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LUST Remediation Technologies: Part I

University of Illinois

TR23
May 1995
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HWRIC TR-023

LUST Remediation Technologies

Part I

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HWRIC Project Number 92-102

Printed by Authority of the State of Illinois

95/200

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ABSTRACT

Releases from leaking underground storage tanks (LUSTs) are potential sources of underground water supply contamination in the United States. The water supplies remain at risk of contamination as long as the contaminated soils remain in place. This volume presents an overview of ten currently or potentially available techniques for remediating contaminated soils at LUST sites. Each technique is described and compared to the other technique on issues such as relative cost, ease of implementation, and permitting. The emphasis is placed on the effectiveness of each technique depending on the particular circumstances of the site. Two companion volumes to the report, *Part II - Soil Corrective Action Descriptions*, and *Part III - Ground Water Corrective Action Descriptions*, present more detailed information on technologies for remediation of soil and ground water, respectively.

INTRODUCTION

Releases from leaking underground storage tanks (LUSTs) have been identified as a major potential source of contamination of underground water supplies in the United States. Contaminated soils around LUSTs are a continuing source of potential contamination of water supplies as long as the soils remain in place. This volume presents an overview of available techniques for remediating contaminated soils at LUST sites. Each of the following technology groups is briefly discussed:

- Removal, Transport and Landfill Disposal;
- Bioremediation;
- Soil Vapor Extraction;
- Thermal Treatment;
- Incineration;
- Soil Washing;
- In-Situ Soil Flushing;
- Solvent Extraction;
- Chemical Dechlorination; and
- In-Situ Vitrification.

The technologies are discussed in a brief question and answer format. This provides an overview of each technology and their relative pros and cons. Seven questions are addressed:

How does the cleanup technique work?

For which chemical groups is the method effective?

Does the method work on all soil types or just some?

How long does it take to clean sites using each technique relative to the other approaches?

How expensive is each technique relative to the other approaches?

Is approval to use the technique easy or difficult to obtain from the appropriate Agencies?

Does the approach require environmental, construction, or operating permits?

These questions all bear on the issue of effectiveness. Put simply, can a technology do the job quickly, cheaply (at least relative to other options), and with minimal technical or administrative difficulty. Unfortunately, the answers to these questions are seldom unequivocal. The contaminants that need to be treated, their distribution in the soil, the nature of the soils present, and the layout of topography, buildings, and utilities are all factors that influence the degree of effectiveness of any particular technology. Each technology has certain characteristics that may make it advantageous in particular circumstances. Each is capable, under the right circumstances, of achieving cleanup objectives. Determining which is most advantageous is dependent on the site-specific requirements of the job, and in part, on the economic and time requirements or constraints on the owner/operator of the site.

Two companion volumes to this report are available: *Part II - Soil Corrective Action Descriptions, and Part III - Ground Water Corrective Action Descriptions*. They present more detailed information on the selection, design, and costs of these alternative soil remediation technologies and technologies for cleanup of contaminated ground water, respectively.

LANDFILLING

How does this cleanup technique work?

This involves using backhoes or other excavation equipment, digging the soil, and hauling the soil to a special waste landfill for disposal.

For which chemical groups will this method be effective?

Generally, all of them. Soil contaminated with organics and lead can be handled with this method. This is the only method currently approved for use if lead is a problem in the soils. In rare cases, LUST soils may be classified as hazardous waste by IEPA and are banned from landfilling at special waste landfills. According to the EPA permit, soil contamination is determined by comparing the concentration levels of certain chemicals in the concentrated soil with the concentrations allowable at the special waste landfill. Disposal costs at hazardous waste landfills are usually more than the cost for other cleanup techniques listed in this overview. Disposal at hazardous waste landfills will not be considered in the overview.

Does this method work on all soil types or just some?

All types of soil can be treated using this technique. Even soil from below the water table can be excavated in some cases, if the water entering the pit can be controlled. However, soils that contain too much water may be banned from a landfill. This is determined by the paint filter test, in which an aliquot of soil is placed into a #4 paint filter for a specified amount of time. If the liquid passes through the filter in that time, free liquids exist in the soil and it can not be transported to a landfill.

