

## VI.11

### **Innovative soil and groundwater remediation: the SITE program experience**

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#### **VI.11.1. Site program introduction: history and goals**

Superfund was initially focused on existing pollution problems, seeking to abate immediate threats or releases of hazardous substances, and most importantly, to clean up past releases. In 1980 when the Superfund law was signed, there were few choices available for cleaning up sites. Removing contaminants to secure chemical landfills and incineration were the accepted alternatives.

Each of those alternatives had problems of their own: landfills leak, and incinerators produce air emissions and ash that need to be controlled and handled. These problems led to public rejection of the cleanup alternatives, and general suspicion of the effectiveness of Superfund, as well as continuing liability for the waste generators.

The Superfund Amendments and Reauthorization Act (SARA) of 1986 attempted to address these problems. Destruction of contaminants was to be preferred over containment. More remediation options were to be identified, tested and developed. The Superfund Innovative Technology Evaluation (SITE) program was established to accomplish the latter task of adding more tools to the remediation "toolbox".

Historically, one of the greatest factors inhibiting the development and use of innovative cleanup technologies has been the lack of credible cost and performance data during technology development at the commercial scale. By addressing this need, SITE has aided in the first time field use of many technologies, contributing to wider acceptance of a particular technology.

The SITE program begins by soliciting those responsible for hazardous waste cleanup to apply to the program. When hazardous waste site owners approach the SITE program during the solicitation period, they may already have a particular technology vendor or technology in mind for their particular waste problem, or they may decide to solicit a variety of technologies. The SITE program and waste site owner will evaluate the technologies together and choose the one with the best potential to solve the problem. This type of solicitation allows the SITE program to better assess and deal with the actual problems of the user community. Also, with this approach, multiple demonstrations per site are possible.

With the SITE program acting as a third-party evaluator, the potential for biased data collection and reporting is negligible. Furthermore, National Risk Management Research

Laboratory NRMRL's Quality Assurance Office also reviews planning documents and performs audits of sample collection and analysis procedures to verify that the data collected are appropriate to their intended purpose. Thus, the SITE program is founded on the program's objectivity as a third-party evaluator and on the credibility and quality of the data.

### VI.11.2. How site encourages innovative technologies

Technology vendors are a central part of the SITE program, because they provide remediation services for sites requiring cleanup. Vendors experience various benefits by participating in the SITE program, namely, increased exposure, market share, technical acceptance and recognition.

How does SITE help developers of innovative environmental remediation technologies? First, by understanding how ideas develop into usable technology. The classic view is that there are six steps from inventor's brainstorm to market:

1. idea;
2. proof of concept on the bench scale;
3. pilot scale;
4. prototype on the field scale;
5. field demonstration;
6. sales.

SITE provides assistance in this process during steps 4 and 5: prototype on the field scale and field demonstration.

If a technology is ready for field demonstration, the SITE program can help in several ways. Field demonstrations take place on Superfund sites or other contaminated ground. Permission to use actual contaminated sites is the first benefit of the program. Access to the site in the form of roads and test pads is the second benefit of the program. SITE provides credibility to the demonstration by taking samples and providing independent analysis of pre- and post-treatment contamination. The extensive quality control/quality assurance that all demonstration plans must pass also adds to the credibility of the results. The results of demonstrations are reported widely, and are included in the evaluation of the economic data. The combination of credible technical and economic data can help the developer over step 6, toward market acceptance and sales.

A demonstration can begin in a few months once a site and vendor have been selected. Field tests can be as short as a few days or weeks for some *ex situ* thermal and chemical treatments, or as long as a few years for *in situ* thermal, chemical or biological treatment. The tasks of a demonstration are divided between EPA and the technology developer (Table VI.11.1), with the developer setting up, running and dismantling the equipment, and EPA leading the planning, sampling, monitoring, analysis and reporting of results.

EPA spends an average of US \$400,000–600,000 to facilitate, support, take samples, provide analysis and report the results of a field demonstration. Each developer spends an average of about US \$250,000 to set up, run and break down the demonstration equipment and process.

