CHAPTER 7

Cost and Performance Results

7.1. Introduction. Pilot-studies and full-scale deployments are increasing our understanding of the underlying scientific principles and the practical field engineering aspects of ISTR technologies.

7.1.1. This chapter provides an overview of case study information. Appendix B provides the case study information, which includes the types of sites and site conditions (stratigraphy, permeability, vadose/saturated conditions, depth, etc.) where the technologies are being employed; cleanup goals and the performance of the technologies in meeting those goals; and cost information and trends where available.

7.1.2. Sites identified and described in this chapter and the appendix are intended to illustrate the types and range of deployments rather than give a comprehensive inventory of all applications. EPA maintains an on-line database of in situ thermal technology deployments. Projects are organized by technology. The database is at http://www.cluin.org/thermal.

7.1.3. Upon completion of an ISTR project, a cost and performance remedial action report should be completed. This includes final actual costs shown to the third level of the HTRW Remedial Action Work Breakdown Structure. Refer to USACE EP 1110-1-19 on remedial action reports. "Guide to Preparing Remedial Action Reports of Cost and Performance," is available at.http://140.194.76.129/publications/eng-pamphlets/ep1110-1-19/toc.htm

7.2. General Observations. While the experience base is growing,* there is not an extensive database of projects, thus limiting general insights. It is worthwhile to note that in virtually all applications of ISTR documented herein, much more contamination was recovered than was originally thought to be present. At the Visalia wood treater, a SEE project recovered over $1{\times}10^6$ pounds of contamination where a pump and treat system had been operating for over 20 years recovering as little as 10 pounds/week. Based on groundwater concentration data for the SEE application in Skokie, IL, the site was initially estimated to have in the order of 1000 kg of trichloroethene and 1,1,1-trichloroethane, based on groundwater concentration data. At the completion of the project, an estimated 29 metric tons of solvent had been removed or degraded through biodegradation or hydrolysis using both SEE and ERH. At the most recent application of SEE at a fractured rock site, a pilot-scale demonstration project at Edwards AFB recovered 910 to 1360 kg (2000 to 3000 pounds) of solvents in an area thought to have on the order of 45 kg (100 pounds) of contamination. Thus, as has been noted elsewhere, in anticipation of significant recoveries, it is important that contaminant recovery systems be adequately sized.

*EPA TIO's data base of in situ thermal project currently lists over 60 entries

7.2.1. Full-scale deployments have occurred in a variety of settings. Many of these applications involve successful subsurface heating and contaminant recovery, despite the presence of underground appurtenances such as sewer lines, phone lines, and optic fiber lines. While engineering adjustments must be made for these features, they are not an insurmountable challenge. TCH applications have been sit up in proximity to residences. As discussed more fully in the ERH section, ERH has been implemented in active commercial settings and within and beneath an operating manufacturing plant.

7.2.2. Standards of practice are emerging about appropriate materials for various contaminant and concentration scenarios. Materials of construction are an important consideration, particularly where corrosive wastes are involved. ERH applications have experienced failures of CPVC piping in monitoring wells. ISTD TCH has experienced severe corrosion of piping while treating highly concentrated pesticide wastes. Similarly, it has become common practice for vendors to identify, locate, and shut in wells whose materials or methods of construction are not compatible with the expected temperature regimes. It is also common practice to identify, locate, and cut-off horizontal conduits that could serve as a lateral preferential pathway for migration of contaminants or steam.

7.2.3. ISTR unit costs are subject to economies of scale and other factors. Subject to adjustments for factors such as contaminant volatility, treatment requirements, etc., as discussed below, unit costs (e.g., $/cubic meter) decrease significantly as quantities to be treated increase. Pilot-scale studies may appear to be disproportionately expensive as many of the mobilization/demobilization and personnel costs are independent of project size. It is also the case that, from a total cost standpoint, “ideal“ applications are those involving smaller volumes of media, with large quantities of waste.

7.2.4. Unit costs for treatment also depend on the depth of the application, the need to treat various waste streams generated during ISTR, the treatment time and temperatures required for adequate removal to achieve goals, the availability of fuel or power, the risk allocation between client and vendor, the level of required monitoring, and the need for engineering controls of ground water flow, utility protection, etc. As the volume of vapor or liquid streams requiring treatment increases, treatment costs may significantly increase, depending on the type of treatment. Sites where vapors may be directly discharged to the atmosphere (rarely the case for ISTR sites) or where condensate or extracted water will not be generated in significant quantities will have lower unit costs for ISTR than those sites where elaborate treatment systems for vapors and liquids must be constructed for the project. Because operating costs, including labor and power or fuel, are related to operating time, the longer heating is required to achieve the objective, the more expensive the job. At sites where contaminants are not easily removed by thermal treatment or where clean-up objectives are stringent, costs may be substantially higher than for sites with easily removed contaminants and less stringent remedial goals.
.