How long does it take to clean a site relative to other approaches?

This is usually a relatively quick approach, if all of the soil that needs to be removed is accessible. A few days of work on-site are generally all that are needed to complete excavation and shipment of the soil to the landfill. However, it may not always be possible to excavate all of the contaminated soil. For example, the soil may be under a building, or it may not be possible to dig because of underground utilities or a shallow water table.

How expensive is it relative to other approaches?

Excavation and landfilling are relatively inexpensive for small sites that are easily excavated, if the transport distance to the landfill is not excessive. Alternative technologies become more cost-competitive when large volumes of soil need to be remediated. Disposal costs are estimated to range from as little as about \$20/ton (about \$30/yd^3), including costs of excavation and transport, to as much as several hundred dollars per ton for soils with unusual characteristics, hazardous contaminants, difficult excavation, or large transport distances. Typically, landfilling can be expected to cost about \$75/ton (about \$105/yd^3), including excavation and transport.

Is this approach easy or hard to get approved by the appropriate Agencies?

Easy. This is the only soil cleanup technique currently accepted by the Illinois EPA that doesn't require special approval by the Alternative Technologies Assessment Group (ATAG).

Will I need to get a lot of permits to use this approach?

This approach requires relatively few permits. It is necessary to obtain an Illinois special waste generator number and manifest the shipment of the soil to the special waste landfill. This generator number should hold if the soil is taken out of state as well because it is a USEPA number.

BIOREMEDIATION

How does this cleanup technique work?

Bioremediation technologies rely on microorganisms to break down organic contaminants in the soil. The microorganisms may be naturally present or introduced. Oxygen, moisture, or nutrients may be added to stimulate microbial activity. Bioremediation processes can be applied to in-place soil, or the soil can be excavated and treated above ground. Land-farming is a special case of bioremediation where contaminated soil is not placed in a lined treatment cell, but spread very thinly over a large area of land. Since there is no liner present, soils and ground water must be monitored throughout the project.

For which chemical groups will this method be effective?

Bioremediation is applicable only for treating organic contaminants. Straight-chain and simple aromatic hydrocarbons such as those found in petroleum products are more easily degraded than chlorinated or poly-nuclear aromatic hydrocarbons.

Does this method work on all soil types or just some?

All types of soil can be treated using bioremediation. In-situ techniques are more effective on high permeability, sandy soils. Very low permeability soils may be difficult to treat due to the difficulty in delivering moisture, nutrients, and oxygen. Soils with high clay and organic matter contents are also difficult to treat, whether using in-situ or above ground techniques.

BIOREMEDIATION
(continued)

How long does it take to clean a site relative to other approaches?

The time to complete remediation is quite variable, depending on the specific technique used and the contaminants being treated. Treatment of simple contaminants (e.g., gasoline constituents) using land treatment or an above ground bioreactor may be completed in a few weeks or months. In-situ treatment of chlorinated poly-nuclear aromatics may take several years.

How expensive is it relative to other approaches?

Because bioremediation systems come in such a wide variety of configurations, the costs of bioremediation can be highly variable. The relative cost per ton of soil treated becomes very competitive for relatively large sites or sites that are difficult to excavate. Costs may range from as little as \$10/ton (about \$15/yd^3) for a simple bioventing approach to over \$100/ton (about \$140/yd^3).

Is this approach easy or hard to get approved by the appropriate Agencies?

Bioremediation is an alternative technology that must be approved by the IEPA on a case-by-case basis. The costs of the proposed cleanup must not exceed conventional approaches by more than 20% if reimbursement from the LUST Fund is sought. Among alternative technologies, the IEPA has historically viewed in-situ bioremediation projects favorably.

Will I need to get a lot of permits to use this approach?

Bioremediation projects require relatively few permits unless they involve land-farming. Obtaining land-farm permits is somewhat difficult and time consuming. Systems involving withdrawal of air or groundwater will require permits for discharge and treatment systems.

SOIL VAPOR EXTRACTION

How does this cleanup technique work?