*Table VI.11.1. Demonstration activities.*

Activities	Responsible organization
<i>Predemonstration</i>	
Site selection	SITE program
Waste characterization	SITE program
Treatability testing	SITE program and technology vendor
Demonstration plan preparation	SITE program
Site preparation	Site owner
Equipment mobilization	Technology vendor
<i>Demonstration</i>	
Equipment operation	Technology vendor
Process monitoring and measurement	SITE program and technology vendor
Sample collection and photo documentation	SITE program
Quality assurance field audits	SITE program
Visitor's day and community relations	Site owner, EPA regions, state agencies
<i>Post-demonstration</i>	
Equipment demobilization	Technology vendor
Site restoration	Site owner
Laboratory analysis	SITE program
Quality assurance laboratory audit	SITE program
Technology and cost evaluation	SITE program
Technology transfer-bulletins, reports, videotape and conferences	SITE program

**VI.11.3. How well does the site program work?**

The success of the SITE program can be measured by the number of demonstrations, projects and related reports produced. The SITE program is working cooperatively with a total of 152 technologies. By September 2003, 136 technologies were field evaluated. Approximately 6–8 field demonstrations are completed each year. An additional 5–6 new projects are accepted into the program annually.

Demonstration evaluation documents and other information are distributed through electronic sources, CD ROM and hard copy annually. For each demonstration, a two-page bulletin is produced to give a quick explanation of the technology. A larger Innovative Technical Evaluation Report, along with a Capsule report, provide data for those who are interested in study details. Document requesters include consultants, industry, universities, media, state and local governments and other US agencies such as the Department of Defense (DOD) and the Department of Energy (DOE). Developers and EPA staff are encouraged to publish results in journals, and to participate in forums and conferences to ensure the widest dissemination of information on successful innovative technologies.

Since 1993, the use of innovative technologies has outpaced that of established technologies, resulting in dramatic cost savings. The SITE program has shown that innovative technology usage has resulted in significant cost savings compared to conventional technologies. The SITE program conducts an annual analysis of technology costs from EPA regional offices. Cleanup of contaminated sites through the use of innovative technologies has resulted in a total inflated cost savings of over US \$2.1 billion adjusted for inflation with an average savings per site of 70%. Innovative technology use has increased in both public and private sector cleanups. While SITE is only one contributing factor in technology selection, the program played a significant role. Innovative technologies were considered in less than 20% of the cleanup decisions prior to 1986; now alternative treatments are considered in almost every Superfund decision (Gatchett and Edwards, 1998).

Figure VI.11.1 shows a breakdown of savings by technology type. Soil vapor extraction (SVE) showed the highest savings of over US \$1.0 billion, followed by US \$500 million for bioremediation. Since SVE was one of the initial technologies accepted into the SITE program (in the late 1980s), large savings would therefore be expected from this technology. Solvent extraction, thermal desorption and vitrification each account for over US \$100 million in savings. Phytoremediation is a newer technology that is beginning to be chosen in Superfund Records of Decisions, with four sites showing a total cost savings of US \$17 million when compared to conventional technologies. The number of sites and associated cost savings for phytoremediation and treatment barriers are expected to increase rapidly in coming years (Superfund Annual Report to Congress, 2000).

One goal of the SITE program is to evaluate and encourage technologies with marketable futures. Some technologies in the program have passed the innovative stage and are now accepted as standards. As mentioned above, SVE is now considered a standard option for removal of volatile organic compounds (VOCs) from the unsaturated zone. The first system was demonstrated in SITE by Terra Vac Inc. SVE uses readily available equipment, including extraction wells, a vapor liquid separator and a vacuum pump.