7.2.5. Other factors may have a significant impact at some sites. If fuel or power is not readily available at the site, such as at the Wyckoff Superfund site, the costs for providing the energy source may significantly increase costs for the project. The more risk the vendor is allocated by contract mechanism at a site, generally the higher the bid cost, though there may be benefits to a risk-averse client for such arrangements. Costs increase somewhat as the amount of required monitoring increases, both for process control (e.g., stack sampling) or environmental purposes (e.g., assessment of contaminant migration toward nearby water bodies or structures). Lastly, the project costs are occasionally influenced by the need to overcome issues such as protection of utilities, prevention of thermal impacts to water bodies, need for ground water control through measures such as sheet piling or pumping. In all, the costs for ISTR application range widely and the estimated cost for a given application must consider the project-specific conditions and goals.

7.2.6. ISTR technologies have achieved a variety of cleanup goals, ranging from very stringent residential and MCL-type standards, to state and site-specific industrial/non-residential standards. In a fair number of cases, the cleanup levels achieved significantly exceeded the required performance. In at least one case, the Charleston Navy Yard where ERH was implemented as an Interim Remedial Measure (IRM), significant quantities of contamination were recovered but the specific percentage reduction goals were not achieved.

7.2.7. There is considerable interest in combining ISTR as an aggressive source removal/reduction technology with other more cost-effective polishing approaches to achieve ultimate remediation objectives at the lowest total cost.

7.3. Technology-Specific Applications**.**

7.3.1. *Thermal Conductive Heating*.

7.3.1.1. *Waste Types*. Many of the initial deployments of thermal conduction addressed PCBs in soil. Conductive heating has been selected to address manufactured gas plant coal tars, pesticide residues (hexachloropentadiene), chlorinated solvents, and wood treatment creosote contamination. It is not necessary to operate conductive heating at maximum temperatures. Thus, the technology is potentially suitable to the full-spectrum of VOC and SVOC contaminants as well as the non-volatile contaminants for which it was originally designed. Other soil contaminants, including metals such as mercury and arsenic have not been tested at present, but are theoretically volatile enough to be remediated by thermal conductive heating.

7.3.1.2. *Site Conditions/Characteristics Affecting Performance and Cost*. Conductive heating in more permeable soils below the water table often requires control of water infiltration across the site. At the Entergy/Lake Charles MGP site, conductive heating was selected to address coal tar and PCB contamination; however, difficulties in dewatering resulted in terminating treatment.

7.3.1.2.1. At the Rocky Mountain Arsenal (RMA) facility near Denver, Colorado, implementation of ISTD was discontinued following severe corrosion of pipes and equipment. As heat was applied to the hexachloropentadiene pit, extremely low pH waste streams were generated, quickly damaging the vendor's equipment. This problem was not revealed by the lab scale treatability studies that preceded the deployment. The application was stopped after it was determined that it would not have been cost-effective to retrofit the entire treatment system with the necessary hastalloy to withstand the corrosive conditions.

7.3.1.3. *Cleanup Goals*. Table 7-1 compares the initial maximum concentrations and the final cleanup concentrations for sites where ISTD has been applied. The PCB projects reduced contamination below 0.033 mg/kg.

Table 7-1. Summary of Completed Thermal ISTD TCH Projects.

Site	Contaminant	Initial Maximum Concentration (mg/kg)	Final Concentration (mg/kg)	Duration	Cost
S. Glen Falls, NY	PCB 1248/1254	5,000	<0.8	Not available	Not available
Cape Giradreau, MO	PCB 1260	20,000	<0.033	3/87-6/97	$2M
Vallejo, Ca	PCB 1254/1260	2,200	<0.033	9/97-12/97	$912K
Portland, IN	PCE	3,500	<0.5	7/97-12-97	Not Available
	TCE	79	<0.02		
Saipan, NMI	PCB 1254	10,000	<1	1 year	$5.34M
Eugene, OR	Benzene Gasoline/Diesel	3.3 3.500/9,300 (+LNAPL)	<0.044 250,000 lbs LNAPL removed	6/97-9-98	$3M
Ferndale, CA	PCB 1254	800	<0.17	9/98=4/99	$456K

7.3.1.4. *Cost*. Turn-key costs for remediation of 8,400 cubic meters (11,000 cubic yards) of material at a solvent site in Ohio, being cleaned up under the Ohio Voluntary Cleanup Program, was reported as $1.3M, yielding a unit cost of $154/cubic meter. The project included a performance guarantee. These numbers are within the range of general costs provided by the vendor. Higher (by 2X or more) unit costs for treatment of recalcitrant compounds such as PCBs have been reported due to the higher temperatures and longer treatment times required.

