SUBMITTAL OF ENGINEERING TECHNOLOGY REPORTS

05/24/96

DOE-0940-96
DOE-FN EPAS
50
REPORTS

Department of Energy
Ohio Field Office
Fernald Area Office
P. O. Box 538705
Cincinnati, Ohio 45253-8705
(513) 648-3155

MAY 24 1996

DOE-0940-96

Mr. James A. Saric, Remedial Project Director
U.S. Environmental Protection Agency
Region V. - SRF-5J
77 West Jackson Blvd.
Chicago, IL 60604-6590

Mr. Tom Schneider, Project Director
Ohio Environmental Protection Agency
401 East 5th Street
Dayton, OH 45402-2911

Dear Mr. Saric and Mr. Schneider:

SUBMITTAL OF ENGINEERING TECHNOLOGY REPORTS

This letter formally transmits the attached four draft technology reports. These reports were committed to in the Operable Unit 5 (OU5) Record of Decision (ROD). The ROD commitment was to evaluate the emerging technologies for the treatment of soils and sediment before placement of soil and sediment into the On-Site Disposal Facility (OSDF). These reports are:

- Brick Maker (vacuum extrusion/compaction of soil)
- Geochemical Barrier
- Physical Separation
- Phosphate Soil Stabilization

The OU5 draft Remedial Design Work Plan identified a submittal date of May 24, 1996.

If you have any questions, please contact Rod Warner at (513) 648-3156.

Sincerely,

Johnny Reising

Johnny W. Reising
Fernald Remedial Action
Project Manager

FN:Jalovec

Enclosure: As Stated

Recycled and Recyclable

cc w/enc:

R. Nace, EM-423, GTN
G. Jablonowski, USEPA-V, SRF-5J
T. Schneider, OEPA-Dayton (3 Total)
Manager, TPSS/DERR, OEPA-Columbus
F. Bell, ATSDR
D. Ward, GeoTrans
R. Vandergrift, ODH
S. McLellan, PRC
AR Coordinator, FERMCO

c w/o enc:

R. Warner, DOE-FN
U. Kumthekar, FERMCO, 52-2
P. Norman, FERMCO, 52-2
N. Weatherup, FERMCO, 52-2

288

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

TECHNOLOGY REPORTS

MAY 1996

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

DRAFT

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

TECHNOLOGY REPORTS

MAY 1996

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

DRAFT

TABLE OF CONTENTS

Section 1	Brick Maker (Vacuum Extrusion/Compaction of Soil)
Section 2	Geotechnical Barrier
Section 3	Physical Seperation
Section 4	Soil Stabilization

DRAFT REV. A
BRICKMAKER REPORT

Fernald Environmental Management Project

Soil Remediation Project

May 1996

2502-ES-002

EXECUTIVE SUMMARY

In the Record of Decision for the Fernald Environmental Restoration Site (FEMP), Operable Unit 2 (June 1995) the FEMP agreed that engineering evaluations will be performed during the Remedial Design process if an emerging technology "...is developed that may significantly reduce the volume, toxicity, or mobility of waste." the FEMP specifically identified "Brickmaker technology" as one of the two key technologies having potential benefit to the planned On-Site Disposal Facility (OSDF). Brickmaker technology is defined here as an extrusion process that compacts soil to a high density, reducing its volume and permeability.

The FEMP conducted an investigation of the development status of this technology, finding it to be in the field testing stage. The extrusion technology and soil processing is well established, but its application to waste processing is less developed.

The FEMP performed an evaluation of the brickmaker technology based on schedule, cost, performance and implementability. These criteria, combined with an accelerated 10-year remediation schedule requiring Phase I OSDF design at the FEMP by October 1996, leads the FEMP to conclude that the benefits of the brickmaker technology are marginal and would add significant cost to OSDF construction and operation.

The brickmaker technology could approximately reduce the volume of soil in the OSDF by approximately 13 percent, and the greater compaction of the soil will reduce the permeability. However, the cost of implementing the brickmaker technology is in the tens of millions of dollars. The FEMP does not believe that the limited benefits to the brickmaker technology offsets the increased cost.

I. INTRODUCTION

In the Record of Decision for Operable Unit 2 (June 1995) for the Fernald Environmental Restoration Site (FEMP), the FEMP agreed that engineering evaluations will be performed during the Remedial Design process if an emerging technology "...is developed that may significantly reduce the volume, toxicity, or mobility of waste." the FEMP specifically identified "brickmaker technology" as one of the two key technologies having a potential benefit to the planned on-site disposal cell. Brickmaker Technology is defined here as a process of soil extrusion that compacts the soil, reducing its volume and permeability. Common extrusion technology was modified and applied at the DOE-Mound facility to reduce off-site shipping volumes. The specific brickmaker process being considered is:

a) processing and blending of the soil to remove rocks and roots; and
b) extrusion of the soil into high density "bricks" to be placed in the disposal facility.

c) treatment of soil moisture waste stream extruded from soil matrix.

