	1,400	770
	duplicate	3,700	2,500		
	triplicate	860	640		
10	30 primary	82	<20	47	>50*
	duplicate	5.6	<20		
	triplicate	120	130		
13	32 primary	3.3	<20	4.6	>29*
	duplicate	14	81		
	triplicate	5.9	20		
16	35 primary	5.3	<20	2.1	>30*
	duplicate	9.2	85		
	triplicate	4.5	<20		
23	30 primary	5,100	5,800	1,300	190
	duplicate	5,300	6,200		
	triplicate	8,000	6,200		

< Not detected at the detection limit shown.
* Calculated using non-detect results at the detection limit; actual standard deviations may be slightly higher.

TOU over the course of treatment by the flame ionization detector (and the LEL meter before the FID was on line), along with the flow rate and inlet temperature, were used to estimate the amount of diesel which was removed in vapor form. Based on these data, it was calculated that approximately 15,400 gal of diesel were treated by the TOU. Therefore, a combined total of approximately 16,000 gal of diesel were removed during treatment with SERP. This volume, compared with the initial estimate of the amount of fuel released (70,000 to 135,000 gal [5,6]), less 4,000 gal recovered prior to treatment with SERP, suggests that between 12 and 24 percent of the original spill volume was removed from the soil and treated above-ground by the SERP technology. This removal efficiency is based on diesel recovered and treated, and although lower than the removal efficiency based on the soil data, is within the percent removal confidence interval for the soil data. It should be noted that vapor stream system measurements were not critical measurements for this demonstration.

Operational problems were encountered during treatment with the SERP technology. Most of the major problems were due to malfunctions of major above-ground process equipment, especially the boilers and the TOU. These malfunctions were partly the result of process system design deficiencies and intermittent operation.

Due to the innovative and experimental nature of the treatment process, adjustments were made frequently. Since the system had been designed for a single year of operation, and operation occurred over a two-year period, some of the process equipment had to be replaced including all the downhole piping for the extraction wells.

It should be noted that this was one of the first full-scale applications of this technology. Operational problems were, therefore, partly caused by the learning process common to any new technology, and probably greater than typically expected.

Process Residuals

One of the major advantages to an *in situ* technology is the reduction in the amount of waste that needs to be disposed of after treatment. Material that is not removed from the site is not subject to any land disposal restrictions and can be left in place at the end of treatment. Residuals from the SERP treatment process include soil removed from boreholes during well construction or sampling (drill cuttings); recovered contaminant product; contaminated water; contaminated vapor; sludge from the oil/water separator; contaminated process equipment, including filters and carbon; and disposable equipment and clothing that has become contaminated through contact with the waste material.

At the Rainbow Disposal site, the contaminated water was treated using activated carbon and discharged to an underground sewer. The contaminant-laden vapor from the extraction wells was treated (oxidized) in the TOU. Therefore, neither of these process streams required off-site treatment or disposal.

Soil removed from boreholes on the site was placed into 55-gal drums. Samples from each drum were analyzed for petroleum hydrocarbons. Drums containing contaminated soil were disposed of off-site at a hazardous waste landfill, while soil from the drums containing nondetectable levels of petroleum hydrocarbons was placed back on the site as fill. Approximately 230 drums of drill cuttings, *approximately 40 percent of which were* contaminated, were generated during the mobilization, treatment, and post-treatment sampling.

Sludge was collected from the bottom of the oil/water separator. This sludge was composed of heavier-than-water components of the wastewater and residue from the extraction wells. This material was drummed for off-site disposal as hazardous waste. Only a few drums of this material were generated and disposed of, mostly in the later stages of treatment. During treatment, filters and spent activated carbon were periodically removed from the system and sent off-site for regeneration and/or disposal as hazardous waste. At the end of the project, the recovered diesel was removed from the site for recycling.

Economics

A detailed cost analysis was performed for the SERP remediation at the Rainbow Disposal site. The total cost for remediation at the site was approximately $4,400,000. This value does not include legal fees, which were significant in this case. The total amount of soil that was considered to have undergone treatment was 95,000 yd^3, which includes the volume of soil within the treatment perimeter between the depths of 20 and 40 ft. This yields a cost per cubic yard of approximately $43.

Since this was the first commercial application of SERP, and because of the frequency and nature of equipment problems experienced, the cost calculated above is higher than expected for other applications. Based on operating logs, a 50 percent on-line factor was calculated for this process at the Rainbow Disposal site.

Two additional cost estimates were prepared based on ideal conditions (i.e., no downtime or a 100 percent on-line factor) and on conditions expected to be typical of a treatment process of this type (using an on-line factor of 75 percent). Total costs for the ideal and typical cases were estimated to be $2,800,000 and $3,400,000 for costs of $29/yd^3 and $36/yd^3, respectively.

