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SCREENING OF ALTERNATIVE TECHNOLOGIES TO INCINERATION FOR TREATMENT OF CHEMICAL-AGENT-CONTAMINATED SOIL

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Abstract

As part of the Rocky Mountain Arsenal (RMA) Remedial Investigation/Feasibility Study, RMA has contracted Argonne National Laboratory to investigate potential remedial alternatives for the cleanup of agent-contaminated soils. The chemical agents of concern include levinstein mustard, lewisite, sarin, and VX. This investigation has been initially divided into three phases: (1) a literature search to determine what, if any, previous studies have been conducted; (2) a technologies-screening critique of remedial technologies as alternatives to incineration; and (3) an investigation of promising alternatives on RMA soil at the laboratory and bench-scale levels. This paper summarizes the document produced as a result of the technologies screening. The purpose of the document was to determine the applicability of 25 technologies to remediation of agent-contaminated soil for a general site. Technologies were critiqued on the basis of applicability to soil type, applicability to the agents of concern at RMA, applicability to other types of contaminants, cost of the treatment, current status of the technology, and residuals produced.

Summary

In support of the U.S. Army's review of appropriate remediation technologies for application to contaminated sites on Army installations, Argonne National Laboratory (ANL) prepared a document entitled *Preliminary Screening of Alternative Technologies to Incineration for Treatment of Chemical-Agent-Contaminated Soil* [1]. This document reviewed technologies for treating soils contaminated with mustard, lewisite, sarin, and VX and their breakdown products. The document focused on assessing alternatives to incineration but also included information on incineration for comparative purposes. The objectives of ANL's work were to (1) provide a brief description of each technology, its general cost, its current status, and residuals (if any) that would require further handling or treatment; (2) identify the suitability and/or constraints of each technology in terms of soil type, agents of concern, and other soil contaminants; (3) present a summary discussion of the overall applicability of each technology in treating the agents of concern; and (4) identify technologies that merit further investigation. The study should not be considered an exhaustive review of all possible technologies or a complete evaluation of the technologies described. The technologies reviewed were included either because they represent a wide variety of state-of-the-art remediation techniques or because they are innovative technologies that may hold some promise for remediation of agent-contaminated soils.
Six criteria were used to screen each of 25 technologies, including biotreatment, physical, chemical, and thermal treatment, both in situ and ex situ. The criteria are applicability to general

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TABLE 1 Soil Treatment Technologies to Be Screened

	In Situ Technologies
1	Biostimulation
2	Bioventing
3	Soil Vapor Extraction without Thermal Enhancement
4	Soil Vapor Extraction with Thermal Enhancement
5	Soil Flushing
6	Solidification/Stabilization
7	Vitrification
8	Natural Attenuation
	Ex Situ Physicochemical Technologies
1	Physical Pretreatment
2	Solidification/Stabilization
3	Solvent Extraction
4	Soil Washing — General
5	Alcoholysis or Cleavage with a Strong Basic Solution
6	Dehalogenation with Alkaline Polyethylene Glycol
7	Chemical Oxidation
	Ex Situ Biological Technologies
1	Slurry-Phase Biological Treatment
2	Land Farming
3	Controlled Solid-Phase Biological Treatment
	Ex Situ Thermal Technologies
1	Low-Temperature Thermal Desorption
2	High-Temperature Thermal Desorption
3	Dehalogenation with Heated Sodium Bicarbonate
4	Incineration
5	Pyrolysis
6	Vitrification
7	Plasma-Torch Treatment

soil characteristics, applicability to the four toxic agents of concern, usefulness for treating other soil contaminants, cost of the treatment, current status of the technology, and residuals or waste streams. In addition to the evaluation in terms of these six criteria, a brief description of the technology and a discussion concerning the technology's applicability on the basis of how it measured up to the screening criteria are provided. A final discussion on the document's findings is also included. The following is a summary of that discussion.

In situ technologies, including soil vapor extraction, soil flushing, solidification/stabilization, and vitrification, may be undesirable for remediation of agent-contaminated soil because of the difficulty in determining whether remediation goals have been met. Because of the nature of in situ technologies, it cannot be proven that all of the agent would be treated or mobilized. In general, in situ technologies could be applied for treatment or removal of sarin with predictable success. However, treatment or removal of mustard, lewisite, LO, and VX would be less successful — the persistence of mustard in the environment and its insolubility in water, the arsenic content in lewisite and LO, and the toxic breakdown products of VX make treatment of these agents by in situ technologies difficult.

