FULL-SCALE FIELD DEMONSTRATION AND TESTING OF PHYSICOCHEMICAL PROCESSES FOR IN SITU TREATMENT OF CONTAMINATED SOIL

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ABSTRACT

A technology demonstration project was conducted to find a feasible and cost-effective process for treatment of contaminated soils beneath the X-231B Solid Waste Management Unit at the DOE Portsmouth Gaseous Diffusion Plant. The X-231B Unit was used as a land disposal site from 1976 to 1983 and soil and ground water beneath the unit were contaminated by volatile organic compounds (VOCs) and radioactive substances. An initial evaluation and screening phase led to research and demonstration of vapor stripping, chemical oxidation, and solidification processes. Soil mixing technology was used to create continuously mixed subsurface soil reactors within which the processes could be implemented individually or in combination. The technology demonstration project included process and spatial modeling studies, bench- and pilot-scale laboratory experimentation, and full-scale field demonstration and testing. During the field demonstration completed at the X-231B site in June 1992, replicated tests of in situ vapor stripping, peroxidation, and solidification were made in soil regions, 10 ft diameter by 15 to 22 ft deep. Tracer studies were also conducted. During each test, intensive monitoring and measurement activities defined key operation and performance parameters. The demonstration revealed that physicochemical processes could be used individually or in combination for effective and rapid in situ treatment of VOCs while limiting worker exposure and controlling the fate of organic and radioactive substances.

INTRODUCTION

Fine-textured soils and sediments contaminated by trichloroethylene (TCE) and other chlorinated organics present a serious environmental restoration challenge. While in situ processes such as bioremediation and soil vapor extraction can function at sites with permeable soils (e.g., $K_{sat} > 10^{-3}$ cm/s), they are normally ineffective in wet, clay soils and sediments. Environmental restoration of these sites has normally consisted of either 1) excavation followed by on-site storage, off-site land filling, or thermal treatment, or 2) in-place containment by capping and slurry wall emplacement.

The X-231B Technology Demonstration project was initiated at Oak Ridge National Laboratory (ORNL) by the U.S. Department of Energy (DOE) and Martin Marietta Energy Systems, Inc. (MMES) in November 1990. The goal of the project was to demonstrate a feasible and cost-effective process for closure and environmental restoration of the X-231B Solid Waste Management Unit at the DOE Portsmouth Gaseous Diffusion Plant located in southern Ohio (Fig. 1). The

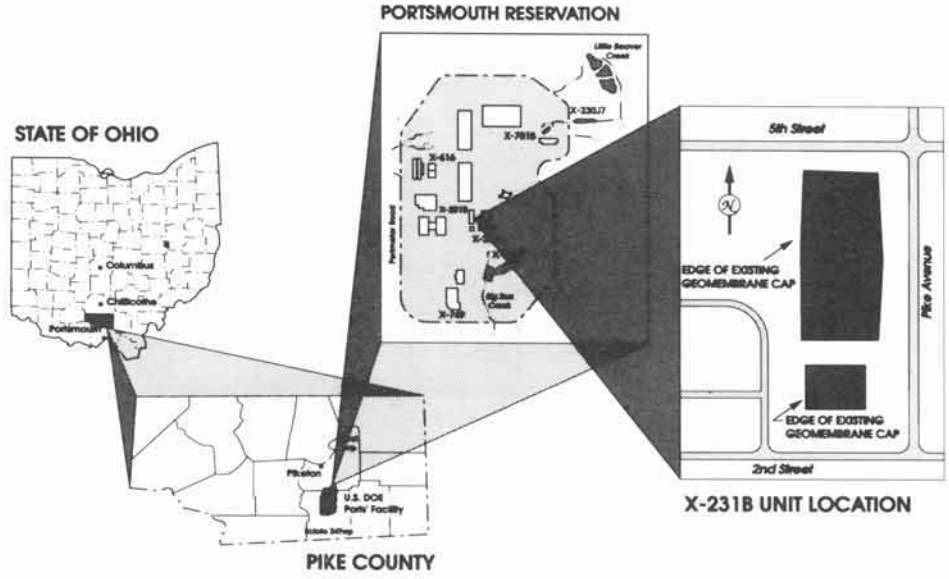

Fig. 1. Location of the DOE Portsmouth gaseous diffusion plant and the X231B unit.

