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EPA

HAZCON Solidification Process, Douglassville, PA

Applications Analysis Report

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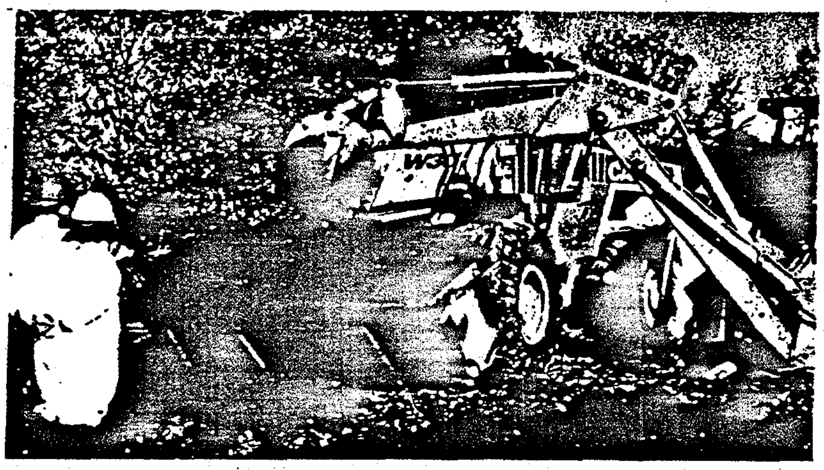
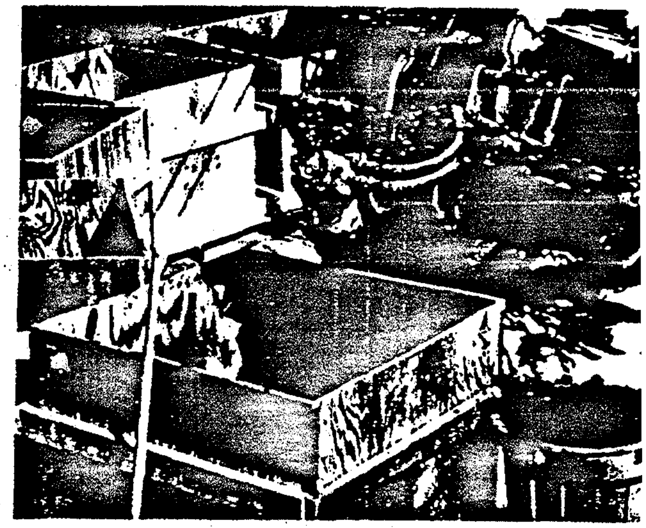
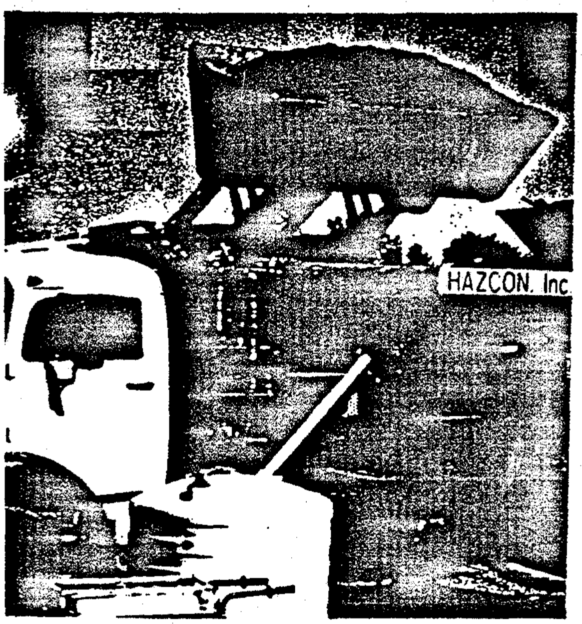
Spoke with Paul dePercin = EPA Project Mgr in Cincinnati, Ohio 1-513-569-7797







SITE

SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

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EPA/540/A5-89/001
May 1989

Applications Analysis Report

HAZCON Solidification Process, Douglassville, Pennsylvania

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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Notice

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Foreword

The Superfund Innovative Technology Evaluation (SITE) program was authorized in the 1986 Superfund amendments. The program is a joint effort between EPA's Office of Research and Development and Office of Solid Waste and Emergency Response. The purpose of the program is to assist the development of hazardous waste treatment technologies necessary to implement new cleanup standards which require greater reliance on permanent remedies. This is accomplished through technology demonstrations which are designed to provide engineering and cost data on selected technologies.

This project consists of an analysis of Hazcon's proprietary solidification process. The technology demonstration took place at a former oil reprocessing plant which comprises the Douglassville superfund site. The demonstration effort was directed at obtaining information on the performance and cost of the process for use in assessments at other sites. Documentation consists of two reports. The Technology Evaluation Report (EPA 540/5-89/001a) describes the field activities and laboratory results. This Applications Analysis provides an interpretation of available data and discusses the potential applicability of the technology.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Bldg., Springfield, VA, 22161, (702) 487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at 1-800-424-9346 or 382-3000 in Washington, D.C. to inquire about the availability of other reports.

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Abstract

This document is an evaluation of the HAZCON solidification technology and its applicability as an on-site treatment method for waste site cleanup.

A Demonstration was held at the Douglassville, Pennsylvania Superfund site in the fall of 1987. Operational data and sampling and analysis information were carefully monitored and controlled to establish a data base against which other available data and the vendor's claims for the technology could be compared and evaluated. Conclusions were reached concerning the technology's suitability for use in clean up of the types of materials found at the test site, and extrapolations were made to cleanups of other materials.

Site materials were sampled to characterize the site. Untreated feedstock materials were sampled to provide a base case against which to compare the product materials, and solidified materials were sampled after 7 days and after 28 days of curing. The samples were analyzed to determine physical properties such as unconfined compressive strength and permeability, chemical properties such as leachability, and microstructural characteristics. The results of these tests were then considered, along with those obtained by other investigators, and conclusions on the technology drawn from all the work.

The conclusions drawn from the test results and other available data are that: (1) the process can solidify wastes high in organics; (2) the process does not immobilize volatile and semivolatile organics in most instances; (3) heavy metals are successfully immobilized; (4) a large volume increase can be expected where moisture content of the wastes is low; (5) the solidified material shows good structure with high unconfined compressive strengths and low permeabilities; (6) the microstructure indicates a potential for degradation over the long term; and (7) the process is economical.

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Abbreviations and Symbols

ANS 16.1	Modified American Nuclear Industry leaching test method
API	American Petroleum Institute
ARAR	Applicable or Relevant and Appropriate Requirements
ASTM	American Society for Testing and Materials
BDAT	Best Demonstrated Available Technology
BNA	base neutral/acid (extractable)
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
cm/sec	centimeters per second
cu ft	cubic feet
cuyd	cubic yard
DSA	Drum Storage Area
EPA	Environmental Protection Agency
EP Tox	Extraction Procedure Toxicity Test - leach test
FSA	Filter Sludge Area
g/ml	grams per milliliter
HSWA	Hazardous and Solid Waste Amendments to RCRA - 1984
KPa	kilopascal (s)
Kw	kilowatt(s)
LAN	Lagoon North
LAS	Lagoon South
lb/min	pounds per minute
LFA	Landfarm Area
m/sec	meters per second
MCC - IP	Materials Characterization Center static leach test method
MFU	Mobile Field Blending Unit
mg/Kg	milligrams per kilogram

Abbreviations and Symbols (Continued)

mg/l	milligrams per liter
ml/g	milliliters per gram
NCP	National Contingency Plan
n/m	Newtons per meter
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&G	oil and grease
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
PADER	Pennsylvania Department of Emergency Response
PAHs	polycyclic aromatic hydrocarbons
Pb	lead
PCBs	polychlorinated biphenyls
PCP	pentachlorophenol
PFA	Processing Facility Area
PL	Public Law
ppb	parts per billion
ppm	perts per million
psi	pounds per square inch
RCRA	Resource Conservation and Recovery Act of 1976
RI/FS	Remedial Investigation/Feasibility Study
RREL	Risk Reduction Engineering Laboratory
SARA	Superfund Amendments and Reauthorization Act of 1986
SEM	Scanning Electron Microscope
SITE	Super-fund Innovative Technology Evaluation Program
SPCC	Spill Prevention, Control, and Countermeasure Plan
TCLP	Toxicity Characteristic Leaching Procedure
TOC	total organic carbon
TSCA	Toxic Substances Control Act of 1976
UCS	unconfined compressive strength

Abbreviations and Symbols (Continued)

µ	micron(s)
µ/l	micrograms per liter
VOC	volatile organic compound
WES	Waterways Experiment Station (Army Corps of Engineers)

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Acknowledgments

This report was prepared under the direction and coordination of Paul R. dePercin, EPA SITE Program Manager in the Risk Reduction Engineering Laboratory, Cincinnati, Ohio. Contributors and reviewer for this report were Dick Valentinetti, John Kingscott and Linda Galer of USEPA, Washington, D.C.; Stephen James, Robert Olexsey, Ronald D. Hill, and Lisa Moore of USEPA, RREL, Cincinnati, Ohio; and Timothy Smith of HAZCON Inc., Katy, Texas.

This report was prepared for EPA's Superfund Innovative Technology Evaluation (SITE) Program by Stephen Sawyer of Foster Wheeler Enviresponse, Inc. for the U.S. Environmental Protection Agency under Contract No. 68-03-3255.

Section 1
Executive Summary

Introduction

The HAZCON solidification process was tested and evaluated under the Superfund Innovative Technology Evaluation (SITE) Program. The process involves the mixing of hazardous waste material and cement with a patented nontoxic chemical called Chloranan. Chloranan is claimed to neutralize the inhibiting effects that organic contaminants normally have on the hydration of cement-based materials. HAZCON claims that the wastes are immobilized and bound by encapsulation into a hardened leach-resistant concrete-like mass by this process. Therefore, the major objectives of the SITE project were to evaluate the HAZCON solidification technology in the following areas:

- Effectiveness for treating and solidifying contaminated soils varying from 1% to 25% by wt oil and grease during the Demonstration Test and other types of waste high in organics.
- Ability to immobilize the site contaminants, which included volatile organics (VOW, base neutral/acid extractables (BNAs), oil and grease, polychlorinated biphenyls (PCBs), and heavy metals.
- Probable long-term stability and integrity of the solidified soil.
- Performance and reliability of the process system.
- Costs for commercial-scale applications.

Conclusions

The conclusions drawn from reviewing the data on the HAZCON process, both from the SITE Demonstration, where the most extensive results were obtained, and the literature, in relation to SITE Program objectives, are:

- The process can solidify contaminated material high in organics. Soils at the Douglassville Superfund site with up to 25% organics were solidified. Other applications showed successful solidification of petroleum refinery waste streams, and other wastes high in organics.
- Heavy metals were immobilized with leachate reductions in excess of a factor of 100 in many instances.
- Organic contaminants, VOC and BNA, were not immobilized for the most part. Instances where immobilization of organics occurred were observed in some studies outside the SITE Program. In the SITE Program the Toxicity Characteristic Leaching Procedure (TCLP) produced equivalent leachate concentrations for the treated and untreated wastes.
- The physical properties of the treated wastes were in general quite satisfactory. High unconfined compressive strength (UCS), low permeabilities, and satisfactory results of weathering tests were obtained. However, large volume increases in treated soils were found. The microstructural analyses of the solidified soil materials indicate a potential for long-term durability problems, although a prediction on solidified mass durability is not possible.
- Efficient operating capabilities of the equipment are attainable, even though numerous operating difficulties were encountered by HAZCON during the SITE Demonstration. It is likely that design changes in the raw material feed system and in the blender, the two areas where shortcomings were observed, can improve operations.
- The HAZCON system is economical. Costs will approach $100/ton of contaminated soil when using larger units and reduced additive consumption within the defined parameters (see Section 4).

Applications for immobilization of heavy metals in wastes containing high organics, even at organic levels higher than those of the SITE project, are likely. Immobilization of organic contaminants in most applications is unlikely; some select applications may exist, and for each a treatability study should be performed. Where solidification of high organic content wastes is the primary concern satisfactory physical properties are expected.

Several moisture-related limitations must be considered in application of the HAZCON technology. For wastes with low moisture contents, such as soils, the large volume increases may require the capability to relocate the treated material so as not to adversely affect site contours and access. For areas where the solidified blocks become water-saturated, weathering cycles, particularly freeze/thaw, may become detrimental to the highly porous treated blocks; they could fracture due to freezing of absorbed water.

In summary, the HAZCON technology has applications for the immobilization of heavy metals in soils and sludges where organics levels are high. In addition, the remediation site should 1) contain organic toxins that are either sufficiently immobile or proven by a treatability study to be immobilized and 2) be such that physical soil solidification is desirable.

Results

Physical Tests

The most extensive physical testing on the HAZCON process was performed as part of the SITE Demonstration, although additional data was obtained by Environment Canada [1], by Waterways Experiment Station (WES) [2], and at tests at the Sand Springs, OK Superfund site [3]. The key physical tests, which are used in evaluating potential treated soil durability, are unconfined compressive strength (UCS), weathering (wet/dry and freeze/thaw), permeability, and bulk density.

The UCS values for HAZCON-treated soil ranged from 220 psi for the Filter Storage Cake Area (FSA) samples during the SITE Demonstration to 2,959 psi in the Environment Canada study on a metal finishing sludge. These are very satisfactory when compared to the EPA guideline of 50 psi [4] for stabilization/solidification systems and other concrete-based waste treatment systems, with results typically in the range of 15 to 150 psi [5].

The results from the 12-cycle wet/dry and freeze/thaw weathering tests showed low absolute weight losses, less than 1.0% by wt in all cases. When compared to control samples, the weight losses were less than 0.3%, which is considered very low. UCS tests after the weathering tests on the SITE Demonstration samples showed no loss of strength. These weathering tests are more severe than weathering under an actual field environment, but due to the limited number of cycles involved, they provide indications of only short-term durability. Quantification of solidified mass integrity in terms of life expectancy is not possible. Permeability is a measure of a solid's ability to permit the passage of water. The treated soil values obtained for the SITE Demonstration and from Environment Canada were very low, about 10^{-8} cm/sec; while at Sand Springs the value was 10^{-6} cm/sec. This relates very satisfactorily to the target value of 10^{-7} cm/sec or less used for designing soil barrier liners for hazardous waste landfill sites. Low permeabilities should reduce both erosion and leaching potentials.

Bulk density results were obtained for the SITE Demonstration and Environment Canada work, where detailed information was available on the wastes and on the material balances. The bulk density changes upon solidification were relatively small, producing large volume increases, averaging 120% during the Demonstration Test. Therefore, for relatively dry wastes, particularly in difficult applications where large quantities of cement and Chloranan may be used, volume increases of 100% or more may occur. HAZCON can reduce the volume increases by optimizing the quantity of additives, but this may alter the physical and chemical properties of the treated soil.

The microstructual analyses performed on SITE Demonstration samples included optical and scanning electron microscopy and x-ray diffraction analysis of the crystalline structures. These results showed a porous and incompletely hydrated matrix with undispersed brownish aggregates. These shortcomings may be due in part to insufficient mixing, which could be corrected with a more vigorous mixer. Therefore, a long-term potential for treated soil degradation exists, although a time frame for degradation cannot be predicted.