The use of ex situ biotreatment technologies for agent-contaminated soils is a new and innovative field. The biodegradation of agents has only been researched in terms of stockpiled agent; virtually nothing is known about the behavior of naturally occurring microorganisms in agent-contaminated soil. Predictions from stockpiled-agent research suggest that sarin and VX have the potential to be directly affected by microorganisms. Mustard has proven to be too toxic to organisms, and the arsenic-containing lewisite or LO may also be too toxic, although these cvompounds have not been specifically tested.

Ex situ physical pretreatment of the soil will hydrolyze and, possibly, volatilize sarin. Hydrolysis of the other agents would also occur to some extent. Ex situ solidification/stabilization could immobilize the contaminants in the soil, but the possibility of future agent release would have to be addressed.

The use of solvents, such as supercritical fluids (e.g., carbon dioxide) and critical solution temperature solvents (e.g., triethylamine), to treat agent-contaminated soils is promising but untested. Solvent washing technology should be useful for soils contaminated with mustard, sarin, and VX. Little is known about the behavior of LO with solvents; if removal of LO were successful using solvent washing technologies, further treatment would be needed to detoxify the extract and isolate the arsenic in a form suitable for disposal. Additional treatment would also be required for VX extract. In general, optimal treatment conditions would be required for critical/supercritical fluid extraction to successfully remove agents from the soil, because the effectiveness of this technology is highly dependent on pressure, temperature, and the presence of co-solvents. Any solvent washing process may be cost-prohibitive unless the solvent can be easily isolated for reuse.

Soil-washing technologies, including alcoholysis or cleavage with a strong basic solution, dehalogenation with alkaline polyethylene glycol, and chemical oxidation, have potential for removing or treating agent-contaminated soil. Because of mustard's low solubility in water, hydrolysis and oxidation by dissolved oxidants would require the use of nonaqueous or mixed aqueous/nonaqueous solvents. The basic solutions used for alcoholysis/cleavage or dehalogenation with alkaline polyethylene glycol or any of the oxidizing solutions listed in the document should be effective. Soil washing with a strongly alkaline aqueous solution, at 50°C or higher, should be adequate to cleave LO to inorganic arsenic (arsenite) and acetylene plus some vinyl chloride. Soil washing with an alkaline solution will also hydrolyze sarin and VX. In general, alcoholysis, dehalogenation, and chemical oxidation would be effective in treating small volumes of agent-contaminated soil; these processes may be cost-prohibitive for larger volumes because of the cost of the additive or the processing necessary to treat the waste solution.

Thermal technologies have proven effective in the removal or treatment of organics and some metals. Costs for several thermal technologies are high, ranging from $300 to $2,700 for treatment of one ton of soil. These high costs are partly attributable to intensive energy requirements and the required air pollution control devices. Low- and high-temperature thermal desorption technologies do not require the extreme temperatures and high energy inputs that are needed for incineration, pyrolysis, vitrification, and plasma-torch treatment, but they are still effective in removing solid contaminants. Low- or high-temperature desorption and pyrolysis should remove mustard, sarin, and VX from soil. Adding sodium bicarbonate would probably decompose the mustard and, through carbon dioxide generation, help carry the vapor-state products to the secondary combustion chamber. However, sodium bicarbonate would likely decompose the VX to other, still somewhat toxic, compounds. Thorough mixing of solid bleach, such as chlorinated lime or supertropical bleach, into the soil, followed by moderate heating (approximately 120°C), should be effective in oxidizing VX residuals to less-toxic derivatives. The effect of low- or high-temperature desorption or pyrolysis on LO-contaminated soil cannot be predicted reliably. Adding sodium bicarbonate to soil would probably cause cleavage of the LO to inorganic arsenic and acetylene, plus some vinyl chloride. Because the volatility of the various arsenic species that might be involved is uncertain, the concentrations of arsenic in each effluent stream or residue should be investigated further.

The document also provides information on the physicochemical profiles of the four agents of concern, toxicological profiles, environmental fate and degredation products of agents in water and soil, and reactions of significance in chemical detoxification of the agents.

To obtain a copy of the document, contact Linda Shem at ANL or Mark Besmer at Rocky Mountain Arsenal.

Reference

[1] Shem, L.M., Rosenblatt D.H.,Smits M.P. , Wilkey P.L., Ballou S.W., Besmer M.G: "Prelimilary Screening of Alternative Technologies to Incineration for Treatment of Chemical-Agent-Contaminated Soil, Rocky Mountain Arsenal," prepared for U.S. Army Program Manager, Rocky Mountain Arsenal, prepared by Argonne National Laboratory, ANL/ESD-32,1995.