Soil Vapor Extraction (SVE) involves withdrawing air from the subsurface using vacuum pumps or vacuum exhausters attached to extraction wells. Low molecular weight, high vapor pressure contaminants such as most or many gasoline constituents are volatilized and withdrawn in the air flow. SVE is not as effective on sites contaminated with heavy fuels such as heating oil. The technology can be applied with minimum disruption of ongoing surface activities and is often effective under buildings and other structures.

For which chemical groups will this method be effective?

SVE is mostly applicable to volatile organic contaminants such as gasoline constituents. High molecular weight hydrocarbons (e.g., PNAs) are much less effectively treated, although some treatment occurs due to the increased oxygen content resulting from the induced subsurface air flow. SVE is ineffective on soils containing inorganic contaminants.

Does this method work on all soil types or just some?

Most types of soil can be treated using this technique. Soils with very low permeabilities or very high moisture content are difficult to treat due to the difficulty of inducing uniform subsurface air flows.

How long does it take to clean a site relative to other approaches?

This is a relatively quick approach for uniform, permeable soils contaminated with gasoline. If the soils are contaminated with heavy fuel constituents with low vapor pressures, volatilization proceeds much more slowly.

How expensive is it relative to other approaches?

SVE is relatively inexpensive and has become the preferred gasoline cleanup approach in some parts of the country, particularly for sites that are not easily excavated. Although SVE is not as effective on sites contaminated with heavy fuels such as heating oil, it may still be cost effective since it involves minimal disturbance to ongoing surface activities and can be effective under buildings and other structures. Costs can range from as little as \$10/ton (about \$15/yd^3) for a simple system to as much as \$150/ton (about \$210/yd^3).

Is this approach easy or hard to get approved by the appropriate Agencies?

SVE is an alternative technology that must be approved by the IEPA on a case-by-case basis. It must be shown that the costs of the proposed cleanup do not exceed conventional approaches by more than 20% if reimbursement from the LUST Fund is sought. Among alternative technologies, the IEPA has historically viewed SVE projects favorably.

Will I need to get a lot of permits to use this approach?

SVE by itself requires relatively few permits. An air emission control system operating and emissions permit is required. If used in conjunction with water treatment systems, additional permits for waste water treatment and discharge will be required.

THERMAL TREATMENT

How does this cleanup technique work?

Thermal treatment employs heat to desorb and volatilize organic contaminants in the soil. This is an above ground process in which excavated soils are treated in commercial treatment units such as rotary kilns. The units are usually trailer-mounted and operated on-site, although regional centers may be used. Thermal treatment units operate at relatively low temperatures and do not destroy the contaminants removed from the soil. The contaminants are discharged to the atmosphere or are trapped and/or destroyed in a secondary gas cleaning system.

For which chemical groups will this method be effective?

Thermal treatment is applicable only for treating low and middle molecular weight organic contaminants. Higher molecular weight hydrocarbons are more difficult to remove. Thermal treatment is ineffective against inorganic contaminants. Actually, some inorganics may be volatilized which is a cause for concern.

Does this method work on all soil types or just some?

All types of soil can be treated using thermal treatment. However, effectiveness is reduced for soils containing a high proportion of clay or organic matter, and a high moisture content reduces the efficiency due to the high cost of needlessly heating, vaporizing, condensing and disposing of water vapor.

How long does it take to clean a site relative to other approaches?

Thermal treatment is generally quite rapid with proper planning. Transportable, on-site units can treat 25 to 50 tons/hr (roughly 15 to 35 cubic yards per hour) of gasoline contaminated soil. Planning is important because it can take about 6 months or more to obtain the permit for the on-site unit. The soils from typical gasoline station excavations can be treated in a couple of days.

How expensive is it relative to other approaches?

Thermal treatment is one of the least expensive among above ground, on-site treatment approaches. However, it is often more costly than landfilling or in-situ approaches such as bioremediation or SVE. Typically, thermal treatment can be expected to cost about \$100/ton (\$140/yd^3).

Is this approach easy or hard to get approved by the appropriate Agencies?

Thermal treatment is an alternative technology that must be approved by the IEPA on a case-by-case basis. The cost of the proposed cleanup must not exceed conventional approaches by more than 20%. Among alternative technologies, the IEPA has historically viewed thermal treatment projects somewhat favorably, although there have been relatively few of these cleanup projects proposed. This is probably because less expensive technologies are available.