X-231B Unit was used from 1976 to 1983 as a land disposal site for waste oils. Dense silt and clay deposits ($K_{sat} < 10^{-6}$ cm/s) beneath the unit were contaminated with trichloroethylene, 1,1,1-trichloromethane, and other VOCs and low levels of uranium and technetium. The shallow ground water (water table at ca. 12-14 ft depth) was also contaminated, with some contaminants at levels well above drinking water standards (Fig. 2).

This paper presents a synopsis of the methods and results of the X-231B Technology Demonstration project with emphasis on the full-scale field demonstration and testing. Some aspects of the project have not been completed and are only briefly mentioned herein. Additional details regarding the highlights presented herein as well as the other elements of the project are presented elsewhere and/or will be available

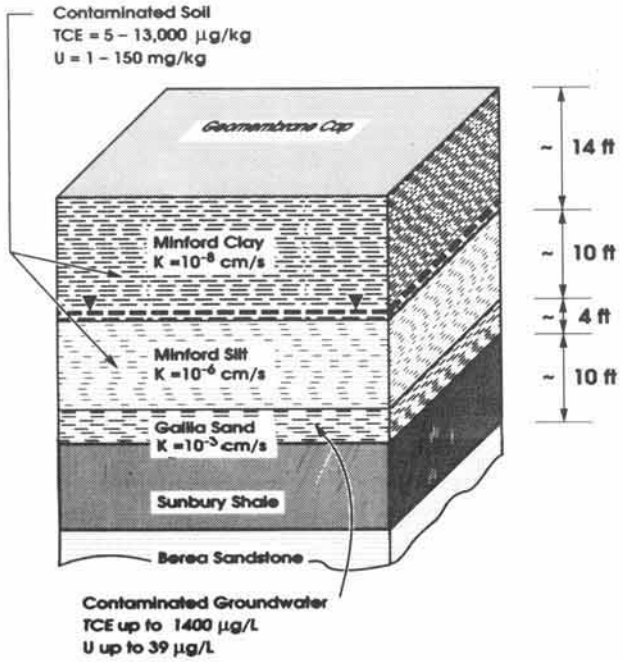

Fig. 2. Reported subsurface characteristics of the X-231B site prior to project initiation.

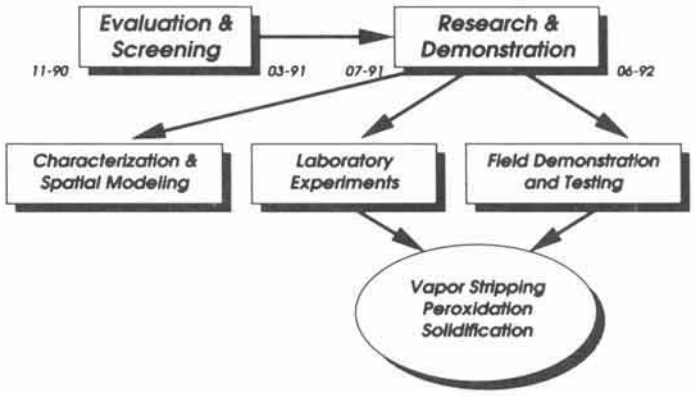

Fig. 3. Elements of the X-231B technology demonstration project.

during 1993 in forthcoming project reports and open literature publications (1-5).

TECHNICAL APPROACH

The X-231B Technology Demonstration began with an evaluation and screening phase that considered the environmental restoration problem and potential technology solutions (Fig. 3). This led to a second phase involving research and demonstration of in situ soil treatment approaches using vapor stripping, chemical oxidation, and solidification processes with reagent delivery achieved by soil mixing technology (Fig. 4). The objectives of the project were to define process operation and performance, including VOC removal/destruction efficiencies, off-gas composition, effects on soil chemistry and microbiology, the fate of heavy metals and radioactive substances, and soil homogenization and translocation. Over an 18-month period beginning in July 1991, the project included process and spatial modeling studies, bench- and pilot-scale laboratory experimentation, and full-scale field demonstration and testing (Fig. 3).

Site characterization studies were required for siting the demonstration area and for performance evaluation during the demonstration. This was accomplished using a hydraulic