7.3.2. *Electrical Resistivity Heating*.

7.3.2.1. *Waste Types*. ERH has been used most widely to address VOCs - TCE, PCE, methylene chloride, etc. As presented in Appendix B, it has also been used to address a diesel range organic waste at a facility in Atlanta, GA. Contaminants are generally recovered as vapor, but at least one application (Waukegan, IL) appeared to have experienced a significant amount of in situ destruction.

7.3.2.2. *Site Characteristics/Conditions Affecting Performance and Cost*. ERH is particularly suitable for lower permeability zones. It has been used in fine-grained lacustrine sand at Skokie, IL, glacial clay tills in Waukegan, Lisle, and Elk Grove Village, IL. ERH has been used to recover contaminants from sand, silt, clay, and gravel strata, and various combinations thereof.

7.3.2.2.1. ERH has been used as deep as 30 m (100 feet) at Paducah, KY. In at least one application, Fort Wainwright, AK, ERH has been used for the primary purpose of creating conditions favorable to in situ biodegradation.

7.3.2.2.2. An important feature of ERH is that the technology can be installed and operated entirely below grade, if necessary. The first example of such an application was for a confidential client at a dry cleaner in western Washington State. An ERH system was installed beneath the building and adjacent roadways and parking lots so as not to interfere with vehicular or pedestrian traffic. A subsequent deployment in Portland, OR, involved subgrade installation of piping and wellheads for a portion of the contamination that extended beneath an adjacent roadway. Most recently, a full-scale ERH application was completed at Air Force Plant 4 in Texas. The system was installed in a building where active F-16 jet fighter airplane manufacturing activities were underway.

7.3.2.3. *Cleanup Goals*. ERH is reported to have achieved MCL's for a dry cleaner site in western Washington State. At the Skokie, IL, ERH project, initial cleanup goals were established as site-specific Illinois Tier 3 (industrial) criteria. ERH performance was sufficiently promising that heating was continued after achievement of the Tier 3 standards to ensure that, after treatment was discontinued, the expected subsequent intrinsic biodegradation did not result in the production of vinyl chloride in excess of the Tier 3 criteria. When the project was terminated, 4 of the 13 monitoring wells established for post-treatment monitoring had achieved the more stringent Tier 1, Illinois Class II Groundwater Standards. Subsequent monitoring indicated a continuing downward trend in contaminant concentrations, such that, 18 months after completion of ERH treatment, 11 out of 13 wells had achieved the Class II Groundwater Standards (Smith et al. 2000). At that time, Illinois EPA approved discontinuing monitoring and removal of the monitoring wells so that the property could be re-developed.

7.3.2.4. *Cost*. Table 7-2 provides vendor-supplied information indicating the range of costs for various contaminants and quantities.

Table 7-2. Summary of Selected ERH Projects.

Site	Contaminants	Quantity, cubic meters (cubic yards)	Cost
Skokie, IL	TCE, TCA	27k (35k)	$32*
Portland, OR	TCE	16.4k (21.5k)	$42
Waukegan, IL	Methylene Chloride	12k (16k)	$61
Chicago area, IL	PCE	9k (12k)	$80
Ft. Lewis, WA	TCE, Hydrocarbon	61k (80k)	>$200 including water treatment

*NOTE: Off-gas treatment not required. Vendor estimates additional $9/cubic yard if off-gas treatment had been required.

7.3.3. *Steam Enhanced Extraction*.

7.3.3.1. *Waste Types*. Steam Injection has been used to recover a variety of compounds, such as wood treatment wastes (creosote, pentachlorophenol) Visalia, CA; chlorinated solvents (TCE, PCE) - Alameda, CA, Skokie, IL and Northlake, IL and Young-Rainey Star Center, Largo, FL; jet fuel - Lemore, CA; mineral spirits - Northlake, IL; and gasoline range petroleum hydrocarbons - Lawrence Livermore National Laboratory Gas Pad. At the Yorktown Naval

Facility, steam within horizontal stainless steel wells is being used to reduce the viscosity of Navy Special Fuel Oil to facilitate recovery in a system of trenches. Further work is under way to use steam to recover diluent from Unocal's Guadalupe field in California. SEE has been selected for use at the Port of Ridgefield wood treater, and a pilot study is underway at the Wyckoff NPL wood treater site on Bainbridge Island, WA.