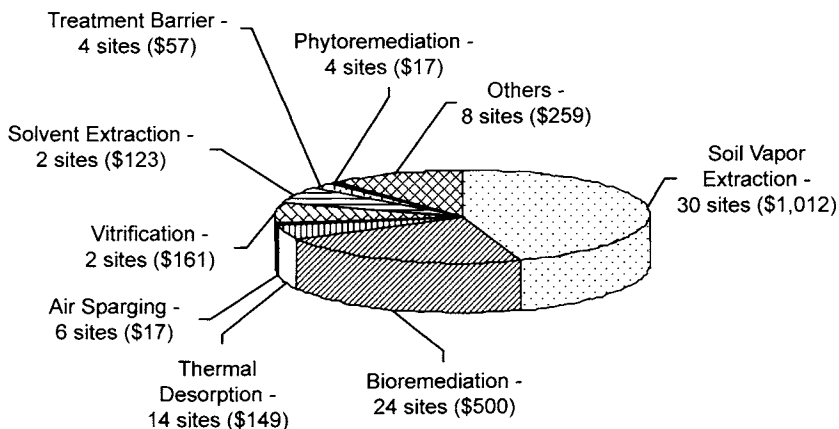


Figure VI.11.1. Cost savings for innovative technology use (Superfund annual report to Congress, Dec. 2000).

The vacuum pump draws the subsurface contaminants from the extraction wells to the liquid vapor separator. The vapor phase contaminants are then treated with an activated carbon adsorption filter or a catalytic oxidizer before the gases are discharged to the atmosphere. The technology is effective in most hydrogeological settings, and can reduce soil contamination levels from saturation to non-detection. The Terra Vac system was demonstrated in 1987–1988 at the Groveland Wells Superfund site in Groveland, MA, and at a Superfund site in Puerto Rico. Terra Vac has since applied the technology at 15 additional Superfund sites, and at more than 4000 other waste sites worldwide.

Many other companies have since developed and are marketing SVE technologies. Some companies with enhancements to the basic SVE system (such as hot air injection combined with groundwater extraction) have become SITE participants.

Private-sector developers continue to show strong interest in the SITE program and many of those who used the program have indicated favorable results. An example of a company that has benefited by its association with SITE is the Terra-Kleen Response Group.

Terra-Kleen is a solvent extraction process, aimed at removing PCBs from soil. The technology was demonstrated between May 16 and June 11, 1994 at the North Island Naval Air Station (NAS) in San Diego, CA. The demonstration showed that the solvent extraction was effective in successfully reducing PCB concentrations from 144 ppm to less than 2 ppm.

As a result of the information provided in the demonstration, the US Navy Environmental Leadership Program (NELP) at NAS has reconsidered cleanup for three sites contaminated with PCBs. NELP selected the Terra-Kleen system because "...it meets all the selection criteria, it is new and innovative, it can be completed in a relatively short time period, and it removes and isolates PCBs from the three sites." The decision also saves about \$3.5 million compared to solidification/stabilization, the previous choice.

Since the demonstration, Terra-Kleen has received many other inquiries from states and countries regarding use of their technology. The founder of Terra-Kleen stated in a July 1994 letter to President Clinton, "These individuals connected with the EPA's SITE program have been of untold assistance in allowing this technology to be demonstrated so that it can now be used in full scale at other sites. Currently, we are removing DDT from soil at the Naval Communication Station, Stockton, saving the Navy considerable cost over incineration destruction of the soil. Again, none of this would have been possible without the ever-present help and assistance of the EPA's SITE program."

Some types of technologies have been sufficiently accepted by the market, so that the SITE program is no longer interested in developing or demonstrating them further. For example, solidification/stabilization technologies for metals-contaminated soil are well proven in the laboratory, field and marketplace. SITE has conducted 12 demonstrations of solidification, stabilization, fixation or vitrification processes; many of these technologies have been selected for site cleanups.

#### **VI.11.4. Future directions**

The science of site investigation has advanced dramatically in the past 20 years. Advancements in field detection equipment and laboratory analyses have revealed new

information about the problems at waste sites. These advancements, coupled with the experience gained from the numerous sites under investigation, have generated a need for new, innovative technologies.

One of the critical needs for remediation technology is for methods to accelerate aquifer cleanup. By nature, groundwater is a slow-moving, slow-to-change medium. Groundwater contamination may consist of multi-phase contaminant plumes, light non-aqueous phase liquids (LNAPLs) and dense non-aqueous phase liquids (DNAPLs), which can potentially move in different directions. As the complexity of the geological formation increases so does the need for innovative technologies to treat or detect DNAPL. New technologies are needed to control and remediate this diverse problem.