Solidification occurred for all wastes reported in the various references on the HAZCON technology, even those high in organics and moisture.

Chemical Tests

Chemical analyses were performed on untreated and treated waste, along with corresponding TCLP leachate analyses. Although extensive leachate analyses exist on treated soil, only limited data is available on the original untreated wastes, and a primary goal of this evaluation is to compare contaminant mobility of treated waste versus raw waste.

The HAZCON process is effective in immobilizing heavy metals, and it is expected that applicable regulations will be met. A reduction factor of over 100 for lead, the predominant metal at the site, as well as for zinc, was seen during the SITE Demonstration. TCLP leachate levels for treated soil were about 100 µg/l. The WES results for treated Basin F liquid at Rocky Mountain Arsenal (untreated copper content, 5,680 mg/l) using the Extraction Procedure Toxicity (EP Tox) leach test showed a value of 410 µg/l in the leachate.

A significant amount of data is available from eight sources, in varying degrees of detail, on the immobilization of organics. In most cases, the results show the extracts from the TCLP leaching tests of untreated soil to be equal to those of treated soil. However, some TCLP data, particularly that prepared for the American Petroleum Institute (API) [5] on petroleum refinery wastes, showed sharp reductions in leachate concentration after waste treatment. This indicates that there may be select applications where immobilization of organics occurs.

TCLP analyses during the Demonstration were performed for VOCs and BNAs. The results for total VOC of untreated and treated soils were below 1.0 mg/l for soil concentrations up to 150 ppm by wt. For BNA, the untreated and treated leachate values for the most contaminated location, FSA, were both about 3.0 mg/l, comprising almost exclusively phenols. The other BNAs, phthalates and naphthalene, were found to leach only slightly (<100 µg/l) from both untreated and treated soils. The results of leach tests MCC-1P and ANS 16.1, where the core sample is left intact (not crushed like TCLP), provided leachate values of the same order of magnitude as the TCLP results, with ANS 16.1 less than MCC-1P.

The results reported by WES [2] indicate that 86.7% of the organics were leached after five cycles of a sequential leach test where the treated material is crushed (similar to the TCLP test). The conclusion of this report was that the HAZCON process did not effectively stabilize the total organic carbon in Basin F liquid. Other reports, by Environment Canada and HAZCON confidential report B [6], showed similar results.

However, the API report [5] on treating refinery wastes showed TCLP leachate reductions for treated waste up to 99%. Also the tests performed at Sand Springs, OK showed TCLP leachate concentration reductions, although all values were very close to detection limits.

Economics

The economic analyses was based upon the HAZCON 10 cu yd/hr mobile field blending unit (MFU) utilized at Douglassville under the SITE Demonstration Test conditions. Then a range of potential operating costs was determined assuming system improvements of a larger unit and lower chemical consumptions, reasonable assumptions for future units. The analyses, based upon remediating part of the Douglassville, PA Superfund site, considered two on-stream factors (70% and 90%), two chemical additive rates (the SITE Demonstration level and two-thirds of that), and operating capacities of 300 and 2,300 lb/min. The cost to process the feedstock, with all the site-specific assumptions defined in Section 4 of this report, ranged from $97 to $206/ton of soil. The lower value is based upon reduced additive consumption and a new and larger processing unit than the one utilized for the SITE Demonstration.

The process is very intensive in labor and chemical additives, with these items amounting to about 85% to 90% of the total reported costs.

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Section 2
Introduction

The SITE Program

In 1986, the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established the Superfund Innovative Technology Evaluation (SITE) Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its third year, SITE is helping to provide the treatment technologies necessary to implement new federal and state cleanup standards aimed at permanent remedies, rather than quick fixes. The SITE Program is composed of three major elements: the Demonstration Program, the Emerging Technologies Program, and the Measurement and Monitoring Technologies Program.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data on selected technologies. To date, the demonstration projects have not involved funding for technology developers. EPA and developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing, and evaluating all test results. The result is an assessment of the technology's performance, reliability, and cost. This information will be used in conjunction with other data to select the most appropriate technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. EPA also will accept proposals at any time when a developer has a treatment project scheduled with Super-fund waste. To qualify for the program, a new technology must be at the pilot or full scale and offer some advantage over existing technologies. Mobile technologies are of particular interest to EPA.

Once EPA has accepted a proposal, EPA and the developer work with the EPA regional offices and state agencies to identify a site containing wastes suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to thoroughly evaluate the technology and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several months, depending on the length of time and quantity of waste needed to assess the technology. After the completion of a technology demonstration, EPA prepares two reports, which are explained in more detail below. Ultimately, the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

The second principal element of the SITE Program is the Emerging Technologies Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies could lead to the development of a system ready for field demonstration. The third component of the SITE Program, the Measurement and Monitoring Technologies program, provides assistance in the development and demonstration of innovative technologies to better characterize Super-fund sites.

SITE Program Reports

The analysis of technologies participating in the Demonstration Program is contained in two documents, the Technology Evaluation Report and the Applications Analysis Report. The Technology Evaluation Report contains a comprehensive description of the demonstration sponsored by the SITE program and its results. This report gives a detailed description of the technology, the site and waste used for the demonstration, sampling and analysis during the test, and the data generated.

The purpose of the Applications Analysis Report is to estimate the Superfund applications and costs of a technology based on all available data. This report compiles and summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations of the technology.

Costs of the technology for different applications are estimated based on available data on pilot- and full-scale applications. The report discusses the factors, such as site and waste characteristics, that have a major impact on costs and performance.

The amount of available data for the evaluation of an innovative technology varies widely. Data may be limited to laboratory tests on synthetic wastes, or may include performance data on actual wastes treated at the pilot or full scale. In addition, there are limits to conclusions regarding Superfund applications that can be drawn from a single field demonstration. A successful field demonstration does not necessarily assure that a technology will be widely applicable or fully developed to the commercial scale. The Applications Analysis attempts to synthesize whatever information is available and draw reasonable conclusions. This document will be very useful to those considering the technology for Super-fund cleanups and represents a critical step in the development and commercialization of the treatment technology.

Key Contacts

For more information on the demonstration of the HAZCON technology, please contact:

1. Regional contact concerning the Douglassville, PA site:

Mr. Victor Janosik
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2. EPA project manager concerning the SITE demonstration:

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3. Vendor concerning the process:

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Section 3
Technology Applications Analysis

Introduction

This section of the report addresses the applicability of the HAZCON process to varying potential feedstocks based upon the results obtained from the SITE Demonstration and other HAZCON applications test data. Since the results of the Demonstration provide the most extensive data base, conclusions on the technology's effectiveness and its applicability to other potential cleanups will be strongly influenced by those results, which are presented in detail in the Technology Evaluation Report. Additional information on the HAZCON technology, including a process description, vendor claims, a summary of the Demonstration Results, and reports on outside sources of data using the HAZCON technology are provided in Appendices A-D.

Following are the overall conclusions being drawn on the HAZCON technology. The Technology Evaluation subsection discusses the available data from the Demonstration, HAZCON, and the literature, and provides more details on the conclusions and applicability of the HAZCON process.

Conclusions

The conclusions drawn from reviewing the data on the HAZCON process are:

- The process can solidify contaminated material high in organics. Soils at the Douglassville Super-fund site with up to 25% organics were solidified. Other applications showed successful solidification of petroleum refinery waste streams, organics, water high in organics from a waste storage pond, metal finishing sludge, and other less clearly defined wastes.

- Immobilization of heavy metals was observed, with leachate improvements for lead and zinc in excess of a factor of 100.

- Organic contaminants, VOCs and BNAs, were not immobilized for the most part. The extensive testing for the Demonstration and other test programs showed no immobilization of the organics. However, there were two instances where immobilization of organics occurred.

- The physical properties of the treated wastes are in general quite satisfactory. High UCS, low permeabilities, and satisfactory results of weathering tests were obtained. However, large volume increases in treated soils can be expected, and the microstructural analyses of the solidified soil materials indicates a potential for long-term durability problems.

Application for immobilization of heavy metals (up to 2.3% by wt) in wastes containing high organics, up to at least 25% by wt in soils, has been shown. Successful immobilization of higher quantities of heavy metals at even higher oil and grease levels would be anticipated. Immobilization of VOCs and BNAs did not occur in the SITE Demonstration test on soils up to 25% by wt oil and grease,and immobilization of other organics, as reported by other investigators, was also unsuccessful. However, immobilization of some petroleum refinery wastes was successful.

Therefore, applications for immobilizing organic contaminants, compared to a simple solidification process with only cementitious materials, may have to be tested on a site-by-site basis to prove applicability of the HAZCON process. For high organics content wastes, solidification may be very difficult; the use of Chloranan will enhance solidification of organics.

Two limitations in the application of the HAZCON process need to be considered. For the treatment of soils or other relatively low-moisture wastes, the large volume increases may limit application to spacious areas where the excess volume of material can be located without adversely affecting site contours and accessibility. In addition, in very wet areas, especially below the water table, where the solidified material would become saturated, weathering cycles could lead to fractures in the highly porous solidified mass of treated soil.

Technology Evaluation

The two criteria defined in the SITE Program Demonstration Plan [7] to evaluate the HAZCON technology are:

- Mobility of the contaminants as determined from leaching and permeability tests, and
- Integrity of the solidified soil as determined from various physical tests such as UCS, weathering (wet/dry and freeze/thaw), and microstructural analyses (microscopy and x-ray diffraction).

The following discussions utilize the available HAZCON information to provide more detailed conclusions on the process, particularly as related to the various physical and chemical properties of treated material. The reader should note that the results differ from the claims expressed by HAZCON in Appendix B in some instances.

Physical Test Results

The most extensive physical testing on the HAZCON process was performed in the SITE Project and reported in detail in the SITE Technology Evaluation Report [8]. Additional data, as defined in Appendix D, was provided by Environment Canada [1], by Waterways Experiment Station (WES) on the laboratory investigation they performed on Basin F fluid wastes at Rocky Mountain Arsenal [2], and for tests at the Sand Springs Superfund site [3] near Tulsa, Oklahoma. This limited quantity of data, both physical and chemical, is not unexpected, since the purpose of the SITE Program is to evaluate new innovative processes.

Unconfined compressive strength is a primary indicator of the durability of solidified wastes. The results of the studies show very satisfactory strengths for the solidified wastes relative to EPA's guideline of 50 psi [4] for stabilization/solidification systems. The Demonstration Test results for 28-day samples ranged from 219 psi at FSA to 1,574 at PFA. An inverse relation exists between strength and oil and grease content, although samples with the lowest oil and grease content, at DSA, did not give the highest UCS. If the inverse relationship of UCS to oil and grease continues at higher concentration levels, then high organic content wastes (>25% by wt) may produce solids approaching the 50 psi guideline.

The values obtained at Sand Springs averaged 530 psi for an undefined formulation. For the Environment Canada laboratory study, with the same ratio of waste to cement to Chloranan as at the SITE project, the UCS was 2,959 psi. The value reported in the WES study was 2,902 psi. The latter three studies did not involve contaminated soils, and all involved higher water content waste than the SITE test material.

SITE Demonstration UCS values at 7 and 28 days were essentially equal. For the formulation tests on samples prepared in the laboratory without Chloranan, the UCS increased about 40% between the 7- and 28-day samples, which is an expected increase for Type I cement. A possible explanation is that Chloranan accelerated the cement setting reactions. The laboratory formulations for FSA showed UCS values below 40 psi; thus, the Chloranan addition in the field tests, as seen above, had a very positive effect on UCS. No apparent effect on strength was seen for soil from LAN. This suggests that the Chloranan's contribution to UCS starts to occur above 16.5% by wt oil and grease and below 25% by wt oil and grease in the untreated soil.

These are all very satisfactory results, especially compared to the EPA guideline of 50 psi for stabilization/solidification systems. High UCS values imply the potential for maintaining structural integrity for many years. Other cement-based waste treatment systems are typically in the range of 15 psi to 150 psi [5], although the comparison may not be fair since the weight ratio of waste to cement varies widely in these processes.

Weathering effects can break down the internal structure of the solidified soil producing potential paths for water flow, which would increase permeability and the potential for contaminant leaching. Twelve-cycle wet/dry and freeze/thaw tests performed during the SITE Demonstration produced good results, in which the weight loss of the test specimens was only slightly greater than their corresponding controls (0.98% vs. 0.84% for the wet/dry and 1.10% vs. 0.80% for the freeze/thaw). Four-cycle wet/dry tests at Sand Springs [3] showed losses of about 0.10%, which is very low. In addition, a 12-cycle freeze/thaw test performed as part of the Environment Canada study showed the test specimen weight loss to be less than that of the control. These tests, which are more severe than conditions in the field, provide an indication of short-term treated soil integrity under natural weathering stresses. The tests are recommended as a means of comparing weathering performance of different processes, but cannot be used to predict long-term durability.

Freeze/thaw weathering is of concern because of the recognized potential for frost damage of concrete structures. The test uses a greater rate of cooling than the maximum of about 5°F per hour that is expected in nature. In addition, the tests are carried out on specimens that are nearly water saturated, where the water can rapidly freeze and cause fracturing of the solidified waste. Relatively dry concrete, below 80% of saturation level, is less likely to fracture than a saturated material.

Unconfined compressive strength tests were performed on both the test specimen and control samples after the 12 weathering cycles during the SITE Demonstration, These UCS results were comparable to the unweathered values. Thus, it can be concluded from the weight loss and UCS values that the HAZCON treated soil maintained its integrity through an initial set of weathering cycles. A scheduled long-term monitoring program exists during which the treated soil blocks will be sampled annually. This will provide additional information on durability of the solidified mass.

Permeability indicates the degree to which the material permits or prohibits the passage of water and is thus one measure of the potential for contaminants to be released to the environment. It is dependent on the solidified material's density, degree of saturation, particle size distribution [5]; as well as pore size, void ratio, interconnecting channels, and the liquid pressure. Results for permeabilities of solidified wastes are reported in the Technology Evaluation Report [8], by Environment Canada [5], and from the Sand Springs [3] tests. The first two sources indicated permeabilities in the range of 10^{-8} to 10^{-9} cm/sec, while the latter test value was 10^{-6} cm/sec. These permeabilities are a major improvement compared to untreated soils, for which values for the Demonstration Test were about 10^{-2} cm/sec. Cement systems usually can attain permeabilities of 10^{-5} to 10^{-6} cm/sec [4], and soil barrier liners for landfills are considered satisfactory by EPA and the hazardous waste disposal industry if the permeability is 10^{-7} cm/sec or less.

The permeabilities performed during the SITE project laboratory formulation work showed that the solidified sample values for LAN may have been greater and those for FSA were about the same as the field samples. Therefore, Chloranan may have a beneficial effect on permeability, but insufficient data exists to confirm it. The permeability values measured in each study were quite low, conforming well with HAZCON's claims, and should prove satisfactory for any site remediation.

Bulk densities on the treated soils were measured during the Demonstration, by Environment Canada on a metal finishing waste containing 50% moisture, and on an oily sludge material high in moisture content provided to HAZCON.