Will I need to get a lot of permits to use this approach?

This approach requires relatively few permits on the part of the site owner/operator, since air emission permitting should generally be handled by the vendor of the transportable treatment unit.

INCINERATION

How does this cleanup technique work?

Incinerators destroy the waste constituents by combustion. Very high temperatures are employed to ensure the complete destruction of the waste chemicals. It is normally not necessary to incinerate soils contaminated with petroleum products. However, incineration may be an appropriate technology for treatment of soils contaminated with hazardous wastes. The soils must be excavated before treatment. Trailer-mounted units may be used on site, or waste soils can be shipped to a regional hazardous waste incineration facility.

For which chemical groups will this method be effective?

Incineration is applicable for treating all organic contaminants. Inorganic elements with low boiling points, such as mercury, lead, and arsenic, are volatilized in incinerators and may pose an air emission problem.

Does this method work on all soil types or just some?

All types of soil can be treated using incinerators. However, low pH soils may have a corrosive effect on the equipment. Soils with a high clay content can cause dust handling problems, and a high moisture content reduces the efficiency due to the high cost of needlessly heating, vaporizing, condensing and disposing of water vapor.

How long does it take to clean a site relative to other approaches?

Incineration is generally quite rapid. Transportable, on-site units are capable of treating 3 to 20 tons/hr (roughly 2 to 15 cubic yards per hour) of contaminated soil. The soils from typical gasoline station excavations could be treated in a couple of days.

INCINERATION
(continued)

How expensive is it relative to other approaches?

Incineration is normally considered too expensive for routine use in the treatment of petroleum-contaminated soils. However, incineration may be competitive for disposal of hazardous wastes. On a per-ton or per-yard basis, treatment costs are highly variable, depending on the characteristics of the waste and the volume of soil to be treated. Incinerators have high capital and set-up costs, so treatment costs are very high for small volumes of soil (in some cases over $1,000/ton). Costs may drop to as low as $200/ton (about $280/yd^3) for large volumes of easily handled soil.

Is this approach easy or hard to get approved by the appropriate Agencies?

Incineration is an alternative technology that must be approved by the IEPA on a case-by-case basis. It is unlikely that the IEPA would approve incineration for treatment of petroleum-contaminated soils, since the treatment cost is likely to exceed conventional approaches by more than 20%. This would increase the risk of non-reimbursement from the LUST Fund. No cleanup projects using incineration have been proposed for LUST sites, since less expensive technologies are available.

Will I need to get a lot of permits to use this approach?

This approach requires relatively few permits on the part of the site owner/operator, since air emission permitting should generally be handled by the vendor of the transportable treatment unit. Permitting for this approach can take 6 months or more.

SOIL WASHING

How does this cleanup technique work?

Soil washing is an above ground treatment technology that employs water-based scrubbing solutions to remove contaminants from coarse-grained soil particles. The contaminants are concentrated in the fine-grained residual clay fraction. Thus, the volume of soil that must be further treated or disposed is reduced. The volume reduction achievable for clay soils is minimal. Water requirements for the technology can be very high.

For which chemical groups will this method be effective?

Soil washing is generally applicable for treating all volatile organic contaminants and many metals. Semi-volatile organic contaminants may be successfully treated in some cases, depending on the soil type and the specific wash formulations used.

Does this method work on all soil types or just some?

Soil washing is most effective on coarse-grained soils with only minor amounts of silt, clay, or organic matter. Contaminants tend to adsorb strongly to these materials and are difficult to remove.

How long does it take to clean a site relative to other approaches?

Full scale soil washing systems are projected to be capable of treating approximately 70 tons of contaminated soil per hour (about 100 yd^3/hr). The soils from typical gasoline station excavations could be treated in a couple of days.

SOIL WASHING
(continued)

How expensive is it relative to other approaches?

Soil washing costs are estimated by vendors of washing systems to range from about \$50/ton (about \$70/yd^3) to about \$200/ton (about \$280/yd^3). However, the lower end of this range does not include the cost of disposing of contaminated residuals.