The search for effective remediation technologies for metals in soils, treatment of recalcitrant compounds and the general need for *in situ* treatment remain SITE program priorities. Because of technical difficulties related to sediment remediation, this is another area where the remediation community would benefit from new processes, approaches or less-expensive methods for treatment. *In situ* treatment, sampling and containment are technology areas of interest that will be addressed in the future (Table VI.11.2).

More recently, there have been significant technology breakthroughs in chemical conversion methodologies. Technologies that rely on chemical conversion of the contaminant species (oxidative/reductive) rather than destruction or stabilization will convert contaminants to environmentally harmless compounds. Metal-enhanced dechlorination or treatment barriers fall into this category. The technology is a groundwater treatment technique that degrades chlorinated volatile organics (VOCs) using an electrochemical process that oxidizes iron while chlorinated VOCs are reduced. Two methods of *in situ* metal-enhanced dechlorination are used: a permeable treatment wall or a funnel and gate configuration. The permeable wall can be used above ground in a reactor (*ex situ*) setting. In the future, material other than iron will be assessed for effectiveness on VOCs and other groundwater contaminants.

The SITE program emphasizes the need for technologies capable of *in situ* remediation of DNAPLs in difficult geological formations. This continues to be a theme through the remediation community as a whole. The program continues to evaluate *in situ* thermal and chemical oxidation type technologies under a broad array of geological conditions. In addition, effective remediation technologies for metals in soils, treatment of recalcitrant compounds and the general need for *in situ* treatment remain high on the priority list (Fig. VI.11.2).

The SITE program also emphasizes the need for technologies that focus more on types of contaminated sites rather than single contaminants (i.e. wood preserving sites,

Table VI.11.2. Contaminant emphasis areas for 2000–2006.

Surface water/groundwater	Soils/sediments
DNAPL/chlorinated solvents	Pesticides
PCBs	PCBs
Arsenic, mercury or other heavy metals	PAHs
	Arsenic, mercury or other heavy metals

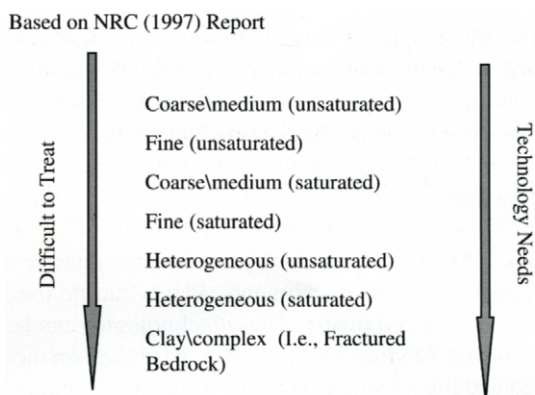


Figure VI.11.2. NRC chart. Future research areas: DNAPL roadmap (NRC, 1997).

manufactured gas plant sites). Most sites are not contaminated with a single contaminant, but with mixtures including by-products formed from normal degradation. Recent applications have led the SITE program to move in this direction. Based on the multi-agency review board, a list of new areas is:

- mining issues/acid mine drainage;
- manufactured gas plants;
- wood treating/preserving;
- pesticide manufacturers/formulators.

### VI.11.5. Technologies on the horizon

As a result of innovative remediation technology field demonstrations each year, the SITE program maintains a unique position in the hazardous waste remediation marketplace. Together with a stakeholder group including representation from a number of other federal and state environmental agencies, the SITE program ensures that the most pressing issues are prioritized and addressed.

A number of promising technologies based on sound scientific principles, but lacking engineering and performance documentation, are appearing on the horizon. Some of these, described below, are being researched and developed under the SITE program, and by the US DOE, US DOD and others. It is likely that field demonstrations may occur within the next few years for these technologies or for second-generation improvements of these techniques.

#### VI.11.5.1. Bioremediation

Various bioremediation technologies have entered the SITE program. In some instances, biodegradation is used with other technologies to accomplish a greater total removal efficiency of organic contaminants. Difficulties associated with biodegradation include: determining which microorganisms can break down specific organic compounds, culturing the microorganism in a favorable environment that provides nutrients and

promotes growth, and the length of time required to completely degrade an organic compound to acceptable levels. Enhancements under investigation include: hydrogen peroxide and other electron acceptors, co-metabolic processes and consortia, nitrate enhancement, and anaerobic or sequential aerobic/anaerobic degradation.