The bulk density increase of the raw residue from the Environment Canada study after treatment was 23.5% (from 1.49 g/ml to 1.84 g/ml) for a weight increase from the addition of water, cement, and Chloranan of 126%. Therefore, the calculated volume increase of the treated residue, compared to the untreated wet residue, was 83%. This compares to an average volume increase for the relatively dry soils tested during the Demonstration of 120%. For an oily sludge, the volume upon solidification decreased, but information on quantities of additives used, composition of the waste, UCS, or other physical properties of this solidified material is not available. These results deviate from the claim of HAZCON that the volume change upon remediation is very small.

HAZCON claims that with optimization of the quantities of cement and Chloranan used (reductions from SITE project quantities of 33% to 66%), the volume increase could be reduced. However, other physical and chemical properties of the treated soil may change with these reductions. It is projected that the minimum volume increase on the Douglassville soils would be 40% to 50% and less for the waste treated by Environment Canada. It has been verbally indicated by HAZCON that wastes high in moisture will have a smaller volume increase. It appears from the Demonstration Test laboratory formulation data that the addition of Chloranan resulted in a small increase in the bulk density of the treated soil. However, more data is required to confirm this observation.

In conclusion, it appears that for relatively dry waste materials, bulk density changes are small and the resultant volume increases are large. This could be a very important remediation design consideration at many sites

Optical microscopy, scanning electron microscopy, and x-ray diffraction analyses were performed on untreated and treated soil samples during the SITE Demonstration. These methods are commonly used techniques for understanding the mechanisms of structural degradation of soil, cement, and soil-cement mixtures both with and without addition of inorganic and organic compounds. Although relatively few studies of the microstructure of complex waste/soil mixtures like those resulting from stabilization/solidification procedures have been reported, useful information can be obtained on the potential durability of the solidified mass. These observations complement the weathering test results, which are short-term measures of solidified mass integrity; and UCS which is an indirect indication of durability.

Microstructural studies from the Demonstration can provide information on the potential for structural change over the long-term, although quantitative predictions on durability are not possible. Results described in this report suggest that the HAZCON-solidified material may have a gerater potential for long-term degradation than ordinary Portland cement concrete. The HAZCON-solidified blocks were found to be porous and incompletely hydrated, and brownish aggregates in the soil passed through the process unaltered. These observations are indicative that mixing in the HAZCON MFU was not highly efficient. It also was concluded that encapsulation was the principal mechanism of solidification/stabilization. This was supported by the observation of brownish aggregates that passed through the soil even after treatment unchanged. Peaks in the x-ray diffraction patterns common to both the soil and cores could not be identified with any expected soil or cement minerals and are likely to be associated with the (possibly unaltered) waste.

Pore concentrations and their distribution can affect both permeability and leaching; connected pores provide pathways for water migration. Studies have shown that although pores of freshly prepared waste forms are normally not saturated, upon contact with water the matrices tend to absorb water and reach saturation [9]. Cement-based systems with high porosity, therefore, may lose integrity as a result of fracturing caused by freeze/thaw or wet/dry conditions.

Chemical Test Results

The most extensive chemical analyses, measuring both the waste feed and leachate compositions, were performed as part of the SITE project. Considerable data is also available on the HAZCON technology from many other sources, which includes those referred to at the beginning of the physical test section and in the IWC report [10], in two independent confidential studies [6,11], and in a report by Risk Science International for the American Petroleum Institute (API) [12]. These results are not consistent with one another, and in many cases, information on waste properties, additive mix quantities, and physical properties of the treated waste are not reported. It is important to know the quantity of the contaminants in the untreated and treated wastes when performing a leach test, and this information is available in only a few of the test programs. Leaching tests indicate the chemical stability of the solidified mass, its tendency [13] to leaching by water, and the mobility of contaminants contained in the solidified waste when they are in contact with aqueous solutions.

The HAZCON process is very effective in immobilizing heavy metals. Reductions in leachate concentrations by a factor in excess of 100 were observed for many of the samples collected during the Demonstration. At FSA, the untreated soil's oil and grease level was 25% by wt with a lead content of 22,600 mg/kg. The leachate of the untreated soil contained 17.9 mg/l of lead, with the 28-day core samples less than 400 µg/l and the 7-day samples, 70 µg/l. Larger leachate concentration changes were noted at other Douglassville plant areas. The WES analyses at Rocky Mountain Arsenal show a low value (0.41 mg/l) of copper in the treated waste TCLP leachate for a Basin F liquid containing 5,680 mg/l copper. HAZCON confidential report "A" [11] (undefined waste and treatment process) for TCLP leachates of a treated waste after 28 days of curing shows values for chromium, cadmium, and nickel of less than 50 µg/l and for arsenic of less than 1.0 mg/l. These values, with the possible exception of arsenic, would probably meet most regulatory requirements. For the WES work and HAZCON confidential studies, concentrations in untreated waste extracts were not performed, so the degree of immobilization cannot be defined.

A significant amount of data is available on the HAZCON technology's ability to immobilize organics, VOCs, and BNAs. This data shows immobilization of organics in a few instances but not in most. In many cases only posttreatment TCLP leachate analyses are available. The most extensive data was accumulated for the Demonstration Test, with soil analyses before and after solidification matched to leachate concentrations. Three different leach tests were performed: TCLP, ANS 16.1, and MCC-1P. In the TCLP test, the solidified samples are crushed, while for the other two the solid is maintained intact. Since many test parameters differ between leach test procedures, and experience with MCC-1P and ANS 16.1 is limited for hazardous wastes, the significance of any differences between leach test results is unclear, but indications of leachability can be discerned.

The results of the TCLP tests performed during the Demonstration Test showed that the VOCs and BNAs were not immobilized. Calculations of migration potential, which is weight of a specified analyte in the leachate divided by its weight in the soil, were approximately equal for treated and untreated soils. The total VOC values were moderately low, less than 1.0 mg/l, for soil concentrations up to 150 ppm by wt in the untreated soil. Leachate analyses for the BNA for both treated and untreated soils showed very low values for phthalates and naphthalene, less than 100 µg/l, but

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high values for phenols. At FSA, where the phenols content was 405 mg/kg, the leachate concentration ranged from 2.8 to 3.8 mg/l for both treated and untreated soils.

Posttreatment leaching results of a 7-day test performed by Environment Canada [1] with a 4:1 weight ratio of leachate to crushed solid showed very low leaching of benzene and trichloroethylene, and very high leaching of phenol. Approximately 80% of the phenol contaminant was extracted, with other organic components between the two extremes. Pretreatment values were not performed for a comparison.

The results for Basin F liquid at Rocky Mountain Arsenal, as reported by WES [2], indicated that a high percentage of the total organics, 86.7%, was extracted after 5 cycles of a sequential leaching test, with 67% extracted after the first cycle. Caution is advised by the authors regarding extrapolating this data to the field, because the test sample leached is crushed and so its surface-to-mass ratio may be different.

Leach tests using EP Tox were also performed, with the results equivalent to other technologies investigated by WES on Basin F liquid. The conclusion of the WES report was that the HAZCON process did not effectively stabilize the total organic carbon in Basin F liquid.

A brief excerpt of confidential HAZCON report "B" [6] on TCLP leach tests for pentachlorophenol (PCP) showed nine points of data: HAZCON in a subsequent letter indicates this was part of an optimization study. The raw sample TCLP extract concentration was 2.1 mg/l PCP, while the nine treated samples ranged from 1.1 to 27 mg/l. Information on quantities of cement and Chloranan were not provided. For eight of the analyses, immobilization did not occur, but for the ninth, where the leachate concentration was 1.1 mg/l, some immobilization may have occurred, but it cannot be confirmed because pretreatment and posttreatment waste compositions are not available and the amount of additives used is undefined.

In a report by Risk Science International for the American Petroleum Institute [12], the HAZCON process was one of many remediation technologies evaluated on petroleum refinery wastes, including API separator sludge, slop oil emulsion solids, and two different filter cakes. The emphasis of the report was to compare different types of processes, mechanical, solvent extraction, thermal, and stabilization/ solidification. However, for each type, a number of technologies were treated. For stabilization/solidification, Process #1 is the HAZCON solidification technology. TCLP leachate results for HAZCON-treated and untreated wastes were presented; the API separator sludge showed a reduction of approximately 99% for VOCs, BNAs, organic acids, and metals. For the slop oil and the filter cakes, the primary contaminants were VOCs, and equivalent reductions were observed. However, for these three wastes the leachate quantities of total BNAs, organic acids, and metals are low and scattered, so the technology's ability to immobilize them cannot be confirmed. The ratio of waste to cement to Chloranan was 2:1:0.05. These results are good, particularly for the VOCs, but are not consistent with the other results noted above. Although not described in any detail, a proper quality assurance program appears to have existed for the analyses.

In an IWC study [10], the HAZCON process was one of three solidification technologies evaluated on organic sludges high in moisture. The HAZCON process proved to be the best and was judged satisfactory by the authors to meet regulatory requirements. One apparently positive set of results on the most difficult waste, which contained a total of 9% to 10% toluene, trichloroethylene, and benzene, showed that the TCLP leachate for treated material contained 23.4 mg/l of these components. Leach tests on untreated waste were not performed, so proof of the technology's effectiveness cannot be confirmed from these results.

TCLP leachate results were obtained on raw sludge from the Sand Springs, OK Superfund site, containing about 10% by wt oil and grease; the HAZCON-treated material contained some VOC and BNA. The treated waste leachates showed no detectable levels of these organics. The untreated waste extract values for the individual VOC components ranged from nondetected to 50 **µg/l.** Thus, some immobilization of organics may have occurred. All the values reported are very low, and analyses of the corresponding site waste were not reported, although various Sand Springs site wastes contained 10 to 100 mg/kg of these organic contaminants.

Thus, it can be concluded that immobilization of volatile and semivolatile organics does not usually occur. This was observed in most of the tests reported, with the Demonstration Test providing the most complete data set available. Demonstration Test results of the special leach tests, which attempt to simulate the leaching of a solidified mass, were the same order of magnitude as the TCLP leachate concentrations. This would appear to show that the TCLP results are indicative for this technology of leaching from a solidified mass. However, as some positive results on organic contaminant immobilization have been reported, some site. speci& tests may need to be performed.

Operations

Since most of the data on the HAZCON process is based upon laboratory tests, operational data is only available from the Demonstration. These results are described in Appendix C. It was noted that although HAZCON encountered many difficulties at Douglassville, particularly for the 5-cu-yd runs, design changes in the feed and mixing systems will produce a reliable operating system.

Summary

Solidification/stabilization technologies generally reduce contaminant mobility, particularly for toxic metals, and increase volume. These techniques nearly always leave some uncertainty about long-term effectiveness, because laboratory tests can neither fully duplicate field conditions over long periods of time nor establish what actually happens to the contaminants during treatment [14,15]. This is true for the HAZCON technology also.

In conclusion the overall physical properties of wastes treated by the HAZCON process are good, although the potential for some remediation design engineering and durability difficulties exists. The innovative aspect of the HAZCON technology is the use of Chloranan in conjunction with solidification by Portland cement or other pozzolans. Chloranan appears to 1) mitigate some of the detrimental effects of organics on the rate of cement hydration reactions, 2) allow solidification of waste high in organics, and 3) improve some physical properties of the treated material. Chloranan may also alter and improve the ability of Portland cement to immobilize heavy metals. However, it does not appear to enhance the immobilization of organics, except possibly in select applications. Thus, the technology appears to have applications for the immobilization of heavy metals in soils and sludges, where oil and grease levels are high; and at sites where specific organic toxins are sufficiently immobile and where physical soil stabilization is deemed necessary. For other applications, at sites containing organic contaminants, treatability studies should be performed.

Environmental Regulations and the HAZCON Results

This section briefly discusses regulations pertaining to hazardous waste cleanups. The discussion particularly focuses on the Land Disposal Restriction (LDR) standards and the use of stabilization/solidification for Superfund actions.

The Resource Conservation and Recovery Act (RCRA)

The Resource Conservation and Recovery Act (RCRA) was passed in 1976 and expanded under the Hazardous and Solid Waste Amendments (HSWA) of 1984. Section 3004 of HSWA prohibits land disposal of untreated hazardous wastes after specified dates and requires EPA to develop treatment standards, which must be met before disposal is allowed.

After these standards, or Land Disposal Restrictions (LDRs), become effective, wastes that are not treated to meet those standards will be banned from land disposal.

The key portion of this section of the 1984 HSWA is the mandate for treatment standards for every waste or group of similar wastes. All industrial hazardous wastes were ranked according to their intrinsic hazard and their volume. Based upon that ranking, the list was divided into thirds, and a schedule was prepared for establishing treatment standards. Wastes that are considered hazardous based upon their characteristics were scheduled for the final third. The hazardous characteristics defining wastes include ignitability , corrosivity, and reactivity, and wastes that are hazardous based on extraction procedure toxicity (EP Tox-leach test). Land disposal of untreated wastes was prohibited on August 8, 1988 for the "First Third"; planned for June 8, 1989 for the "Second Third"; and May 8, 1990 for the "Third Third" of the scheduled wastes.

Treatment standards are based on the performance of the Best Demonstrated Available Technology (BDAT) to treat the waste. A technology is considered to be demonstrated for a particular waste if the technology is in full-scale commercial operation for treatment of that waste. Treatment standards can be established either as a specific technology or as a performance standard based on a BDAT technology. When treatment standards are fixed at a performance level, the regulated community may use any technology not otherwise prohibited to treat the waste so that it meets the treatment standard.

On August 17, 1988, EPA promulgated treatment standards for the First Third of the restricted hazardous wastes. For three of these nonwastewater inorganic wastes, F006, K046, and K022, the BDAT performance standard is based on stabilization/solidification technology; the standard for four other wastes is also based on stabilization/solidification as the BDAT for nonwastewater residuals (K001 and K086) or ash residue (K101 and K102) following the initial treatment.

On January 11, 1989, EPA proposed additional treatment standards for the "Second Third" of the restricted hazardous wastes. EPA also proposed additional treatment standards for some "First Third" wastes and for "Third Third" wastes. Of these, BDAT performance standards for F012, F006, and F019 were based on stabilization/solidification.

In each case research to develop the performance standard indicated that full-scale stabilization/solidification is widely used throughout the country to bind these metal waste constituents into a cementitious matrix that immobilizes them, thereby reducing their leaching potential.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for federal funding to respond to releases of hazardous substances to air, water, and land. CERCLA authorized EPA to prepare the National Contingency Plan (NCP) for hazardous substance response. The NCP defines methods and criteria for determining the appropriate extent of removal, remedy, and other measures. Specific techniques mentioned in the NCP for remedial action at hazardous waste sites include stabilization /solidification as a cost-effective technology for handling contaminated soil and sediment.

Section 121 of SARA, entitled Cleanup Standards, strongly recommends remedial actions using on-site treatment that"...permanently and significantly reduces the volume, toxicity,or mobility of hazardous substances." The actions must assure protection of human health and the environment, must be in accordance with the NCP, and must be cost-effective. This means that when selecting an appropriate remedial action, the first step is to determine the level of cleanup that is necessary to protect the environment, and the second step is to choose the most cost-efficient means of achieving that goal. SARA further states that "off-site transport and disposal... without such treatment should be the least favored alternative remedial action where practical treatment technologies are available."