7.3.3.2. *Site Attributes/Conditions Affecting Cost and Performance*. As discussed in previous paragraphs, steam injection is most appropriately applied in situations of adequate permeability to conduct the steam. Low permeability zones may be amenable to steam injection remediation through conductive heat transfer if they are of limited thickness and steam can be delivered above and below the low permeability zones. At the Visalia site, significant contamination was recovered from a 9-meter-thick aquitard at a depth of 30 meters by installing injection wells through the aquitard and injecting steam from below the confining layer.

7.3.3.2.1. Steam injection has been used in a variety of hydrogeological settings. It is generally not necessary to dewater the site prior to steam injection. At the Visalia, Skokie and Northlake sites, most of the contamination addressed was in the saturated zone. Groundwater flow/recharge rate at the Visalia site was on the order of 0.3 to 0.9 m/day (1 to 3 ft/day), while at the Skokie and Northlake sites there was minimal natural movement.

7.3.3.2.2. For porous media sites, stratigraphy and the thickness of individual layers is important for the steam injection approach. For sites with multiple aquifer zones separated by aquitards, multiple injection and extraction intervals may be necessary (Livermore Gas Pad, Savannah River Site, SC; Visalia Pole Yard, CA). Sites with a low anisotropy ratio (ratio of horizontal to vertical permeability) such as Alameda Point, CA, which consisted of fill material and bay muds, and The Guadalupe Sand Dunes, consisting of wind-deposited sands, must be carefully designed to prevent excessive steam override. This can involve multiple injection intervals, shallow vapor extraction systems to capture steam, quenching designs to inject cold water where steam is undesired, and potentially using air injection to block steam migration into certain areas.

7.3.3.2.3. SEE has been used on a site as large as 12,100 square meters (3 acres) (Skokie and Northlake, IL). It has been used as deep as 41 meters (135 feet) at Visalia and as shallow as 3 meters (10 feet) at Alameda where heating occurred beneath a concrete pad in front of a former hangar.

7.3.3.2.4. At a number of sites, SEE was selected owing to the availability of previously existing on-site steam generation capacity.

7.3.3.2.5. SEE has been deployed at fractured bedrock sites at Edwards AFB and former Loring AFB under the auspices of EPA's Superfund Innovative Technology Evaluation (SITE) program. These rock sites were treated to 18 and 27 meters (60 and 90 feet), respectively. Two additional pilot scale demonstrations are underway in 2003–2004.

7.3.3.2.6. Case study summaries for these projects are provided in Appendix B.

7.3.3.3. *Cleanup Goals*. Provided below is a listing of the cleanup goals that have been put in place for a variety of SEE applications:

a. Demonstrate that heating can be achieved, and that mass removal can be accelerated compared to previously deployed methods (Savannah River Site, Edwards AFB Site 61, Loring Quarry, Beale AFB).

b. Achieve pre-determined numeric standards for soil and groundwater concentrations (Alameda Point, Young-Rainey Star Center).

c. Remove mobile NAPL and restore groundwater quality at compliance points (Visalia Pole Yard, Wyckoff-Eagle Harbor, Port of Ridgefield).

d. Eliminate source zone input of COCs to down-gradient dissolved plume (Alameda Point).

e. Meet MDCA standards for soils or MCL for groundwater (Wyckoff-Eagle Harbor).

f. Implement the best available steam technology, operate it until diminishing returns are achieved, and follow-up by sampling and negotiations with regulators for site closure with or without alternative contaminant levels.

7.3.3.4. *Cost Information*. At the Visalia Pole Yard NPL site, Southern California Edison spent approximately \$21.5M to remediate the 8,100 square meter (2-acre) parcel. Cost per pound or gallon of contaminant information is also available. SCE had been conducting pump and treat operations at the facility since 1976, recovering approximately 4.5 kg (10 pounds) per week at a cost of \$1M/year. Cost per pound for pump and treat was on the order of \$4,400/kg (2,000/pound). In approximately 3 years of steam heating, SCE recovered or destroyed more than 590,000 kg (1.3M pounds) of creosote and pentachlorophenol wastes. The cost for SEE was less than \$44/kg (\$20/pound) and less than \$130/m^3. Unit costs at other sites ranged from \$20/m^3 at another full-scale project to >\$500/m^3 at another pilot project. Refer to Table B-1 in Appendix B for additional information on costs for steam-enhanced extraction.