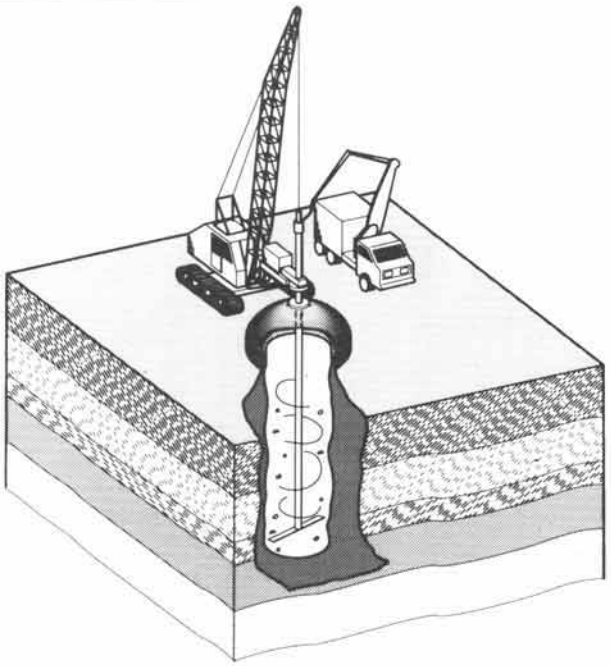

Fig. 4. Illustration of the continuously mixed subsurface soil reactor concept. (Note: treatment agents are delivered through the mixing blade with emissions captured in the shroud covering the mixed region).

probe sampling system to collect over 400 soil samples with on-site laboratory analysis for seven target VOCs (TCE, TCA, etc.). These data were used for statistical simulation and 3-dimensional modeling of contaminant distribution. Probe sampling and on-site analyses were conducted by Envirosurv,

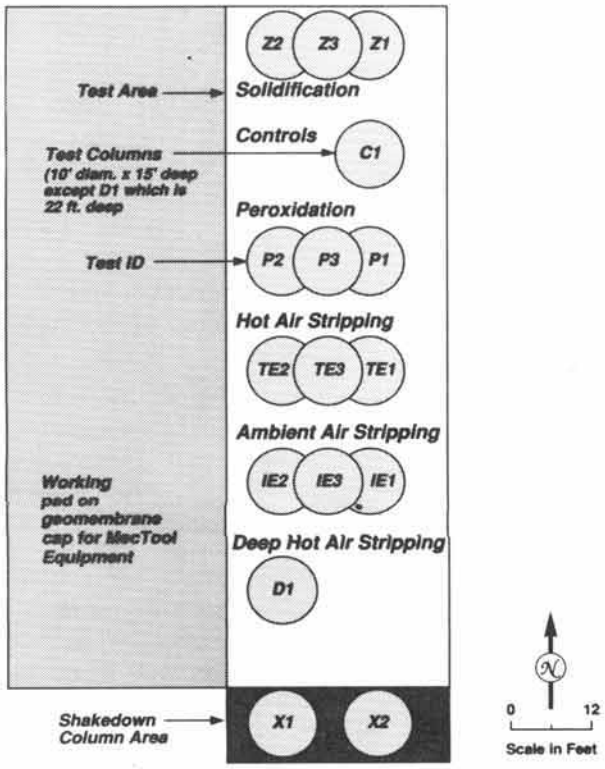

Fig. 5. Schematic of the test site layout for the full-scale field demonstration and testing in the X-231B unit at the DOE Portsmouth Gaseous Diffusion Plant.

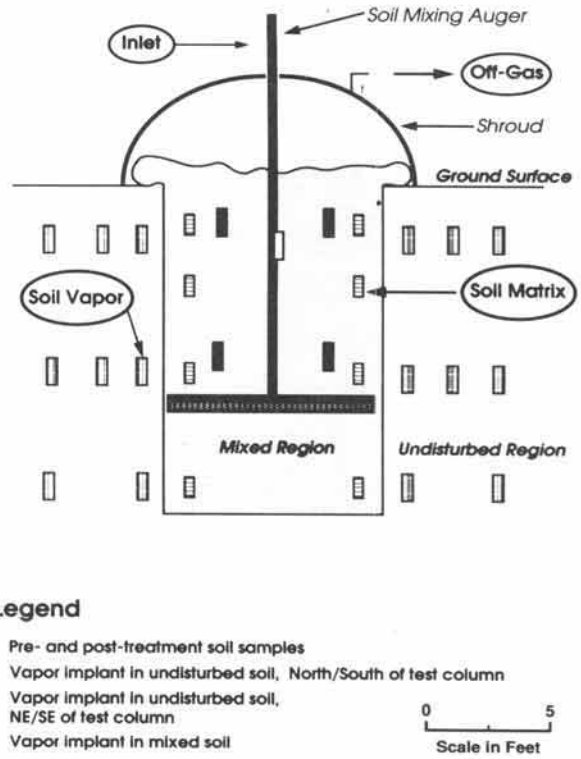

Fig. 6. Profile view of a treated soil region and associated monitoring points.