SARA also added a new criterion to CERCLA to be used in determining cleanup priority: the contamination or potential contamination of the ambient air that is associated with a release. Since stabilization/solidification often involves the treatment of organic constituents, this criterion is of primary concern in that the method of stabilization/solidification selected must not release VOCs into the ambient air.

Superfund Response Actions

Superfund response actions must meet "applicable or relevant and appropriate requirements" (ARARs) for cleanup. If land disposal restrictions are applied to Superfund actions, they may be "applicable or relevant and appropriate." LDRs are applicable when existing federal or state laws can be utilized to have direct authority over placement of restricted hazardous wastes in or on the land. LDRs may be relevant and appropriate when Superfund hazardous substances are sufficiently similar to restricted industrial hazardous wastes such that use of LDRs is suited to the circumstances of the releases.

In addition to industrial process waste, the HSWA also addresses soil and debris that result from CERCLA response actions and RCRA corrective actions. Effective August 8, 1988, EPA issued a national capacity variance through November 8, 1990 for all CERCLA/RCRA soil and debris, which are contaminated with hazardous wastes whose BDAT standards are based upon incineration.

In the meantime, the EPA intends to develop separate BDAT treatment standards for soil and debris, because the BDAT standards were developed for industrial waste processes, which are often different from the soil or debris waste matrices in terms of chemical/physical composition, concentrations, and media within and among sites.

Until standards are developed for soil and debris, remedies will continue to be selected on a site-specific basis. Since these remedies are not likely to conform to the BDAT standards for industrial process waste, a variance is required.

Under a treatability variance, treatment will be applied with the goal of achieving substantial reduction in toxicity and mobility through treatment to a range of treatment levels. These treatment levels were developed from a data base that EPA has compiled of treatability data for contaminated soil.

The data were divided into treatment for organic and inorganic constituents, and further divided into structural-functional groups based upon treatability for the organics, and for individual metals for the inorganics.

The treatment ranges for soil and debris have been developed as interim guidance until final treatment standards for soil and debris are promulgated. Modifications to the treatment ranges may occur and will be issued as revised guidance as additional treatment information becomes available.

In developing the interim guidance, solidification and stabilization technologies have not been demonstrated to be effective technologies for the

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treatment of organic wastes. Solidification and stabilization data resulting from the treatment of organic wastes were, therefore, not considered. Consequently, the treatment levels are expressed as total composition values for organics and as leachate values for inorganics.

Toxic Substances Control Act (TSCA)

The disposal of PCBs and PCB-contaminated materials, 50 ppm by wt and greater, are regulated under the provisions of the Toxic Substances Control Act of 1976. The regulations, which are found in 40 CFR 761.60, address disposal requirements in relation to the concentration of the PCBs in the waste. PCBs in concentrations of 50 to 500 ppm may be disposed of either by landfilling or incineration. PCBs in concentrations greater than 500 ppm must be disposed of by incineration. A contaminated waste under 500 ppm by wt is a candidate for stabilization/solidification. Unless regulations change, PCBs in concentrations greater than 500 ppm may not be disposed of by stabilization/solidification technology. Also, several states have their own PCB regulations that may impact on the use of stabilization/solidification technology.

Comparison of Regulations to HAZCON Results

Stabilization/solidification has been shown to be an effective technology for treating metals. In addition, the HAZCON process appears to overcome the inhibiting effect from the presence of organics on the solidification process. However, there is uncertainty concerning the potential use of stabilization/solidification for Superfund soils contaminated with organics. The Land Disposal Restriction standards have been developed with the assumption that stabilization/solidification is not a BDAT for organics. Test results from the Douglassville demonstration for the HAZCON technology tend to substantiate this assumption, as long as the TCLP leach test is assumed as the sole criterion for effectiveness.

Superfund legislation requires consideration of alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances. Since remedies are chosen site-specifically based on cost-effectiveness, there may be applications where stabilization/solidification is an acceptable remedy for wastes with some organics. This will be especially true if a measure of performance other than TCLP is chosen.

It is more feasible to evaluate the HAZCON process with respect to regulations and treatment levels for metals-bearing wastes. There are regulations and approved delisting petitions for several waste-coded materials, primarily F006, which is electroplating wastes. For these metals, barium, cadmium, lead, chromium, nickel, and mercury, some treated waste leachate values exist that provide a guideline for leaching results. In addition, the national capacity variance for RCRA and CERCLA soil and debris provides proposed treatment levels for contaminated soils. These treatment concentrations for leachates are in the range of 0.1 to 3.0 ppm when the metals in the waste are below the threshold range, which is essentially the same order of magnitude as the values in the Demonstration for all metals except lead; lead soil concentrations were higher than the threshold value by a factor of 10-70. Thus, only a 95% reduction factor is required.

A comparison of the HAZCON results and the regulatory values are shown in Table 1. Based upon the available data, primarily from the Demonstration, the HAZCON process would readily meet the range of regulatory concentration values that are currently accepted. Even for the high lead values in the Demonstration waste, the treatment range and reduction factors were readily met.

Waste Characteristics and Performance of the Technology

Solidification/stabilization processes involve the addition of agents that are intended to mechanically or chemically bind or encapsulate hazardous constituents to prevent their release into the environment. These processes generally increase the strength and decrease the permeability of the solidified mass. In general, the stronger, more impermeable, and more durable a treated waste, the more effectively it will contain hazardous constituents. If the material does not fragment, create dust, or increase the surface area available for leaching, losses will be minimized. Some processes produce solid pellets, where compressive strength is not a criterion.

The HAZCON process is a cement-based process whose design concept is to solidify and immobilize waste contaminants. The principal difference between this process and other cement-based processes is the use of a proprietary component-Chloranan-which is claimed to permit solidification of waste materials with high organic concentrations. It has long been known that organics may inhibit the cementation process, which may result in less favorable physical characteristics of the solidified product, such as UCS, permeability, and bulk density.

Batch system feeds are preferred by HAZCON, Inc. to continuous feeds, since the developer believes feed variations can be more easily identified with a batch system and steps can be taken to adjust admix ratios to compensate for feed variations. The HAZCON process claims to be able to handle any type of feed. Matrices preferred by HAZCON in order of

Table 1. Comparison of HAZCON Results to Some Regulatory Values for Metals

Metal	Regulatory range, mg/l[d]			HAZCON untreated waste, mg/l[e]	HAZCON treated waste, mg/l[a] (waste concentration, mg/kg)	
	LDRs	Delisting	Interim Guidelines			
Pb	0.25-0.5	0.31-0.5	0.1-3.0	17.9	0.40[b]	(22,400)
Cr	0.32	1.7	0.5-6.0	< 0.008	< 0.007	(95)
Ni	2.2	0.048-0.32	0.5-1.0	0.07	0.025	(17)
Cd	0.066-0.14	0.063	0.2-2.0	0.13	< 0.004	(6)
Cu	-	-	0.1-3.0	-	0.41	(5,680)[c]

(a)Leaching results after 28 + days of curing.
(b)The 7-day core leachate from the Demonstration Test was 0.070 mg/l.
(c)Rocky Mountain Arsenal - Basin F pond water. There are not any regulatory values for copper.
(d)All values based upon using EP Toxicity leaching test.
(e)Results from the Demonstration Test using TCLP.

preference are soils, sludges, emulsions, and lastly liquids, with the preferred contaminants being metals, organics, and lastly volatile organics.

Although the Chloranan admix was selected for use at the Douglassville site and usually not defined in the other tests of the HAZCON technology, other formulations or admixes can be chosen dependent upon the waste contaminants. HAZCON is continuing to develop admixes that are contaminant-specific, but has not provided any information on what these changes are or the factors that influence their selection.

HAZCON usually tests all site materials before operation to determine the proper formulations, admixes, and ratios for optimum results. However, this was not done for the Demonstration, and conservatively high levels of Chloranan and cement were utilized. Cement-based mixtures generally are used, as they have proven to be effective, but the equipment can process other pozzolanic (fly ash, kiln dust, etc.) mixtures as well.

The HAZCON system is claimed to work best with soil feeds; sticky materials are more difficult to treat because of materials handling problems. However, during the Demonstration, the sticky filter cake was processed more easily by the MFU than the other soil feeds. Information from other tests on ease of processing various feedstocks was not reported. The 10 cu yd/hr continuous system used in the SITE Project works best with materials of a consistency ranging from soil-like to light sludges. Liquids cannot be handled because of insufficient equipment component sealing.

Variability of feedstock components can result in product problems. This can be overcome by using larger than optimum ratios of admixes, but at the cost of volume increase or the necessity to frequently sample the feedstock to ensure constancy. Out-of-specification product material may be recycled while still in a slurry state, but after solidification the problems with recycle become much more serious. For further treatment, special equipment such as crushers, screens, etc., are required. In addition, laboratory analyses may have to be obtained promptly to minimize the quantity of recycle.

Cold weather (below 40°F) can affect the hydration reactions and thus the product quality. However, this effect may be overcome by the use of special cements or by preheating the process streams and feedstock to a maximum of 40°F to 50°F, which would avoid volatilization of the light organics. Preheating of any feed materials would increase equipment and operating costs. Since the hydration of cement is exothermic, additional heat is not required once the reactions commence.

Ranges of SITE Characteristics Suitable for the Technology

Currently HAZCON has available two continuous Mobile Field Blending Units (MFU) that can process up to about 10 cu yd/hr of untreated soil. HAZCON indicates that five 100 cu yd /hr batch systems are in the planning stages and are expected to be available in the fall of 1988; they will be managed through five planned regional offices tentatively selected to be opened in Atlanta, Chicago, Houston, Los Angeles, and New Jersey. Prior to the start of operations of the 100 cu yd/hr systems, HAZCON intends to serve as the prime contractor to design site-specific batch remediation system components and to subcontract the use and operation of the equipment. Remediation time constraints, areas of remediation, and costs will determine which system will be selected for remediation of a specific site. Multiple systems operating in parallel will allow handling of large sites. HAZCON has indicated that sites greater than those capable of being handled by the multiple 100-cu-yd arrangement may be handled by subcontracted process equipment. All equipment is selected based on contaminants and costs. HAZCON places no limits on the size of the site that can be remediated. For a site the size of Douglassville-250,000 cu yd to be remediated-assuming a 90% on-stream factor and 24 hours processing per day, one 100 cu yd/hr system could remediate the entire site in approximately 4 months. The 10 cu yd continuous system would take more than 3 years to complete the remediation.

The 10 cu yd/hr system is compact, weighs approximately 17,000 pounds (empty) is mobile, and requires no special over-the-road or operating permits. Thus, it would be accessible to nearly all hazardous waste sites. The system must be nearly level to operate, and the site soil must be able to support the system's weight fully loaded with cement, water, feedstock, and admixes, as well as support auxiliary equipment and storage tanks. Therefore, some site preparation work may be required to level the terrain, pour slabs, and build access roads. The trailer and support equipment require a setup area of about 500 sq ft. Additional area is needed for storage of cement, Chloranan, and fuel, as well as personnel facilities for any long-term project. The moving components-pumps, feeders, etc.-are driven by a hydraulic power pack deriving its power off the diesel engine of the transporting vehicle. The cement is air conveyed from a separate cement truck to the cement hopper on the MFU.

The 100-cu-yd/hr proposed system consists of a feed aggregate bin where the waste feed is weighed, a cement feed bin, and a rotary drum mix tank. The feed and cement are combined and conveyed to the mix tank, where water and admixes are added. Pumpable materials can be metered directly into the mix tank. The system will be mounted on an over-the-road trailer and will weigh approximately 40,000 pounds (empty). Some site work may be required to level an area for the trailer or to pour support slabs. Good traction for the earth-moving equipment is required. The trailer and support equipment provided by HAZCON will occupy approximately a 1,000 sq ft area. Additional area is needed for cement, fuel, and Chloranan storage bins, as well as personnel facilities. The system power source for the HAZCON unit is a 60 KW diesel generator, plus additional power for support systems.

Although the MFU used at Douglassville is not corrosion-resistant, the proposed 100-cu-yd/hr batch system's major components, such as the feed and aggregate bins, belts, and rollers, will be corrosion-resistant stainless steel. The new systems are designed to be operated under negative pressure to reduce emissions. The small MFU is not leak-tight and would experience difficulty in maintaining negative pressure. The MFU is claimed by HAZCON to be explosion-proof, and at least one of the five 100-cu-yd/hr systems will be designed to be explosion-proof.

Auxiliary equipment consists of storage tanks and feed equipment for the fuel, Chloranan, and cement; a personnel trailer for administrative functions; on-site sampling facilities for any laboratory work; parts supplies; health and safety supplies; and an area with equipment for personnel and equipment decontamination.

Typically, the process consists of excavating the waste; transporting it to the solidification unit; and sizing, processing, and removal of the solidified product to a permitted landfill. It may be left on a site if it meets the established site regulations or, for a coded waste, the land ban (RCRA) requirements. The placement of the treated waste back into the original excavations is possible, although this has not yet been satisfactorily demonstrated for most system applications. Disposal on or off site for rejected screened materials must be anticipated. Local bridges and roads must be able to support standard excavating equipment.

Off-site migration of airborne contaminants or vapors can be a problem during excavation, mixing, and transport of the waste to remediation. High water tables can result in groundwater contamination during excavation; high groundwater that results in bearing losses at the site could preclude use of the technology without appropriate support slabs for equipment and roads for transport.

The HAZCON technology can process a wide range of feedstocks, from dry soils to liquid wastes. However, monitoring of the feedstock is required, so that adjustments in the quantity of cement, Chloranan, and water can be made. All feedstocks should not be processed with the same quantities of additives, or the economics of the process will suffer.

Material Handling Required by the Demonstrated Technology

A successfully solidified product from HAZCON's continuous system is dependent on proper time, weight, flow calibrations, and ratios of the admixes. Component feed variations, such as "slugs" of oil and grease in an otherwise uniform soils feed, cannot be easily handled by this system, as would be the case for many systems, and could result in improper mixture ratios. Continuous measurements of oil and grease or of individual contaminant levels is not possible. In order to overcome this disadvantage the process is capable of using higher-than-required admix ratios, but this procedure is less cost-effective. HAZCON, therefore, prefers to use batch systems where they claim the mix ratios can be carefully monitored, variations in the feed components can be easily adjusted, and improved mixing can be applied. HAZCON does not define how feed variations will be identified or defined.

Heavy earth-moving equipment is required to properly excavate the feed stock material and transport it to the system free inlet. Both the continuous and batch systems require air monitoring equipment to track organic and dust exposures during excavation, transport, and feed to the system. Feed materials must be screened and/or crushed to 3-inch diameter for the continuous system, and to 6-inch diameter for the 100 cu yd/hr batch system. Grinding, crushing, or other appropriate size reduction equipment may be used to pretreat the feedstock. HAZCON claims that contaminated water, whether surface or ground water, can be used in the process as the water additive.

Any site conditions that could interfere with excavation would present a problem for the technology, as they probably would for most other similar technologies. For example, a high water table might require process adjustments, present excavation problems, and might indicate insufficient support for access by heavy equipment. Frozen ground could present an excavation, screening, and processing problem.