The most significant cost factor in all three cases was the labor to operate and maintain the process equipment, especially the boilers. Labor was approximately 30 percent of the total costs estimated in this economic analysis. Other significant costs were mobilization, which include designing and installing the process equipment, and utility costs. Natural gas usage was the greatest utility cost, and comprised more than 10 percent of the total costs.

Costs for use of SERP are highly site-specific, since the equipment and operating techniques are tailored to the individual characteristics of the site. Factors that would tend to increase treatment time, such as less volatile contamination, larger site area, or less permeable soils, would have the most significant effect on the costs for use of the technology.

Technology Status

Technologies similar in concept to *in situ* SERP have been investigated on a field-scale level at other contaminated sites. Most notably, a portion of a site contaminated by gasoline to a depth of about 135 ft was recently remediated with Dynamic (Steam) Stripping at the Lawrence Livermore National Laboratory in Livermore, CA. The technology was successful in removing and recovering a significant portion of the gasoline

contamination from more permeable unsaturated and saturated soil in the test area. Innovative techniques were applied to monitor the steam zone and control the process.

At this time, other tests of steam injection technologies are planned at sites contaminated with dense non-aqueous phase liquids such as trichloroethene. The ability of the technology to remediate sites contaminated with these less volatile compounds, without causing downward or off-site migration, will be key evaluation objectives for these tests.

The SERP technology can be designed, within engineering constraints, to treat a large area of a site to significant depths. Based on results from the full-scale application of SERP technology at the Rainbow Disposal site, the critical factor in scale-up from pilot- or field-scale to full-scale site remediation seems to be maintaining control of the *in situ* process. The poor results at this site appear to be partly due to inadequate monitoring capability over the large treatment area (2.3 acres), resulting in poor process control.

Hughes Environmental Systems operated the SERP technology at the Rainbow Disposal site; however, they are not vending the technology for use at other sites. Since SERP uses commonly available process equipment, the technology can be designed and operated by consultants knowledgeable of the process. Developers of similar *in situ* steam technologies may have a patented process or monitoring equipment available only through them.

SITE Program

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), also known as Superfund, committed to protecting human health and the environment from uncontrolled hazardous waste sites. CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986 to include amendments that emphasize the achievement of long-term effectiveness and permanence of remedies at Superfund sites. SARA mandates implementing permanent solutions and using alternate treatment technologies or resource recovery technologies, to the maximum extent possible, to clean up hazardous waste sites.

State and federal agencies, as well as private parties, are now exploring a growing number of innovative technologies for treating hazardous wastes. The sites on the National Priorities List total over 1,700 and comprise a broad spectrum of physical, chemical, and environmental conditions requiring varying types of remediation. The EPA has focused on policy, technical, and informational issues related to exploring and applying new remediation technologies applicable to Superfund sites. One such initiative is EPA's SITE Program, which was established to accelerate the development, demonstration, and use of innovative technologies for site cleanups. EPA SITE Technology Capsules summarize the latest information available on selected innovative treatment and site remediation technologies and related issues. These capsules are designed to help EPA remedial project managers, EPA on-scene coordinators, contractors, and other site cleanup managers understand the types of data and site characteristics needed to effectively evaluate a technology's applicability for cleaning up Superfund sites.

Disclaimer

While the technology conclusions presented in this report may not change, the data have not been reviewed by EPA's Quality Assurance/Quality Control office.

Source for Further Information

EPA Contact:

U.S. EPA Project Manager
Paul de Percin
U.S. Environmental Protection Agency
National Risk Management Research Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
Telephone No: (513) 569-7797
Fax No: (513) 567-7620
E-Mail: dePercin.Paul @ EPAMAIL.EPA.GOV

References

1. Udell, K.S., and L.D. Stewart. Combined Steam Injection and Vacuum Extraction for Aquifer Cleanup. Keynote Paper for Conference of the International Association of Hydrogeologists, Calgary, AB, Canada, 1990.
2. Udell Technologies, Inc. Field Design for In Situ Recovery of Hazardous Wastes by Combined Steam Injection and Vacuum Extraction. Prepared for Naval Civil Engineering Laboratory. Jan. 1991.
3. Isaaks, E.H., & Srivastava, R.M. *An Introduction to Applied Geostatistics.* New York: Oxford University Press, 1989.
4. Efron, B., & Tibshirani, R. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. *Statistical Science*, Volume 1, 1986, pp. 54–76.
5. Converse Environmental Consultants California. Site Characterization, Conducted for Rainbow Disposal, 17121 Nichols Street, Huntington Beach, CA. Costa Mesa, CA, Aug. 11, 1988
6. Telephone communication with John Dablow, formerly of Hydrofluent, Inc. Jan. 26, 1994.

United States
Environmental Protection Agency
National Risk Management
Research Laboratory (G-72)
Cincinnati, OH 45268

Official Business
Penalty for Private Use
$300

EPA/540/R-94/510a

Please make all necessary changes on the below label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35