Is this approach easy or hard to get approved by the appropriate Agencies?

Soil washing is an alternative technology that must be approved by the IEPA on a case-by-case basis. No cleanup projects using this technology have been proposed for LUST sites, probably because less expensive technologies are available.

Will I need to get a lot of permits to use this approach?

This approach requires relatively few permits on the part of the site owner/operator, since water treatment system and air emission permitting should generally be handled by the vendor of the transportable treatment unit. The owner of the site will likely be responsible for obtaining a permit for the discharge of treated wash water.

IN-SITU SOIL FLUSHING

How does this cleanup technique work?

In-situ soil flushing involves extracting contaminants from in-situ soils with water or water-based washing solutions. First, the solution is applied to the ground surface or pumped under pressure into wells previously installed into the contaminated area. Once applied, the water or flushing solution infiltrates the body of contaminated soil. The contaminants are then transported in the solution. Finally, the solution is recovered for treatment through extraction wells.

For which chemical groups will this method be effective?

In-situ soil flushing has been demonstrated in cleaning soils of gasoline constituents as well as other soluble organic compounds such as alcohols and phenols, and for a variety of inorganic metal salts. It is likely to be effective on other contaminants as well if suitable surfactants, solvents, chelants, or acidifying additives are used in the flushing solution.

Does this method work on all soil types or just some?

In-situ soil flushing is most effective on coarse-grained soils with only minor amounts of silt, clay, or organic matter. Contaminants adsorb strongly to these fine grained materials and are difficult to remove. In addition, soils with silt and clay tend to be less permeable and therefore less amenable to fluid transport. Careful hydraulic control is necessary to prevent the migration of contaminants off-site and to ensure that all of the contaminated soil is cleaned. This is more difficult in low-permeability, heterogeneous soils. It may be difficult to demonstrate that the site has been satisfactorily cleaned up.

How long does it take to clean a site relative to other approaches?

Because of the relative slowness of diffusion processes and the capacity of soils to transmit fluids, remediation times using this technology are generally expected to be lengthy (one to many years). However, with a small site with suitable geology contaminated with gasoline, cleanup could potentially be accomplished in one season.

How expensive is it relative to other approaches?

Cost data for in-situ soil flushing is scarce. One project in the Chicago area projected costs of about $92/yd^3 (about $65/ton) for a site with very favorable hydrogeologic conditions (uniform coarse sand beach deposits contaminated with gasoline constituents). This is competitive with landfilling, bioremediation, and SVE.

Is this approach easy or hard to get approved by the appropriate Agencies?

Soil washing is an alternative technology that must be approved by the IEPA on a case-by-case basis. Only one site in the Chicago area has employed this technology to date. However, given suitable geology, in-situ soil flushing would probably be viewed with favor due to the apparent success of this one project.

Will I need to get a lot of permits to use this approach?

This approach typically requires permits for wastewater treatment systems, treated wastewater discharges, and may require air emission permits.

SOLVENT EXTRACTION

How does this cleanup technique work?

Solvent extraction is an above ground treatment technique similar to soil washing. However, instead of washing the soil with an aqueous wash solution, an organic solvent such as liquified gas (propane and/or butane) is used to extract the organic contaminants from the soil. Once the contaminants are extracted they must still be disposed.

For which chemical groups will this method be effective?

In general, solvent extraction is most effective on light and middle distillate fuel constituents and least effective on very high molecular weight organic compounds. The process has been used successfully on soils contaminated with PCB oils. Solvent extraction is not effective on inorganics.

Does this method work well on all soil types or just some?

Solvent extraction is most effective on coarse-grained soils with only minor amounts of silt, clay, or organic matter. Contaminants adsorb strongly to these fine grained materials and are difficult to remove. In addition, soils with silt and clay tend to be less permeable and therefore less amenable to fluid transport. Careful hydraulic control is necessary to prevent the migration of contaminants off-site and to ensure that all of the contaminated soil is cleaned. This is more difficult in low-permeability, heterogeneous soils. It may be difficult to demonstrate that the site has been satisfactorily cleaned up.