At the Douglassville site, the feed material had a tendency to pack when compressed, causing HAZCON to reduce the feedrate to slower than originally intended because the feed screw had a tendency to ride up on the material and jam. The soil also was fed to the 7 1/2 cu yd feed hopper only as rapidly as the process screw could process it, which added significant time and expense to the site support operations. In addition, an uncontrolled and crudely measured water feed stream was fed directly to the storage bin to facilitate soil movement. HAZCON suggests, without providing any details, that in such circumstances, pretreating the feed material to obtain a nonpackable slurry would resolve such difficulties. HAZCON indicates that the 100-cu-yd batch system is not expected to experience the same problems.

Personnel Issues

Personnel required for the 10 cu yd/hr system at Douglassville were four operators as a minimum, not including operators of other earth-moving equipment, office and laboratory workers, etc. HAZCON claims that the 100 cu yd/hr batch plant will require two people--a control room operator and an outside person--plus earth-moving, office, lab, and maintenance personnel.

HAZCON claims that personnel are usually widely available, and if not trained can be trained on site by HAZCON. However, these people must pass appropriate physical exams and have completed an EPA-approved IO-hour hazardous material training course, which reduces local manpower availability.

Personnel are subjected to the standard OSHA requirements for operating moving equipment and would be required to wear the proper personal protective equipment dictated by the specific site conditions and contaminants.

Testing Procedures

The samples taken and analytical procedures used for the Demonstration Test were selected based upon the information required to provide answers to the technology evaluation criteria. The two important technical criteria to evaluate any stabilization/solidification technology are:

- Mobility of the contaminants
- Durability of the solidified mass

Tests were drawn from various related fields and applied to hazardous waste to obtain the answers.

The most important factors in evaluating contaminant mobility are:

- To relate pretreatment to posttreatment results
- To measure contaminant concentration in the waste for the samples being used in leaching tests

Therefore, for all pretreatment and posttreatment samples for the Demonstration Test, soil analyses for VOC, BNA, PCB, and heavy metals were performed before samples of the same material were leached. The TCLP test is the most widely accepted leaching procedure and is capable of measuring both organics and heavy metals. It is the most important test in the program for evaluating contaminant mobility. Two additional leach tests, MCC-1P and ANS 16.1, were also used on selected posttreatment samples; they attempt to simulate leaching from a solidified mass. MCC-1P simulates a stagnant groundwater regime and ANS 16.1 a more rapidly moving groundwater where the boundary (surface) concentrations are below saturation levels. These tests were drawn from the nuclear industry and are relatively expensive to perform. The three tests use different leachate-to-solid ratios, so only a qualitative relationship between test results is valid.

Following the TCLP test, the next most important test is permeability, which is a measure of flow of water through the solid. Since water is the leaching

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agent, only water coming in contact with the contaminant can leach the toxins out. A constant head permeability test, such as ASTM D-2434-68, can be used for untreated soils where permeabilities are relatively high, more than $1x10^{-4}$ cm/sec. For the treated soils, where permeabilities may range from $1x10^{-6}$ cm/sec to $1x10^{-10}$ cm/sec, the falling head permeability test is used. This is described in Test Methods for Solidified Waste Characterization (TMSWC) (a draft document prepared by the Materials Characterization Center of EPA).

Once the contaminant is immobilized, the concern is how long it will remain that way. Therefore, tests were performed to provide information on potential durability of the treated soil. In addition, a long-term monitoring program, for this SITE project over a five-year period, is included; samples will be collected from treated soil that is buried at the Douglassville site. The most prominent test is UCS, which provides a measure of the quality of the solidified mass. It is a test commonly used by the cement industry to evaluate cement quality and is relatively inexpensive.

Wet/dry and freeze/thaw 12-cycle tests provide additional information on degradation of the solidified material. The tests used are described in TMSWC and are very similar to the ones used by ASTM. These tests, although more severe than field weathering, provide an indication as to whether the solidified material when saturated or near saturation, as when buried, will disintegrate over the first few weathering cycles, which may take place within the first few years. The tests cannot be used to quantitatively predict the life of the solidified mass in terms of years, decades, or centuries.

The final group of tests, which can be performed and interpreted at only a few laboratories, go under the general heading of microstructural analyses. Both treated and a few untreated soil samples are analyzed by the following methods:

- X-ray diffraction (XRD) - defines crystalline structure, which can indicate changes from the normally expected structure.
- Microscopy both optical and scanning electron (SEM).- These techniques characterize crystal appearance, porosity, fractures, and presence of unaltered waste forms. From these observations, mixing efficiency can also be obtained.
- Energy dispersive x-ray spectrometry - elemental analysis of crystal structures can be determined.

These tests are proven methods of analysis for understanding the mechanism of structural degradation in materials similar to those of the SITE Demonstration. The literature is replete with examples of SEM and XRD analyses of soil, cement, soil-cement mixtures, and each of these mixed with various inorganics and organic compounds. However, there have been relatively few studies of the microstructure of complex waste/soil mixtures, such as those resulting from a stabilization/solidification procedure. Consequently, in some cases, interpretation of the microstructural observations may be difficult.

These observations provide information on the potential for long-term durability of the solid. They cannot quantitatively predict the life of the solid mass or provide a direct relationship to the other tests described above. In the future, if a body of data is developed from long-term monitoring programs, the predictability of these procedures will improve.

Another test of importance, but not directly related to the two technology evaluation criteria, is the inexpensive test of measuring bulk density. In all solidification processes, pozzolans and special additives, along with water in many cases, are added to the waste. This could lead to major waste or soil volume changes, which may affect the remediation procedures. Bulk density measurements of the soil before and after soil treatment, along with a material balance, will provide a method of calculating volume change during the remediation process.

The other physical tests--moisture, pH, and particle size distribution (PSD)--are typical soils tests and provide background information that could become important if problems occur. Moisture and pH analyses are very inexpensive, and a PSD is moderately priced.

Section 4
Economic Analysis

Introduction

A primary purpose of the economic analysis is to attempt to estimate costs (not including profits) for a commercial-size remediation. It was expected that stabilization/solidification technologies would be less expensive than most other technologies, such as incineration. The basis for this analysis was remediation of part of the Douglassville site. Because the Douglassville Superfund site is a spacious area in a rural setting, it allows a simplification and elimination of some potentially expensive site-specific costs. Many costs are site specific, being affected by such factors as site geology; being in a floodplain (as at the Douglassville site); type and quantity of contaminants; proximity to the community or to other industrial sites; regulatory requirements, and local costs of labor, utilities, and raw materials.

Due to the short-term nature of the Demonstration and the fact that labor and chemical expenses dominate the remediation costs, the actual test costs for HAZCON and EPA were not used. However, since HAZCON used a small-scale (300 lb/min), continuous, commercial unit, the capacity, on-stream factor, and chemical usage during the Demonstration Test comprise the starting basis for a commercial cleanup estimate. One change was made for the analysis in each of these variables, which would progressively improve the commercial potential. First, the existing small-scale unit was assumed to operate at on-stream factors of 70% and 90%. Then, based upon HAZCON's recommendations for the size of the unit that will be available in the foreseeable future, a 2,300 lbmin batch unit is assumed at both 70% and 90% on-stream factors. If a treatability study had been performed by HAZCON on Douglassville wastes, reduced quantities of cement and Chloranan might have been used. However, since this did not occur, HAZCON utilized a conservative approach and probably used more cement and Chloranan than required for all or most of the plant areas. HAZCON has indicated that lower cement and Chloranan rates are likely to be used, possibly 25% to 50% by wt lower. Therefore, a 33% reduction in usage for each of the above conditions was investigated. Thus, eight cost scenarios were developed ranging from using the existing unit at Demonstration conditions to using future commercial equipment at optimized chemical consumptions. These costs are presented in Table 2.

Important assumptions were made in preparing the eight cases that could significantly impact the remediation costs. Many actual or potential costs that exist were not included as part of this estimate. They were omitted because site-specific engineering designs would be required, which were beyond the scope of this SITE project. Therefore, certain functions were assumed to be performed by others and were not included in the estimates. The major assumptions that reduced the cost estimates were:

- A prime contractor is at the site who will perform many site functions including many services not charged to the HAZCON remediation and so only partially included in this cost estimate. These are:

  Site preparation--roads, access to feedstock, and providing utilities to plant battery limits. Battery limits can be defined as a space envelope that includes all of the HAZCON equipment plus support equipment to which utilities and access must be provided.

  Installation of support tankage, pumps, piping, etc., for feeding the cement, Chloranan, and fuel to the operating unit.

  Removal of support equipment at the completion of the cleanup.

- A large volume increase between untreated and treated wastes exists. Thus, the total treated waste may not be able to be placed back into the original excavation. A cost for removal to a landfill is not included and could be quite substantial. Even moving the excess material to treated waste may not be able to be placed back into the original excavation. A cost for removal to a landfill is not included and could be quite substantial. Even moving the excess material to

Table 2. Estimatd Costs[a,c]

	Demonstration Test Chemical Consumption				Reduced Chemical Consumption			
	300 lb/min On-Stream Factor		2300 lb/min On-Stream Factor		300 lb/min On-Stream Factor		2300 lb/min On-Stream Factor	
	90%	70%	90%	70%	90%	70%	90%	70%
Site Preparation	--	--	--	--	--	--	--	--
Permitting and Regulatory	--	--	--	--	--	--	--	--
Equipment								
HAZCON, $[b]	100,000	100,000	300,000	300,000	100,000	100,000	300,000	300,000
Support, $/ton	2.25	2.25	6.75	6.75	2.25	2.25	6.75	6.75
Equipment Rentals, $/ton	8.05	10.36	1.05	1.35	8.05	10.36	1.05	1.35
Contingency, $/ton (10% of Direct Costs)	0.25	0.32	0.11	0.13	0.25	0.32	0.11	0.13
Startup and Fixed Cost, $/ton								
Operator Training	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Site Mobilization	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Depreciation (10% of Direct Costs)	0.25	0.32	0.11	0.13	0.25	0.32	0.11	0.13
Insurance and Taxes (10% of Direct Costs)	0.25	0.32	0.11	0.13	0.25	0.32	0.11	0.13
Labor Costs, $/ton								
Salaries and Living Expenses	50.32	64.70	6.56	8.44	50.32	64.70	6.56	8.44
Administration (10% of Direct Costs)	0.25	0.32	0.11	0.13	0.25	0.32	0.11	0.13
Supplies - Raw Materials, $/ton								
Cement	50.00	50.00	50.00	50.00	33.33	33.33	33.33	33.33
Chloranan	66.67	66.67	66.67	66.67	44.44	44.44	44.44	44.44
Supplies - Utilities, $/ton								
Fuel	1.00	1.29	0.23	0.29	1.00	1.29	0.23	0.29
Electricity	0.03	0.03	—	—	0.03	0.03	--	—
Water	0.08	0.08	0.07	0.07	0.08	0.08	0.07	0.07
Effluent Treatment	—	—	—	—	—	—	—	—
Residual Transport	—	—	—	—	—	—	—	—
Analytical, *$/ton*	5.65	6.50	2.26	2.40	5.65	6.50	2.26	2.40
Facility Modifications, $/ton (10% of Direct Costs)	0.25	0.32	0.12	0.14	0.25	0.32	0.12	0.14
Site *Demobilization, $/ton*	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
TOTALS, $/ton	187.80	205.98	136.65	139.13	148.90	167.08	97.75	100.23

a This cost analysis does not include profits of the contractors involved.
b Not used directly but is used for the estimate of other costs.
c The American Association of Cost Engineers defines three types of estimates: order of magnitude, budgetary, and definitive. This estimate would most closely fit an order of magnitude estimate with an accuracy of + 50% to -30%. However, as HAZCON is a new technology, the accuracy range is probably significantly wider.

another area at the Douglassville site, along with land contouring, would add appreciable expense.

- Permitting and any environmental monitoring of operations for any regulatory authority are not included.

- Operations are assumed to be 7 days per week and 24 hours per day. Any reductions in this schedule would add to the remediation cost by increasing the labor costs.

Results of Economic Analysis

The results of the analysis show a cost per ton range of $97 to $205. The lowest value is based upon HAZCON's expectation of reducing chemical consumptions by 33% attaining an on-stream factor of 90%, and using a new 2,300 lb/min batch processing unit . Since a 70% on-stream factor is closer to that actually seen at Douglassville, PA, the costs for this level of operating efficiency are also calculated. These cost values are higher than those normally claimed by HAZCON, see Appendix B. In addition, many costs not charged to HAZCON as mentioned in the previous subsection and discussed in more detail under Basis of Economic Analyses, would increase the actual cost to those responsible for remediating the site. Extreme care in defining the ground rules for the economic analysis is required.

The results show that 85% to 90% of the costs are for raw materials (cement and Chloranan) and labor. HAZCON provided the cost for cement at $50/ton delivered, which may be a little low for the Douglassville area, and for Chloranan at $3.00/gallon ($66.67/ton). The labor costs include 17 people to operate the HAZCON equipment, 17 people to provide support services such as feedstock preparation, plus 5 management and office personnel. The same size work force for both the large and small processing unit is assumed.

The two largest potential savings in remediating the site result from chemical use reductions and the increased size of the processing unit, which would reduce operating time to remediate the same quantity of contaminated soil, compared to the 300 lb/min system used at the Demonstration. The next largest cost factors are on-stream time, analytical costs, and equipment rentals and consummables. This suggests that larger remediations would be more cost-effective, and that equipment operation must be closely monitored to ensure high on-stream factors. Stable operations may also allow reduced sampling frequency, but this potential variable was not included in the economic analysis.

Basis of Economic Analysis

The cost analysis was prepared by breaking the costs into twelve groupings. These will be described in detail as they apply to the HAZCON process. The categories, some of which do not have costs associated with them for this technology, are as follows:

- Site preparation costs -- including site design and layout, surveys and site investigations, legal searches, access rights and roads, preparations for support facilities, decontamination facilities, utility connections, and auxiliary buildings.

- Permitting and regulatory costs -- including permit(s), system monitoring requirements, and development of monitoring and analytical protocols and procedures.

- Equipment costs -- broken out by subsystems, including all major equipment items: process equipment, materials handling equipment, and residual handling equipment. Also included descriptions of the equipment specifications (i.e., throughput and utilization rate).

- Startup and fixed costs -- broken out by categories, including mobilization, shakedown, testing, working capital, depreciation, taxes, and initiation of environmental monitoring programs.

- Labor costs -- including supervisory and administrative staff, professional and technical staff, maintenance personnel, and clerical support.

- Supply costs -- includes the raw materials, cement, and Chloranan. This is the largest of the twelve cost categories for the HAZCON technology, and any design optimizations based on treatability studies or direct field experience could have a large impact on the bottom line.

- Supplies and consumables costs -- both the utilities required, which include fuel, electricity, and water, and any byproducts or posttreatment of the treated soil.

- Effluent treatment and disposal costs -- both on-site and off-site facility costs including wastewater disposal and monitoring activities.

- Residuals and waste shipping, handling, and transport costs -- including the preparation for shipping and actual waste disposal charges.

- Analytical costs -- including laboratory analyses for operations and environmental monitoring.

- Facility modification, repair, and replacement costs -- including design adjustments, facility modifications, scheduled maintenance, and equipment replacement.
- Site demobilization costs -- including shutdown, site cleanup and restoration, permanent storage costs, and site security.