#### **VI.11.5.2. Phytotechnology**

Phytotechnology is a set of technologies using plants to remediate or contain contaminants in soil, groundwater, surface water or sediments. Plants can be used to remediate, treat, stabilize and control contaminated media. These technologies can be implemented either *in situ* or *ex situ*. The specific phytotechnology chosen is based on the type of contaminant, media that are affected and the remediation goals. Remediation goals include areas such as phytotechnology containment, stabilization, sequestration, assimilation, reduction, detoxification, degradation, metabolization and/or mineralization. To achieve these goals, the proper phytotechnology system must be designed, developed and implemented, using detailed knowledge of the site layout, soil characteristics, hydrology, climate conditions, analytical needs, operations and maintenance requirements. Other factors that need to be taken into consideration are the economics, public perception and regulatory environment.

Plants naturally remove man-made contaminants through several mechanisms. Some plants degrade organic pollutants directly or indirectly by supporting microbial communities. Other plants take up inorganic contaminants from soil or water and concentrate them in the plant tissue where the contaminant can be removed and disposed of separately, leaving the soil clean.

Phytoremediation can reduce concentrations of hydrocarbons from spills and leaking underground storage tanks; PCBs from transformers; PCP and creosote from wood preserving sites; and nitrates, pesticides and herbicides from agricultural runoff. Some plants can extract heavy metals such as lead, chromium and uranium. Phytoremediation is best suited for cleanups over a wide area, with contaminants in low to medium concentrations.

Wetlands constructed with reeds and cattails are used to prevent acid mine drainage from polluting streams; poplar and willow trees are planted as interceptor barriers to remediate groundwater contamination. Common crop plants like mustard are used for extraction, and alfalfa and ryegrass are used for *in situ* soil remediation. Planted areas can be used in conjunction with other technologies, for example, following a removal action of high-concentration hot spots.

Using plants to remediate, contain, stabilize or provide hydraulic control has the potential to be much less expensive than conventional cleanup options. The cleanup time can be longer than with some physical or chemical processes, but the installation and maintenance costs are typically very low. Public acceptance of the phytotechnology can be very high, in part because of the added benefits of park-like esthetics, including bird and wildlife habitat.

Well proven at the greenhouse and pilot scale, phytoremediation is too new to have widespread acceptance among site managers, owners and responsible parties. US EPA National Risk Management Research Laboratory tested and evaluated the technology's efficacy and cost in the field at sites in Oregon, Utah and Ohio. More demonstrations and

applications of the technology will verify and disseminate information on this technology (Interstate Technology and Regulatory Cooperation, 2001).

#### **VI.11.5.3. Electroremediation techniques**

Techniques such as electro-osmosis, electromigration, and electrophoresis through electrokinetics, and electrochemical oxidation are used *in situ* to treat contaminated soils, sediments and aqueous media. In electrokinetics, direct current flowing from positive to negative electrodes in combination with pore-conditioning fluids circulating in the soil provide *in situ* removal of contaminants. The contaminants are directly deposited on the electrodes or removed from the conditioning fluid through a purification process. Electrokinetics can effectively increase the flow of fluids and/or gases within formations where intrinsic permeability is very low. In electrochemical oxidation, electrodes are used to generate hydrogen peroxide from contaminated groundwater. The hydrogen peroxide catalytically decomposes on iron particles to form hydroxyl radicals, which then react with organic contaminants. This technology performs chemical conversion, thereby destroying the contaminants.