How long does it take to clean a site relative to other approaches?

Transportable systems are capable of treating on the order of 5 to 10 tons of soil per hour (roughly 7 to 15 yd^3/hr). The soils from typical gasoline station excavations could be treated in several days.

SOLVENT EXTRACTION
(continued)

How expensive is it relative to other approaches?

Solvent extraction is relatively expensive for treatment of gasoline contaminated soils. Cost estimates for commercially available solvent extraction units range from about \$100/ton (about \$140/yd^3) to about \$500/ton (about \$700/yd^3). However, solvent extraction may be competitive for treating soils contaminated with PCB oils.

Is this approach easy or hard to get approved by the appropriate Agencies?

Solvent extraction is an alternative technology that must be approved by the IEPA on a case-by-case basis. No Illinois LUST sites have employed this technology, probably due to the relatively high cost.

Will I need to get a lot of permits to use this approach?

This approach typically requires permits for wastewater treatment systems, treated wastewater discharges, and will likely require air emission control permits depending on the configuration of the equipment. However, vendors of transportable commercial units likely should have all necessary operating permits and only discharge permits may be required for a particular site.

IN-SITU VITRIFICATION

How does this cleanup technique work?

In-situ vitrification is an emerging technology that is not readily available for commercial applications. The process employs electrical power to heat and melt the contaminated soil in place, forming a glassy substance with a very low potential for release of contaminants. Organic contaminants are volatilized and/or combusted during the melting process. Inorganic contaminants are fixed in the resulting glassy soil mass.

For which chemical groups will this method be effective?

In-situ vitrification has been demonstrated to be effective in immobilizing radioactive wastes and is considered likely to be effective in the treatment of virtually any organic or inorganic waste.

Does this method work on all soil types or just some?

Virtually all soil types can be treated using in-situ vitrification. However, soils below the water table are difficult and expensive to treat because the water must be evaporated first. If the soil permeability is greater than about 10^{-5}, the soil will resaturate as fast as the water can be evaporated.

How long does it take to clean a site relative to other approaches?

Approximately 4 to 6 tons of soil can be processed per hour (roughly 6 to 8 cubic yards per hour).

IN-SITU VITRIFICATION
(continued)

How expensive is it relative to other approaches?

This is a very costly technology that currently is considered viable only for the treatment of soils contaminated with radioactive wastes. Treatability studies cost on the order of from $25,000 to $100,000. No commercial applications have been undertaken. Cost data for commercial applications are therefore unavailable.

Is this approach easy or hard to get approved by the appropriate Agencies?

This technique could be considered for a unique site posing an unusual and very high hazard. Otherwise it would be very difficult to obtain approval due to its semi-experimental nature and very high cost.

Will I need to get a lot of permits to use this approach?

In-situ vitrification is currently licensed by the U.S. Department of Energy exclusively to Geosafe Corporation, a subsidiary of Batelle Memorial Institute. The process requires control of volatile emissions and would likely require air pollution control and emission permits.

Table 1. Effectiveness of the various techniques relative to chemical groups.

	Organics			Inorganics		
	Volatile	Semi-Volatile	Non-Volatile	Mercury, Lead, & Arsenic	Other Metals	Other In-organics
Land-filling	++	+++	+++	+++	+++	+++
Bioremedi-ation	+++	++	+			
SVE	+++	++	+			
Thermal Desorption	+++	++	+			
Inciner-ation	+++	+++	+++	++		
Soil Washing	+++	++		++	++	
In-Situ Soil Flushing	+++	+++	+++	++	++	++
Solvent Extraction	+++	+++	+			
In-Situ Vitrific-ation	++	++	++	++	++	++

Table 2. Effectiveness of the various techniques relative to soil types.

	Sand	Silt	Organic and Clay	Water Saturated
Landfilling	+++	+++	+++	+++
Bioremediation	+++	+	+	
SVE	+++	+	+	
Thermal Desorption	+++	++	+	+
Incineration	+++	++	+	+
Soil Washing	+++	+	+	
In-Situ Soil Flushing	+++	+	+	
Solvent Extraction	+++	+	+	
In-Situ Vitrification	++	++	++	+