Some general ground rules defining the basis of the estimates are as follows:

- The remediation occurs at the Douglassville Superfund site, No. 102 on the National Priority List (NPL).
- A total of 35,400 tons of soil are processed in each of the eight cases estimated. (This figure is based upon the HAZCON MFU used for the Demonstration Test operating at 300 lb/min, continuously for six months at a 90% on-stream factor.)
- There is a prime contractor on site responsible for the complete site cleanup, who will provide certain functions for the HAZCON processing unit, such as site preparation, whose costs are not included.

The twelve cost factors, along with the assumptions utilized, each are described below.

Site Preparation Costs

It is assumed that this work will be performed by the site prime contractor and that there will be no charges to the HAZCON cleanup. This assumes that roads, site preparation for the HAZCON MFU and its support equipment, and access to the feedstock are provided by others, along with the supply of electricity and water to battery limits and connecting them to the system. It is also assumed that the design of the facilities and any final contouring of the land will take into consideration that the Douglassville Superfund site is in a 100-year floodplain and that it is covered by the Pennsylvania Scenic Rivers Act of 1972. These latter two factors may add considerable cost to any remediation.

Permitting and Regulatory Costs

Since Douglassville is a Superfund site, it is assumed that no permits will be required, neither federal nor state. The need for developing analytical protocols or monitoring records is assumed not to exist. On non-Super-fund sites, this activity could be expensive and very time consuming.

Equipment Costs

Based upon information provided by HAZCON, the capital cost for the small continuous processing unit used during the Demonstration Test is $100,000, and the cost of their future large batch processing system is $300,000. In addition to the HAZCON mobile unit, there are stationary facilities required for the storage of cement, Chloranan, and fuel oil. In addition, there are pumps for the fuel and Chloranan and an air conveying system for the cement. This involves added expenses within battery limits: site preparation, foundations, interconnecting piping, support steel, instrumentation, and electrical supplies. For the small HAZCON system, second-hand support equipment may be utilized that might be discarded at project completion.

Tanks and pumps might be available from used equipment suppliers. Even with refurbishing and checkout, major savings both in time and cost may be realized. It is assumed that there is a project charge of $80,000 or $2.25 per ton of soil processed. For the large system, the charge is assumed to be triple this amount, or $6.75 per ton of soil. A preliminary design, along with ground rules for operation at the site, would be required to provide a more accurate estimate. Since there are so many variables involved and this type of design is outside the scope of the SITE Program, this preliminary design was not performed

A contingency cost, approximately 10% of the direct costs on an annual basis, is allowed for unforeseen or improperly defined cost definitions. This is separate from the previously described design basis uncertainties.

One of the largest costs after chemicals and labor is the rental of equipment and consumables. Rental equipment includes such items as: front-end loaders, backhoes for soil excavation and transport, a steam cleaner for decontamination, a pickup truck, a drill rig, and personnel facilities. This latter item includes expendable health and safety clothes, health and safety instrumentation, trailers for office space, sanitary facilities, lights, and sampling materials. Based upon a six-month program, this is estimated to add up to about $285,000. It is assumed that these costs are directly proportional to the time at the site.

Startup and Fixed Costs

The costs included in this group are operator training, initial shakedown of the equipment, equipment depreciation, and insurance and taxes.

It is assumed that three days of operator training are required for the HAZCON MFU operators, supplementary field personnel, the Site Health and Safety Officer, and the sampling technician. The costs include salaries, overheads, and expenses at the rates described under the grouping for labor.

Initial startup includes setup of the HAZCON equipment and checkout of its operation. This is equivalent to the HAZCON site mobilization, but travel costs to the Douglassville site are not included. Three days are allowed for this function. The installation of the support tankage, pumps, etc., is not assumed as a charge to the remediation. This is probably a significant cost, equivalent to many dollars per ton, but the design of a system and a budgetary or detailed estimate of it is outside the scope of this economic analysis. For purposes of this estimate, this installation work is assumed to be by the site prime contractor and not charged directly to the HAZCON operation.

The depreciation costs are based upon a lo-year life for all the equipment. Therefore, the costs are based upon the write-off of $180,000 worth of equipment for the small system and $540,000 for the large system.

Insurance and taxes are lumped together and are assumed for the purposes of this estimate as 10% of direct costs taken on an annual basis.

Labor Costs

These costs are salaries plus overhead along with living expenses and some miscellaneous administrative expenses. It is expected that a total of 39 people will be required, with the same number needed for both the large and small operating units. It is expected that most of the people will be on expenses, except for some support people that are assumed to be local hires.

HAZCON indicated they require three operators plus one supervisor per shift, with their salaries ranging from $17.50 to $35.00/hr. It is also assumed that there is one overall coordinator, which costs the project $50/hr. In addition, it is assumed that all personnel are allowed $85/day living expenses.

In order to provide feedstock and other field support services it is assumed that three operators plus a supervisor are required each shift plus an overall coordinator. Expenses for these personnel are assumed to range from $25/hr for the operators, who are local hires and do not charge living expenses, to $40/hr for shift supervisors, and $50/hr for the coordinator.

In addition, it is assumed there is one site health and safety officer at $50/hr, an overall project manager at $60/hr, a part-time sampling technician at $40/hr, an office manager at $40 /hr to handle field accounting and purchasing and one secretary at $20/hr. The living expenses, with some rental cars included, for the field support supervisors, field support coordinator, health and safety officer, project manager, and office managers are estimated at $120/day. A contingency of about 10% to 15% for all personnel is also allowed for overtime plus unexpected expenses. This results in a total average daily cost of approximately $9,800.

An additional labor-related expense item is administrative costs, which include office expenses, such as supplies, telephones, furniture, and reproduction equipment, but not salaries. This cost is assumed to be 10%, on an annual basis, of direct costs.

Supply costs

The cost of raw materials includes typical variable costs and is the largest expense; the raw materials are cement and Chloranan. The costs were provided by HAZCON and were assumed to be on a delivered basis. Cement was charged to the project at $50/ton, which may be a little low for the Douglassville area, and Chloranan at $66.67/ton ($3.00/gal).

Supplies and Consumable Costs

The utilities included are fuel, electricity, water; also included are byproducts that require treatment or transport to a landfill.

HAZCON indicated that their small mobile field blending unit (MFU) would consume fuel for its operation at 4 gph, and the proposed large unit at 5 gph. External electricity is not required for the MFU. It is assumed that the support vehicles, front-end loaders, backhoes, and pick-up truck consume an equivalent amount of diesel fuel. The fuel was assumed to cost $1.00/gal. Electricity is assumed to power lights, trailers, pumps, etc. at an average daily rate of 5 kw. The cost of electricity is assumed at $0.04/kwhr.

Water use is primarily for the process, with small quantities required for equipment decontamination. Based upon material balances in the SITE Program Technology Evaluation Report, the water consumption is assumed to be 14 gpm for the small MFU and approximately 100 gpm for the large unit. The cost of water is assumed at $0.80/1000 gal. There are not any byproducts from the HAZCON process, and soil pretreatment or posttreatment is not necessary. If this were to change due to low pH or other factors, where neutralization of the untreated soil feed or special covering of the treated soil becomes necessary, another major cost could be added.

Effluent Treatment and Disposal Costs

Since there are not any liquid effluent streams associated with this technology no costs accrue to this category.

Residual and Waste Shipping, Handling, and Transport Costs

There are no residuals or byproducts associated with the HAZCON technology. Therefore, there are no expenses associated with this category of potential costs. However, if this changes due to the inability of the site to handle the large volume increase produced in the treatment of the wastes, a major new expense for transporting the excesses to an approved landfill would occur.

Analytical Costs

It is assumed that sample sets will be taken daily for the first two weeks of operation at all operating conditions. After that, sample sets will be collected once per week until the cleanup is completed. Both physical and chemical analyses will be run on all sample sets, with the cost per set estimated at $5,000. The cost/ton reported in Table 2 is an overall average value, based upon a completed project.

Facility Modification, Repair, and Replacement costs

The costs accrued under this category include maintenance and working capital. Maintenance materials and labor costs are difficult to estimate and cannot be predicted as functions of preliminary design concepts. Therefore, annual maintenance costs are assumed as 10% of capital costs. Working capital costs are assumed to be negligible, as all supplies purchased to have on-hand are assumed to be fully consumed by the project's completion. The cost of using money early in the project is neglected.

Site Demobilization Costs

It is assumed that all personnel will be on site for three days for demobilization. This is sufficient time for disassembly of the HAZCON mobile equipment, decontamination and cleanup, but insufficient for removal of support equipment, storage tanks, pumps, etc. The additional work required is assumed to be by the site prime contractor and not charged to HAZCON.

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APPENDIX A

PROCESS DESCRIPTION

Description of the Primary Treatment Mechanisms

Solidification and stabilization are treatment processes that are designed to accomplish one or more of the following results [1,2]:

- Improve the handling and physical characteristics of the waste, as in the sorption of free liquids.
- Decrease the surface area of the waste mass across which the transfer or loss of contaminants can occur.
- Limit the solubility of any hazardous constituents of the waste such as by pH adjustment or sorption [3,4].
- Change the chemical form of the hazardous constituents to render them as innocuous compounds or make them less leachable.

Solidification entails obtaining these results primarily by producing a monolithic block of treated waste with high structural integrity. Stabilization techniques limit the mobility of the waste contaminants or detoxify them, whether or not the physical characteristics of the waste are changed or improved. This is accomplished usually through the addition of materials to ensure that the hazardous constituents are maintained in their least mobile or least toxic form [4,5].

The HAZCON process is a cement-based process in which the contaminated material is mixed with Portland cement, a patented additive called Chloranan, and water. The process is capable of treating solids, sludges, semi-solids, or liquids. The unit used for the Demonstration Test could only process solids. The Developer's claim is that the mixture hardens into a cohesive mass that immobilizes contaminants. The Chloranan is reported to make it possible to fixate wastes contaminated with high concentrations of organic compounds.

The cement hardens in a process brought about by the interlacing of thin, densely packed silicate fibers that grow from the individual cement particles. The fiber matrix incorporates the added aggregates and the waste into a monolithic, rocklike mass. The waste soil is entrapped in the rigid matrices of the hardened concrete. A process flow diagram of the HAZCON technology is shown in Figure A-1.

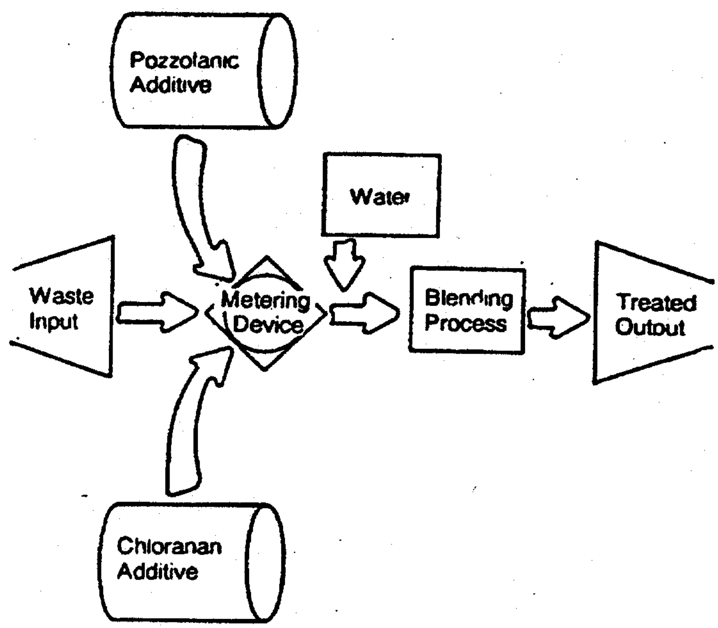

Figure A-1. HAZCON process flow diagram.

The Chloranan is claimed to act upon the waste to remove the Figure A-1. HAZCON process flow diagram. inhibiting effect that organic contaminants

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normally have on the crystallization of pozzolanic materials such as cement, by reacting to form a coating around the organic molecules. The microencapsulation prevents the organics from inhibiting the normal crystallization of the pozzolan. According to HAZCON, Chloranan is a patented, proprietary, and nontoxic chemical blend.

Typical ratios of waste/cement on a weight basis range from 1:1 to 3:1. For the test at the Douglassville site, a conservative ratio of 1 part waste to 1 part pozzolan was selected by HAZCON. Chloranan is pumped into the mixing chamber followed by the addition of cement. Through precise control of the flowrate, ratios of waste-to-Chloranan can be metered accurately from a 10:1 to a 50:1 blend ratio by weight. For the Demonstration Test, a 10:1 ratio was used. After initial combination of the primary ingredients, water was added as necessary to achieve a desirable consistency of the mix as visually determined by HAZCON.

All additives are fed through a mixing chamber to achieve a homogenous blend. Various types of mixers can be used, and the selection may be dependent upon the type of contaminants.Thorough mixing is required, particularly when high levels of organics are present, so that the Chloranan is thoroughly dispersed into the waste, and then intimately mixed with the cement and water. A screw blender, used for the Douglassville test, or a higher energy more efficient pugmill or ribbon blender may be used. The resultant mass is discharged into either a temporary or a permanent disposal area.

Comparison to Existing Treatment Technologies

Comparing the HAZCON Engineering, Inc. solidification process to other cement-based technologies reveals that few differences exist in equipment and still fewer in the processes. Although the means to convey and mix the materials can vary, the basic unit operations remain the same. A different type of cement can be used in the process or a more efficient mixer to blend the waste, cement, and additive, but the solidification reactions are essentially the same.

The unique characteristic of the HAZCON process is the use of the proprietary ingredient Chloranan. The wastes most effectively solidified by the process are aqueous solutions, suspensions, or solids containing appreciable amounts of heavy metals and inorganic salts. The claimed characteristic of the Chloranan to inhibit the effects of organics on the crystallization of the cement is unique to the HAZCON process.

APPENDIX B

VENDOR'S CLAIMS FOR THE TECHNOLOGY

This appendix to the report is based upon claims made by HAZCON either in conversations or in written or published materials. The reader is cautioned that these claims and interpretation of the regulations are those made by the vendor and are not necessarily correct or able to be substantiated by test data. Many of HAZCON's claims are evaluated in section 3 against the available test data.

Potential Applicability

The HAZCON Process

The HAZCON mobile field blending units are capable of treating extracted solids, sludges, or fluids at rates up to 60 cu yd per hour. These truck- or trailer-mounted units are supported by bulk cement carriers and chemical tankers. Two continuous processing units are currently available; the one used for the Demonstration Test was sized for 10 cu yd per hour. This system is not designed to process fluids.

The HAZCON process is intended primarily for on-site use at RCRA- and CERCLA-regulated remediations. Utilization of multiple units of high production concrete batching equipment allows treatment of up to 200 cu yd of waste each hour in high volume applications.

Materials that are either pumpable, able to be extracted by earth-moving equipment, or conveyable using conventional means are most applicable to the process, because of the ease of introducing the material into the blending equipment.