#### **VI.11.5.4. Advanced physical/chemical treatment**

Many new technologies are under development in the area of physical and/or chemical treatment of contaminated matrices. Many of these technologies remain unproven or are in developmental phases. Using these technologies can expand *in situ* cleanup opportunities to medium- and low-permeability soils, semivolatile organic compounds (SVOCs), VOCs, in addition to metals and areas where excavation costs are prohibitive or excavation is infeasible. These advanced physical/chemical treatment technologies include:

- *In situ chemical oxidation* involves the use of various oxidants and delivery techniques in various combinations to destroy heavy organic compounds. The method involves thoroughly permeating the contaminated zone with sufficient quantities of chemical oxidants so that the chemical can contact and fully react with contaminants. Oxidants used in the systems include hydrogen peroxide, ozone, potassium and sodium permanganate (Interstate Technology and Regulatory Cooperation, 2000).
- *In situ extraction techniques* are used to mobilize heavy organic-based contaminants such as DNAPLs. These techniques are designed to effect rapid mass transfer from the immobile contaminant phase into a mobile fluid phase, either a liquid or a gas. The subsurface may be heated by either resistive heating techniques or steam. Another technique is the subsurface injection of co-solvents or surfactants in order to lower the interfacial tension between the contaminant and soil while increasing contaminant solubility in water.
- *In situ delivery systems* such as directional drilling to place wells under surface structures or in horizontal positions for increased injection or sparging efficiency will be important in areas where buildings or structures cannot be removed.
- *New materials used in permeable reactive barrier (PRB) designs* may reduce costs, and enhance barrier longevity or contaminant treatment. PRBs are an *in situ* treatment technique where contaminated groundwater flows through a reactive zone.

The contaminants are either immobilized or chemically transformed to a more desirable state. The PRB serves as a barrier to the contaminants, but not to the groundwater flow. There are currently four types of barrier designs: (1) funnel and gate, (2) continuous wall, (3) injection well configuration and (4) passive collection with reactor cells.

- *Soil amendment techniques* are designed to reduce both bioavailability and leachability of inorganic contaminants by changing geochemical form. By the addition of amendments such as phosphates and sulfites, contaminants are bound by forming insoluble metal species. These insoluble species reduce the bioavailability of the compound if ingested. Delivery systems such as pressure injection are important in delivering amendments to the subsurface uniformly (Interstate Technology and Regulatory Cooperation, 1999).

#### **VI.11.5.5. Treatment trains and combination technologies**

A treatment train is a sequential combination of technologies or unit processes that treat recalcitrant waste matrices more effectively than any single technology could. Treatment trains of innovative technologies can be less costly and more effective in achieving treatment goals than conventional technologies. The “Lasagna” process is an example of several innovative technologies used in concert to treat contaminants *in situ* in less permeable soils including clays and silts. Electro-osmosis first drives contaminants out of soil pores and into treatment zones created by hydrofracturing, pneumatic fracturing or trenching. Contaminants are then treated in treatment zones by biodegradation, catalytic dechlorination or adsorption. Electrodes for the electro-osmosis system can be placed by sheet piling, hydrofracturing or horizontal drilling. Much of the development of this process has proceeded under a Cooperative Research and Development Agreement with Monsanto Company, DuPont, General Electric and EPA.

#### **VI.11.6. Conclusion**

The SITE program of the United States Environmental Protection Agency (EPA) has been bringing together the private sector, EPA, and other federal and state agencies to successfully address complex hazardous waste problems.

The SITE program is a key element in EPA’s efforts to increase the availability and use of innovative technologies for remediation of the nation’s hazardous waste sites. For more than 15 years, the SITE program has successfully promoted the development, commercialization and implementation of innovative treatment technologies. The program provides environmental decision-makers with relevant data on new, viable remediation technologies that may have performance or cost advantages compared to conventional treatment technologies. The SITE program technology evaluations are used by the remediation community to choose cleanup technology options, and that data are credible because of the rigorous quality assurance and careful planning of the demonstrations. To date, the program has completed 136 field demonstrations and is currently working with an additional 16 projects. Some technologies once considered innovative such as SVE, *ex situ* thermal desorption and *ex situ* solvent extraction have been accepted as standard in part because of this program. Superfund site managers, who in 1986 had the choice of incineration or

landfill, can now find many other tools in the “remediation toolbox”. SITE continues to look to the future for innovative solutions to solve the cleanup challenges of the past. General information, full reports and technology profiles on the SITE program are accessible through <http://www.epa.gov/ORD/SITE>.

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