Inc. with off-site analyses conducted at ORNL. Spatial modeling and 3-dimensional visualization studies were conducted at ORNL.

Numerous laboratory experiments were completed using bench-scale apparatus as well as a pilot-scale soil mixing system in which 8 in. diameter by 24 in. long soil cores from the site were treated. Modeling and experimental studies were completed by ORNL, Michigan Technological University, The University of Tennessee, Chemical Waste Management, Inc., and NovaTerra, Inc. The results of the laboratory studies were used to design and conduct a full-scale field demonstration at the X-231B site during April to June 1992 (Fig. 5-8).

During the full-scale demonstration, replicated tests of in situ vapor stripping, chemical oxidation, and solidification were made in soil regions, 10 ft in diameter by 15 to 22 ft deep (Tables I, II). A computerized data acquisition system linked to nearly 60 sensors enabled near-continuous monitoring of process operation and performance (e.g., auger position, off-gas air flow rate and VOC content, soil vapor pressure and temperature, at recording intervals of 0.2 to 2 min). In addition, nearly 500 soil matrix and soil gas samples were collected before, during, and after soil treatment for analyses of physical, chemical, and biological properties. Soil matrix, soil vapor, and off-gas VOC measurements were made by multiple methods. The field demonstration was conceived and directed by ORNL and MMES in collaboration with Chemical Waste Management, Inc., Millgard Environmental Corporation, and Envirosurv, Inc.

PRELIMINARY RESULTS

The results of the field demonstration portion of the X-231B project have been insightful and very positive. Characterization efforts required for design of the field demonstra-

Fig. 7. The X-231B site during the full-scale field demonstration in May 1992.

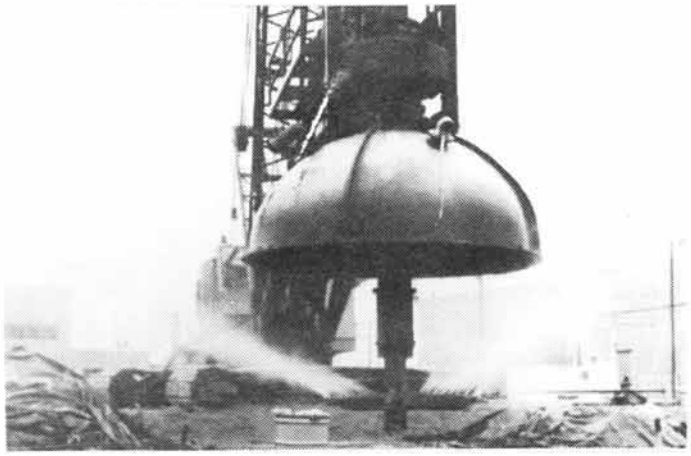

Fig. 8. The soil mixing auger and peroxide mist injection during a shakedown test.

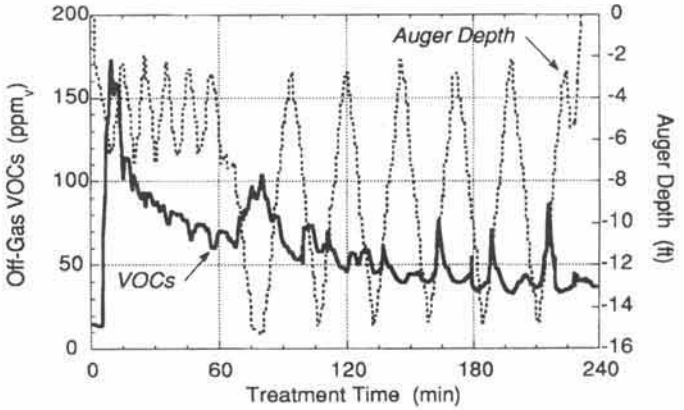

Fig. 9. Treatment operation and off-gas VOC concentrations for a 10 ft diameter by 15 ft deep region treated by in situ hot air vapor stripping.

tion and treatment process performance assessment involved a hydraulic probe for soil sample acquisition coupled with on-site VOC analyses. These data were analyzed using spatial modeling and 3-dimensional visualization techniques to describe contaminant distributions in the subsurface before and after treatment. This approach was found to yield rapid and enhanced data compared to that provided by conventional auger sampling, off-site analyses, and routine data treatment. Moreover, based on numerous sample comparisons, results of conventional preservation and off-site analyses exhibited up to 90% negative bias for TCE and the other target VOCs compared to more rigorous preservation (e.g., infield solvent immersion).