HAZCON adapts commonly available conventional concrete processing equipment to its waste solidification operations. Truck and trailer systems are the most convenient, since they are readily available, but almost any standard mixing equipment can be used. For large sites, transportable systems, such as an asphalt batch plant or cement mixers are appropriate. Batch blending units are the systems of choice, since, according to HAZCON, feed variations can be more easily identified. Thus, steps can be taken to adjust admix ratios to compensate for feed changes, allowing better control of blending ratios and mix consistencies. These systems are far more accurate than the in-line blenders, such as was used during the SITE demonstration; the in-line blender was used only because it was most suitable for a relatively small-scale operation.

HAZCON suggests that their process is superior to competitive systems such as in situ processes, in that their excavation and mixing process assures more effective mixing than in situ systems. Admix ratioing is more effective and can be better optimized, whereas in situ systems must use excess admix materials to ensure proper ratios, leading to larger volume increases in the product material.

HAZCON makes no claim to a universal treatment advantage in the use of the chemical blend Chloranan. Applications of their process where little or no organic contamination exists would not be appropriate. The additive has been proven through extensive internal testing to be capable of producing a highly leach-resistant product, yielding high compressive strengths, from highly organic wastes.

HAZCON has the capability of targeting waste-specific contaminants with the most optimal mix formulations available, and also has the expertise to put these formulas to use in actual field applications. Scale-up from laboratory-sized batches to full-scale application can be made directly, since the stabilization chemistry is more significant than the equipment used-any mechanical equipment that uniformly mixes the waste and additives is satisfactory.

HAZCON usually tests all site materials before operation to determine the proper formulations, admixes, and ratios for optimum results. Cement-based mixtures generally are used, as they have proven to be effective systems, but the equipment can process other pozzolanic (fly ash, kiln dust, etc.) mixtures as well, as needed. HAZCON claims that optimal results have been achieved using Chloranan/cement mixes.

Posttreatment is not required. HAZCON also claims that contaminated clothing and water can be used as raw materials in the process, and that any materials that cannot be fed through the system can be entombed within the solidified mass.

Treatable Wastes

HAZCON claims to be able to handle any type of feed, such as liquids, sludges, emulsions, and soils. Only reactive components in the feed may affect the technology. These components are identified during laboratory characterization tests, and proper precautions are taken to keep reactive components separated, or to pretreat them to nullify their reactive characteristics. If the laboratory testing indicates that feed pretreatment can enhance the solidification process, the waste feed may be pretreated as needed. HAZCON stresses that pretreatment usually is not required.

HAZCON reports that the waste types shown in Table B-1 are compatible with their technology. The waste types listed, found at RCRA and CERCLA sites, are those for which test data are available. Additional waste types and contaminants for which no leachate data are available are also treatable by the HAZCON process. Matrices preferred by HAZCON in order of preference are soils, sludges, emulsions, and lastly liquids, with the preferred contaminants being metals, organics, and lastly volatile organics. Additional materials treated by HAZCON and process results are shown below:

To date the most common full-scale treatment process performed by HAZCON has been on sludges containing oil and grease. HAZCON indicates that they have successfully solidified material for Monsanto Company, Sterling Chemicals, Phillips Puerto Rico Core, Inc., Mobil Chemical Co., NALCO Chemical Co., and others. Laboratory treatment has been accomplished on all types of refinery, plating, and blending by-product wastes.

Table B-l. Wastes Compatible with the HAZCON System*

Arsenic (6,7)	Polychlorinated biphenyls (PCBs) (8)	Toluene (3,8,9)
Barium (5)	Oil & Grease (8)	Trichloroethene (6)
Cadmium (6,7,8)		Tetrachloroethane (9)
Chromium (3,6,7,8)	BNA Phthalates (3.8)	Ethylbenzene (3,8,9)
Copper (3,8)	BNA Phenols (3,8,10)	Xylenes (3,8)
Lead (3,7,8)	BNA Naphthalene (3,8)	Benzene (3,9,10)
Mercury (7)	Methylene Chloride (9)	Trichloroethylene (9,10)
Nickel (6,8)	Pentachlorophenol (PCP) (11)	Chloroethylene (9,10)
Selenium (7)	1,1 -Dichloroethylene (9)	Tetrachloroethytene (9)
Silver (7,8)	1,2-Dichlorobenzene (9)	Carbon Tetrachloride (6,9)
Zinc (8)	1,1,1-Trichlorobenzene (9)	Vinyl Chloride (9)
Chloroform (9)	1,1,2-Trichloroethane (9)	Carbon Disulfide (9)
Isobutanol (9)	1,1,1,2-Tetrachloroethane (9)	Acenaphthene (10)
Acrylonitrile (9)	1,1,2,2-Tetrachloroethane (9)	Aniline (10)
Methyl Ethyl Ketone (MEK) (9)	Bis(2-chloroethyl)ether (10)	o-Cresol (3)
p&m-Cresol (3)	2,4-Dimethylphenol (3)	Endrin (7)
Lindane (7)	Toxaphene (7)	2.4-D (7)
Indene (3)	1 -Methylnaphthalene (3)	Phenanthrene (3)

The numbers in brackets designate references cited.

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Material Treated	Volume	Results
Nonhazardous organic sludge	>67,000 gal	landfillable>300 psi
40% aromatic organics	>60,000 gal	landfillable>500 psi
Organic wash-out pit	>10,000 gal	landfillable> 600 psi
API separator sludge	>20,000 gal	landfillable> 100 psi
Asphaltic sludge, < 1 pH	> 500 gal	nonhazardous, 6.4psi
Slop oil	> 500 gal	landfillable> 1500 psi
Oil base paint + solvents	> 250 gal	landfillable> 1500 psi
AN centrifuge cake	> 100 gal	landfillable> 2500 psi
Acetone	> 50 gal	landfillable> 1200 psi

Extensive investigations are underway to identify other wastes that can be treated by the process, including low-level radioactive wastes.

System Advantages

Some of the claimed advantages of the HAZCON system over existing systems are:

- Formation of a homogeneous mass that is capable of being emplaced as a unit and is retrievable, traceable, or useable for other purposes.
- Leach resistance of the product, which can be accurately measured and recorded.
- Creation of a material after treatment that is transportable without risk of dispersion, incremental loss in transit, dilution, or mixing with other materials.
- Creation of an extrudable cement-like slurry that can be formed into any shape and emplaced in any sort of form or container prior to hardening to meet a multiplicity of requirements for disposal, emplacement, or reuse.
- Readily available ingredients (fly ash, kiln dust, Portland cement) except for small quantities of the proprietary reagent controlled by HAZCON.
- Reduction of toxicity immediately upon hardening, which occurs within 30 minutes of pouring into forms or containers.
- Capability to immediately return the mass to the blending system for reprocessing in case the mix is faulty, without degradation of chemical or physical characteristics.
- No necessity to pH-balance waste streams, allowing the HAZCON system's universal application.
- No need to decant or filter to remove moisture, as the system has very tolerant allowances for moisture content, which is utilized in the cement hydration reactions.
- Improved safety as designed, since the HAZCON extraction and pumping system that carries the waste to a blending station requires only one person to be in the exclusion zone in protective clothing-the remainder of the staff are from 1,000 to 4,000 feet away.

HAZCON has performed in-house laboratory studies to verify that they can solidify pure acetone into a homogeneous, strong, and very dense solid free of volatile gases and practically odorless. As a result of this capability combined with previous solidification successes, HAZCON claims that no compounds known to exist in typical RCRA and Super-fund sites cannot be treated by their process. Feeds having solvents, volatiles, or variations in pH or temperature do not present a problem in the solidification process. HAZCON presents Table B-2 as indicative of their treatment successes.

Product Characteristics

The prime advantage of the HAZCON organic fixation technology is in its ability to overcome the inhibiting effect that organics typically have on pozzolanic fixation. The additive Chloranan, when mixed with the waste and cement or kiln dust, reacts to form a coating around the organic molecules. This microencapsulation prevents the organics from inhibiting the normal crystallization of the pozzolan. Other fixation processes, many of which do not use proprietary chemicals, cannot claim to treat wastes with high concentrations of organic material.

The HAZCON solidification process is claimed to produce a hardened mass with the following characteristics:

- Compressive strengths of 300 to 5000 psi
- Leach resistance
- Low permeability (10^{-7} to 10^{-9} cm/sec)
- More dense than concrete
- Volumetric reduction with most wastes or very small increases
- Toxicity reduced
- Product available for useful purposes such as road construction

HAZCON's formulation creates a hardened mass of sufficient strength for allowing capping even when applied to wastes containing over 50% total organic compounds. The most significant capability claimed

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Table B-2. Priority Pollutant Limits In TCLP Extracts (ppm)

* Priority Pollutant	Before Treatment	Regulatory Level	After Treatment
Arsenic	11.6	5.0	0.001
Barium	131.0	100.0	0.70
Cadmium	13.2	1.0	0.28
Chromium	68.0	5.0	0.132
Lead	265.0	5.0	0.503
Mercury	1.2	0.2	0.0008
Selenium	2.0	1.0	0.005
Silver	7.5	5.0	0.038
Benzene	22.0	0.07	0.04
Cresol-o	>10.8	10.0	0.68
Cresol-m	>10.8	10.0	0.66
Cresol-p	>10.8	10.0	0.68
Endrin	1.0	0.003	0.0004
Lindane	3.0	0.06	0.00001
Methoxychlor	10.0	1.4	0.00001
Pentachlorophenol	70.0	3.6	1.65
Phenol	> 14.4	14.4	0.67
Toxaphene	1.0	0.07	0.0002
2,4-D	20.0	1.4	0.00001
2,4,5-TP Silver	10.0	0.14	0.00001
Toluene	1.0	14.4	0.66
Xylenes-m	50.0		0.29
Xylenes-o	51.0		0.34
Xylenes-p	51.0		0.34
1,2-Dichloroethane	1.0	0.4	0.001
1,1-Dichloroethylene	> 0.1	0.1	0.0001
2,4-Dinitrotoluene	> 0.13	0.13	0.002
Chlorobenzene	> 1.4	1.4	0.00001
Chlordane	> 0.03	0.03	0.00001
Chloroform	> 0.07	0.07	0.0001

* Proposed toxicity characteristic contaminants regulatory levels that define, using TCLP, if a waste is hazardous - Federal Register Vol. 51, No. 114 Friday, June 13, 1966. [12]

for the solidified product is resistance to leaching of toxins in excess of the EPA's Maximum Concentration Limits (a standard used to evaluate treatment alternatives as they affect the ability of a contaminant to pollute the surrounding environment.)

Once blended, the cement-like slurry can be pumped into concrete forms for hardening or returned to the ground for in situ emplacement. The product is denser than cement; its high strength reduces the possibility of fracturing and release of toxic components.

The addition at normal ratios of the Chloranan additive is more cost-effective than the higher fixing agent ratios required in competitive systems to fixate high-organic wastes. HAZCON claims that their lower ratio admix levels also can result in a lower volume increase of the solidified product than produced by competitive systems. HAZCON has the ability to optimize its additive blend to limit volume increase in situations when volume is of concern. At the Demonstration site ratios of cement-to-waste of 1:1 and of Chloranan-to-waste of 1:10 were used. HAZCON claims that ratios as low as 1:3 and 1:20, respectively, can be used in some applications. Volume increases as low as 10% have been achieved in the past on soil wastes; 30% to 40% is average.

Cost Information

HAZCON calculates that the normal cost range for treatment of one cubic yard of waste varies from $15.00 to $12 0.00 ($12 to $96/ton of soil), as based on actual previous bid amounts and completed remediations. Typically the cost increases as treatment criteria become more stringent, and according to the magnitude of difference between the treatment requirements and the initial condition of the raw waste.

Capital costs range from $75,000 to $250,000 depending on the output capacity of the blending equipment. These are typical operating costs: $100/hour for operators, $3 to $6/ton of soil for miscellaneous expenses, and $15 to $80/ton of soil for additives.

Overview

HAZCON states that their solidification technology offers an alternative for on-site remediation of RCRA and CERCLA sites. The Environmental Protection Agency evaluation of the HAZCON process under the Super-fund Innovative Technology Evaluation or SITE program was the first solidification process evaluation and has provided an abundance of data on the technology. HAZCON expects that the emerging data base from the test will set the stage for the future use of their technology on CERCLA sites throughout the country.

Under the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), the stabilization/solidification process is recognized as a Best Demonstrated Available Technology (BDAT) under the land banning regulations. The HAZCON process probably can meet Federal and State applicable or relevant and appropriate requirements (ARARs) for the disposal of hazardous wastes.

The HAZCON technology has been evaluated and reported upon at the Douglassville SITE Demonstration [8]; in tests reported in the I.T./IWC report [9]; in two independent confidential studies [6,11]; in a report by Risk Science International for the American Petroleum Institute (A.P.I.) [1]; in a Canadian report [10]; by the Waterways Experiment Station (WES) at the Rocky Mountain Arsenal [7]; and at the Sand Springs Superfund Site [13]. HAZCON offers these evaluations, the results of which are highlighted in Section 3 and Appendix A, as confirmation of their capabilities to remediate a wide range of sites and contaminants.

SITE DEMONSTRATION RESULTS

Introduction

A wide variety of soil contaminant concentrations exist at the Douglassville Superfund Site, and a variety of feedstocks were used in the tests to evaluate the HAZCON technology. The soils treated contained oil and grease ranging from 1% to 25% by wt, heavy metals (primarily lead) from 0.3% to 2.3% by wt, volatile organics up to 150 ppm by wt , base neutral/acid extractables (semivolatile organics) ranging up to more than 500 ppm by wt, and small amounts of polychlorinated biphenyls (PCBs). A test was run on contaminated soil from six plant areas, each providing a different composition feedstock.

The analytical data consist of test results of untreated soil, treated soil collected in the field as a slurry after a 7-day curing period, and core samples from the solidified blocks after curing in the field for 28 days. Clean soil, FSA soils, and LAN soils, these two areas containing the highest organics content, each were mixed in the analytical laboratory with the cement used in the field without Chloranan and checked for physical properties as a baseline against which to compare the field results. The Demonstration results are discussed separately in terms of the physical tests, chemical tests, and operations.

Results

A large amount of analytical and operating data was obtained, and it was sufficient to meet the program objectives. The detailed results and operating summaries are in the Technology Evaluation Report [8].

Physical

The physical tests showed that the HAZCON process can readily solidify contaminated soil with oil and grease content up to 25% by wt. The HAZCON process produced a structurally firm material, with few negative properties observed. The unconfined compressive strengths (UCS) of tested samples ranged from 220 psi at FSA, the highest oil and grease content area, to 1,570 at PFA, one of the lower oil and grease areas. In general, the treated soil strength was inversely proportional to the oil and grease content. These UCS values easily meet the EPA guideline of 50 psi [14] for this type of technology.

Soil samples were prepared in the laboratory without Chloranan for FSA and LAN. For FSA, the solidified soil had a UCS of less than 40 psi, while for LAN the results were equal to those samples with Chloranan. Therefore, for the highest oil and grease content samples, Chloranan appears to have a very beneficial effect.

The permeabilities and other results of the wet/dry and freeze/thaw weathering tests were good. The permeabilities, for both the field samples with Chloranan and the two laboratory formulations without Chloranan, were in the range of 10^{-8} to 10^{-9} cm/sec, which is less than an EPA and industry guideline of 10^{-7} cm/sec for hazardous waste landfill soil barrier liners. Not only does a low permeability reduce contaminant mobility, but it reduces solid erosion and weathering. The wet/dry and freeze/thaw weathering tests showed relatively low weight losses, less than 1.0%, over the twelve cycle tests, with the test specimen losses only slightly larger than the control samples, not subjected to drying or freezing. Unconfined compressive strength tests performed on the weathered test specimens showed no losses in strength.

Less positive results were observed from the bulk density and microstructural analyses. The treated soil bulkdensity increased approximately 10% to 15% resulting in a volume increase of the treated soil compared to the untreated soil of 120%. Thus, one part soil plus one part cement plus water and Chloranan yields 2.2 parts treated soil by volume.

This may provide remediation difficulties involving where to place the excess material. HAZCON has indicated that smaller quantities of cement and Chloranan might have been used, which would greatly reduce the volume increase, but this may impact other physical and chemical properties. In addition, the microstructural analyses showed that the solidified mass was porous, that mixing of the various components was not highly efficient, and that brownish aggregates passed through the process unchanged. These characteristics are factors that may impact upon durability of the solid mass and immobilization of the contaminants. A more efficient mixer, such as a ribbon blender, may eliminate many or all of these deficiencies.

The physical properties of the untreated and treated soils are shown in Tables C-l and C-2.

Chemical

The chemical analysis consists of both soil and leachate analyses for metals, volatile organics (VOCs), base neutral/acid extractables (BNAs), and polychlorinated biphenyls (PCBs). The leachate results can be directly related to the corresponding soil composition.

Table C-3 presents the results for these contaminants (except PCBs) in terms of migration potential, which is defined as the weight of an analyte in the leachate divided by the weight in the solid being leached. Migration potential provides a method of comparing the fraction of an analyte extracted from the solid for both the untreated and treated soils.

The untreated and treated soil analyses are shown in Tables C-4 and C-5. The TCLP and special leach tests, ANS 16.1 and MCC-IP, showed that the HAZCON process immobilized heavy metals, which consist predominantly of lead, but not organics. The heavy metals were reduced in the TCLP leachate from concentrations of 20 to 50 mg/l for untreated soils to 5 to 400 ug/l for treated soils, with most of the treated soil values below 100 µg/l. These results are shown in Table C-6.

The leachate analyses for organics, VOC, and BNA showed that they were not immobilized, since the leachate concentrations of the contaminants in the treated soil were equivalent to those in the untreated soil (See Tables C-7 and C-8). The primary VOCs detected were toluene, xylenes, tetrachloroethene, trichloroethene, and ethylbenzene. The individual location values for total VOCs varied greatly as the soil composition ranged from nondetected to a maximum of 150 ppm by wt at FSA. For the three areas of lowest VOC concentrations, DSA, LFA, and PFA, toluene was injected at a rate sufficient to provide an equivalent of 125 ppm by wt VOC concentration in these soils. The TCLP leachate results ranged, for both the treated and untreated soils, from less than 100 ug/l to about 1000 µg/l. The soils without toluene injection provided the best comparisons.

Table C-l. Physical Properties of Untreated Soils

				Untreated Soil			
Plant Area	Moisture, Weight %	pH	Bulk density,(a) g/ml	Oil & Grease,(c) Weight %	Total Organic Carbon, Weight %	Permeability, cm/sec(b)	Less than 200 mesh (74µ), %
DSA	11.8	6.41	1.23	1.0	4.9	5.7 x 10-1	58
LAN	17.6	3.69	1.40	16.5	23.0	1.8 x 10-3	37
FSA	24.7	2.56	1.60	25.3	27.3	Impermeable(d)	NA(d)
LFA	16.7	4.58	1.68	4.3	8.9	10.5 x 10-2	57
PFA	6.6	7.00	1.73	4.5	7.5	7.7 x 10-2	19
LAS	11.9	4.11	1.59	7.7	14.3	1.5 x 10-5	47
Clean Soil	15.7	6.43	1.63(e)	0.26	0.3	6.0 x 10-3	32

(a) Values reported are of undisturbed soil samples except for clean soil.
(b) Permeability as measured by constant head permeability test.
(c) Oil and grease is fraction of TOC extracted by a solvent.
(d) Could not be run due to excessive stickiness.
(e) Compacted loose sand.

Table C-2. Physical Properties of Treated Soils

	<-----7 Day-----			>	<-----28 Day-----			>
Plant Area	Moisture, %	Bulk Density, g/ml	Unconfined Compressive Strength, psi	Permeability,[a] cm/sec	Moisture, %	Bulk Density g/ml	Unconfined Compressive Strength, psi	Permeability, cm/sec
DSA	14.2	1.95	1446	1.6×10^{-9}	14.8	1.99	1113	1.8×10^{-9}
LAN	20.1	1.61	427	1.7×10^{-9}	17.2	1.59	524	3.6×10^{-9}
FSA	24.7	1.51	238	4.5×10^{-9}	22.1	15.1	219	8.4×10^{-8}
LFA	17.0	1.84	947	4.5×10^{-9}	15.1	1.86	945	4.5×10^{-9}
PFA	11.6	2.07	1435	4.3×10^{-9}(d)	10.0	2.02	1574	5.0×10^{-9}
LAS	16.0	1.07	894	2.4×10^{-9}	15.8	1.74	889	2.2×10^{-9}
Cement only	9.9	1.98	1758	(c)	11.0	2.07	2949	
Clean[b] soil & cement	13.3	1.88	2000	(c)	13.0	2.04	2908	5.9×10^{-9}
FSA &[b] cement	28.2	1.41	27	(c)	28.9	1.36	38	3.2×10^{-8}
LAN &[b] cement	19.6	1.60	373	(c)	20.6	1.55	539	3.8×10^{-8}

(a) Permeabilities all performed after 28 days elapsed.
(b) Laboratory formulations prepared without the use of Chloranan: Baseline.
(c) Not scheduled to be performed.
(d) The two low values average 4.7×10^{-10} cm/sec. The third value was 1.2×10^{-8} cm/sec.

The BNAs consisted of phthalates, phenols, and naphthalene. The phthalates and naphthalene concentrations in both untreated and treated soil TCLP leachates were very low, less than 50 µg/l. However, the phenol concentrations in the leachates were much greater. For FSA, where the untreated soil contained 405 ppm by wt phenols, the untreated and treated soil leachate concentrations were both in the range of 3 to 4 mg/l. Thus, for phenols, which have a moderate solubility in water, the migration potentials were approximately the same for the treated and untreated soils. Since the phthalate and naphthalene leachate concentrations were so low, determination as to whether they were immobilized is difficult.

The TCLP leachate analyses for PCBs provided values all below detection limits of 1.0 µg/l, both for the treated and untreated soil samples.

The special leach tests, ANS 16.1 and MCC-1P, attempt to simulate leaching from the solidified mass, as compared to the TCLP test where the sample is crushed. Tests equivalent to ANS 16.1 and MCC-1P were not performed on untreated soil. Therefore, these results can only be compared to the treated soil TCLP results. Since experience with these tests for hazardous wastes is limited, and each test uses a different weight ratio of solid to leachate, significance of the results is unclear. However, the leachate concentrations from all three tests were the same order of magnitude. This indicates leaching of the blocks in the field may be similar to that shown by a TCLP test. This was surprising, since the surface area and the intimacy of mixing for leaching in the TCLP test is much greater than for ANS 16.1 and MCC-1P.

Operations

Many operational difficulties were encountered by HAZCON during the 5-cu-yd runs. Control of Chloranan and water rates were erratic. In addition, on two occasions the soil feed screw jammed with soil, and operations had to be discontinued so the HAZCON unit could be flushed clean. In the extended run (3 hr) at LAS, where 25 cu yd of treated soil was produced, operations ran relatively smooth with an on-stream factor of about 85%. For all tests a labor-intensive effort was required to maintain operations.

Material balances performed on each test run showed that the soil processing rate ranged from 180 lb/min to 300 lb/min and was constant for each test area. The cement-to-soil additions were maintained at the targeted ratio of 1:1 except during the extended run when the cement rate tailed off. The feed ratio of Chloranan to soil varied between runs, ranging from 0.052 to 0.094; this compares to the targeted value of 0.

Table C-3, Migration Potential, **µg leached/µg** in soil[(a)]

Plant Area	VOC Untreated	VOC Treated	Toluene Untreated	Toluene Treated	**BNAs** Untreated	**BNAs** Treated	Phenols Untreated	Phenols Treated	Metals - **Pb** Untreated	Metals - **Pb** Treated	Migration Reduction of Lead, %
DSA	13.55	5.70	13.55	5.97		ND[(b)]	ND	ND	0.0093	0.000169	98.19
LAN	0.166	0.265	0.200	0.625	0.938	0.617	3.73	0.81	0.0691	0.000036	99.95
FSA	0.137	0.148	0.192	0.274	0.108	0.151	0.139	0.429	0.0159	0.00080	95.03
LFA	8.35	0.300	8.35	0.312	0.0625	ND	ND	(c)	0.0404	0.000540	98.67
PFA	4.78	0.730	4.78	0.757	0.0519	0.533	ND	(c)	0.0567	0.000061	99.89
LAS	0.154	0.305	0.667	0.562	0.0059	0.306	ND	1.93	0.0706	0.000313	99.56

(a) Based upon TCLP leaching test.
(b) ND - Not detected.
(c) Below quantification limits.

Table C-4. Chemical Analyses of Untreated Soils

Parameter	DSA	LAN	FSA	LFA	PFA	LAS
PCBs – ppm by wt						
Aroclor 1260	1.2	51	40	10	14.5	250
Aroclor 1248	ND	ND	ND	ND	19	270
Oil and grease, %by wt	0.98	16.5	25.3	4.27	4.47	7.800
Metals – ppm by wt						
Lead	3,230	9,250	22,600	13,670	7,930	14,8300
Chromium	24	19	31	46	95	730
Nickel	23	6	8	22	46	170
Cadmium	1	2.3	6	4	5.5	3.50
Copper	74	35	128	90	440	1400
Zinc	315	150	655	735	1,600	5800
BNA – ppb by wt						
All phthalates	12,150	15,700	14,200	33,500	10,750	34,2000
All phenols	ND	5,200	405,000	ND	ND	ND0
Naphthalene	ND	ND	115,000	3,200	7,700	5,4000
Volatiles – ppb by wt						
Toluene	ND	1,000	26,000	ND	ND	2900
Trichloroethene	ND	130	13,800	ND	ND	5800
Tetrachloroethane	ND	160	6,100	ND	100	1,500
Ethylbenzene	ND	180	13,000	ND	ND	400
Xylenes	ND	970	91,000	ND	320	3,700

ND – None detected

Table C-5. Chemical Analyses of Treated Soils*

Parameter	DSA	LAN	FSA	LFA	PFA	LAS
Total PCBs (ppm)						
Oil and grease (%)	0.54	7.54	9.45	1.53	2.11	1.67
Lead (ppm)	830	2800	10300	1860	3280	3200
Total BNAs (ppb)	ND	42800	368900	ND	4130	15700
Phthalates	ND	ND	1300	ND	ND	2150
Phenols	ND	32400	126800	ND	ND	6700
Naphthalene	ND	10400	216700	ND	4130	4550
Total Volatiles (ppb)	1320	3550	105300	24700	22700	7200
Toluene (ppb)	1240	1280	19000	23700	17700	1780

*Based on 28-day results

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Table C-6. Concentration of Metals in TCLP Leachates mg/liter*

	Pb	Cr	Ni	Cd	Cu	Zn
Soil						
DSA	1.5	< 0.008	0.02	< 0.004	< 0.03	0.07
LAN	31.8	< 0.008	0.07	0.02	< 0.3	1.1
FSA	17.9	0.27	0.11	0.13	< 0.03	23.0
LFA	27.7	< 0.008	0.06	0.03	< 0.08	6.7
PKA	22.4	< 0.008	0.05	0.01	< 0.03	1.4
LAS	52.6	< 0.008	0.07	0.04	0.13	4.8
7-Day Cores						
DSA	0.015	< 0.07	<0.15	< 0.04	< 0.06	< 0.02
LAN	< 0.002	< 0.07	<0.15	< 0.04	< 0.06	< 0.02
FSA	0.07	0.02	< 0.008	< 0.003	< 0.03	0.02
LFA	0.04	< 0.07	<0.15	< 0.04	< 0.06	0.04
PFA	0.01	< 0.07	<0.15	< 0.04	< 0.06	0.02
LAS	0.14	< 0.008	< 0.008	< 0.003	< 0.05	0.04
28-Day Cores						
DSA	0.007	< 0.007	0.020	< 0.004	0.023	0.037
LAN	0.005	0.007	<0.015	< 0.004	0.010	0.017
FSA	0.400	< 0.070	<0.15	< 0.040	< 0.060	0.037
LFA	0.050	0.009	0.015	< 0.004	0.080	0.013
PFA	0.011	< 0.007	<0.015	< 0.004	0.027	0.030
LAS	0.051	0.015	0.025	< 0.004	0.055	0.258

* Where the symbol < is used, indicates values below detection limits of quantity shown. The detection limits vary between metals and from analysis to analysis.
Where 2 of 3 values are above detection limits, three values were averaged assuming the one below detection limits is zero. if only one of three values is above detection limits, the results are reported as below detection limits.

Table C-7. Volatiles in TCLP Leachates, µg/l(a)

Volatile Organic	DSA	LAN	FSA	LFA	PFA	LAS
Untreated Soil						
Toluene	915	10	245	5100	1100(b)	10
Xylenes	<50	7	525	< 230	<180	35
Trichloroethene	<20	2.4	165	<95	<76	8
Tetrachloroethene	<40	<4	19	<210	<160	5
Ethyl benzene	<70	<7	80	< 360	< 290	<7
7-Day Cores						
Toluene	380	<6	220	201	350	<15
Xylenes	3.5	6	340	5	20	15
Trichloroethene	<10	<2	105	<2	<5	<5
Tetrachloroethene	<20	<4	11	<4	<10	<10
Ethyl benzene	<40	<7	60	<7	<20	<20
28-Day Cores						
Toluene	370	40	230	370	670	50
Xylenes	6	8	330	<8	170	40
Trichloroethene	<9	2	100	<9	<9	8
Tetrachloroethene	<6	3	20	<6	<6	10
Ethylbenzene	<3	2	60	2	<3	4

(a) < indicates less than detection limits. Within one sampling area, the detection limit may change between samples. For these, the highest detection limit is shown.
(b) Two values < 60 and 2200 µg/l.

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Table C-8. Base Neutral/acid Extractables In TCLP Leachates, µg/l

BNA	DSA	LAN	FSA	LFA	PFA	LAS
Untreated Soil						
Phthalates	ND	10	ND	10	10	ND
Phenols	ND	1010	2810	ND	ND	ND
Naphthalene	ND	ND	50	ND	ND	10
7-Day Cores						
Phthalates	ND	30	ND	10	20	ND
Phenols	40	1310	3850	30	50	470
Naphthalene	15	ND	60	10	20	ND
28-Day Cores						
Phthalates	ND	10	10	20	30	80
Phenols	ND	1440	2720	80	80	650
Naphthalene	ND	ND	60	ND	ND	ND

ND — not detected

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