With regard to in situ treatment of contaminated soil, full-scale testing was completed using either ambient or heated air stripping, peroxidation, and solidification processes in continuously mixed subsurface reactors. Mixing of a dense silt/clay soil to depths of 15 to 22 ft was successfully accomplished using a single blade, 10-ft diameter auger (MecTool, Millgard Environmental Corporation). As a result of soil mixing, lifting of soil material above the ground surface (a.k.a. berming) did occur and resulted in berm volumes of approximately 15% of the treated region for the vapor stripping and peroxidation processes compared to 30% for the solidified regions. During full-scale treatment by vapor stripping, VOCs were removed from the subsurface as the mixing auger was moved up and down from 2 to 15 ft below ground surface (Fig. 9). With hot air stripping, VOC removal efficiencies averaged >95% after approximately 225 min of treatment. For ambient air stripping, removal efficiencies were slightly lower, but still above 90% after 225 min of treatment. When the treatment depth was increased to 22 ft, including 10

TABLE I
Summary of Test Conditions During The Field Demonstration at the Doe Portsmouth X-231b Site (2)

In Situ Treatment Process	Code	Mixed Region Diameter and Depth (ft)	Approximate Operating Conditions	Mixed Region Treatment Time(min)
Solidification Stabilization	(Z1 - Z3)	10 x 15	Grout volume = 30% v/v	30 - 60
Ambient Air Stripping	(IE1 - IE3)	10 x 15	1000 - 1400 cfm @ 90°F	225
Hot air Stripping	(TE1 - TE3)	10 x 15	1000 - 1400cfm @ 250°F	225
	(D1)	10 x 22	1000 - 1400 cfm @ 250°F	225
Peroxidation	(P1 - P3)	10 x 15	7% v/v of 5% peroxide and 300 cfm @ 90°F	75
Special Studies	(C1)	10 x 15	-	-

TABLE II
Summary of Monitoring and Measurement Activities During the Field Demonstration at the Doe Portsmouth X-231b Site (2)

Element	Monitoring and Measurement Highlights
Operation	Injection depth, flow, pressure, temperature Off-gas flow, pressure, temperature Off-gas VOCs by FID, GC/ECD, sorbent trap GC/MS Off-gas particulate concentration and radioactivity
Mixed Soil Region Effects	Soil morphology, homogeneity, temperature Soil VOCs by on-site GC/ECD and off-site GC/MS Soil water content, pH, TOC, cation and anion content Soil microbiology
Unmixed Soil Region Effects	Soil gas pressure and temperature Soil gas VOCs by on-site GC/ECD
Soil Mixing	Discrete bromide and diffuse sulfate tracers

ft beneath the ground water table, VOC removal efficiencies with hot air stripping dropped to somewhat less than 90%. For peroxidation treatment, VOCs were both removed in the off-gas and oxidized in situ. During a treatment time of approximately 75 min, total VOC reduction efficiencies of approximately 70% were achieved. It was speculated that mass transfer limitations within the dense silt and clay soils may have hindered more effective treatment. For the solidification process, limited data suggested that 90% of the VOCs originally present in the soil were captured in the grout/soil mixture. Further testing is in process to evaluate the stability of the immobilized VOCs and metals.

During treatment, the air emissions from each process were readily captured within the shroud and treated in a simple carbon adsorption and HEPA filtration system. VOC concentrations in the off-gas fluctuated during treatment, demonstrating a gradual decline over time (e.g., Fig. 9). Off-gas particulates appeared to be relatively low in concentration and non-radioactive.

Monitoring of soil vapor pressure and temperature in undisturbed soil surrounding the mixed soil regions revealed little physical effect beyond the mixed region boundary. However, soil gas concentrations of VOCs declined substantially (e.g., 50%) in the shallow, unmixed regions surrounding each treated area. Effects observed on the mixed regions included elevated soil temperatures (e.g., 100°F following hot air stripping) and increases in soil bacteria levels (e.g., increases of up to 10^4 organisms/g following ambient air stripping). Soil property changes were related to treatment process operation. Tracer studies to evaluate soil translocation indicated that contaminated soil "hot spots" would be attenuated to some degree but limited homogenization would occur. Soil migration was observed to occur inward and upward but not downward. Analyses of soil metals indicated no

significant change in metal concentration with depth as a result of soil mixing and treatment.

Based on the successful results of the X-231B Technology Demonstration, plans are proceeding for implementation of in situ vapor stripping and peroxidation processes for full-scale remediation of the X-231B Unit and other contaminated areas at the DOE Portsmouth Gaseous Diffusion Plant.

ACKNOWLEDGMENTS

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