This report summarizes the FEMP investigation of the Brickmaker Technology as a process to reduce volume and permeability in contaminated soil. The investigation was performed to determine the state-of-the-art and to evaluate the potential benefit of incorporating Brickmaker Technology into the planned disposal cell at the FEMP. The report also presents a description of the technology, general summary of development efforts and results, and the evaluation criteria used to reach recommendations relative to remediation plans at the FEMP.

II. TECHNOLOGY REVIEW

Brickmaker methods being evaluated for the compaction of contaminated soil consist of standard soil processing and extrusion technologies. The concept of soil extrusion is well established and researched, but the application of this process to contaminated soil is new.

The brickmaker technology as it is currently being applied to contaminated soil consists of a soil preparation process followed by an extrusion process and a packaging process. The soil preparation process uses standard sorting and pulverizing equipment to sort the rock and vegetation out of the soil and process it. The crushed rock is then remixed with the soil and it is fed through a standard vacuum extrusion system. The extruded soil can be in many different forms, including; bars, pellets, and noodles. Handling equipment has been developed to manage the extruded soil. Current handling systems are capable of stacking bars of contaminated soil in shipping containers.

The system most applicable to the OSDF would include two 90 ton/hr vacuum extrusion systems with front end soil preparation systems and a back end conveyor to transport the extruded soil into the OSDF for placement. Stacking of the "bricks" into the cell would be performed manually or by a modified crane or loader system. The soil preparation and vacuum extrusion systems are currently available, and they are standard technologies. The conveyor system and stacking systems would need to be engineered. For purposes of this report, it is assumed that the bricks would be banded into standard 4 by 4 by 4 foot cubes on a 3-inch thick post-stressed concrete pallet. These cubes would be interspersed throughout the OSDF, similar to debris, to minimize differential settlement of the capping system.

III. TECHNOLOGY EVALUATION CRITERIA

In order to determine the viability of incorporating any emerging technology into the Fernald Soil Remediation Project (SRP), four primary criteria were selected. In order of priority, these criteria are:

1. Schedule - under the accelerated 10-year remediation option at the FEMP, the application of proven new technologies must be integrated into field operations in time to realize a quantifiable benefit to remediation.

2. Cost - the implementation of new technologies must not appreciably add to the approved baseline cost. Higher cost may be justified if dramatic reductions in risk are achievable versus conventional methods.

3. Performance - the technology must reliably produce a quantifiable reduction in volume, mobility or toxicity of FEMP radiological waste.

4. Implementability - new technologies must be supported by the availability of commercial equipment or materials, delivered to the FEMP on a scale necessary to meet remediation requirements.

Using these criteria, DOE performed an evaluation of the applicability of brickmaker technologies to the FEMP disposal cell, which is presented in Section IV below.

IV. CONCLUSIONS

Schedule

Based on the description of the brickmaker technology, the schedule impacts as a result of implementing the brickmaker technology can be minimized by scaling up the number of extrusion and placement systems. A separate design submittal would be required with the system operational by March 1998. However, the construction cost of the brickmaker system is not in the current 10-year accelerated site restoration plan and may require diversion of funds from other projects potentially affecting the overall site schedule.

Performance

The main measure of performance for the brickmaking technology is reduction of volume. The OSDF contains approximately 2.5 million cubic yards of impacted soil. Of that 2.5 million, 900,000 cubic yards are needed for infilling and compaction around debris, and 600,000 cubic yards are needed for cushion and berm systems to protect the liner and cap. The 1.5 million cubic yards described above is not available for extrusion because bricks cannot be used to backfill around debris, and the cushion and berms would be difficult to construct out of bricks. The volume of soil that is

available for extrusion is approximately 1 million cubic yards.

Current estimates of soil compaction within the OSDF are about 90 percent of the standard proctor density. A graph of FEMP soil proctor densities is provided as Attachment A. A conservative standard proctor maximum dry density of 108 lbs/cubic ft at 17 percent moisture was chosen to represent the soil in the OSDF. The compacted dry soil density after placement in the cell will then be about 97 lbs/cubic ft.

Communication with the brickmaker industry indicates that a vacuum extrusion system can compact soils to the zero voids line shown on the attached Proctor curve at optimum moisture. For the soils depicted in Attachment A, the zero voids line at 17 percent moisture for a soil with a specific gravity of 2.6 results in a dry density of 112 lbs/cubic ft. If the brickmaker achieves this density, it will compact the soil 13 percent more than the current proposed construction specification would require. This translates to a 13 percent reduction in the volume of soil placed in the OSDF.

To summarize the volume reduction gained by the brickmaker process, 13 percent reduction of 1 million cubic yards saves 130,000 cubic yards of disposal facility space. The OSDF has 2.5 million cubic yards of soil and is 3700 feet long, therefore there is 675 cubic yards of soil per foot. The 13 percent reduction saves about 200 feet of disposal facility, or 5 percent of the total length. This reduction is considered insignificant to the scope of the project.

A second measure of performance for the extrusion system is its ability to reduce the permeability of the contaminated soil by compaction. The 13% greater compaction on the soil will decrease the permeability slightly, but the impacted soil at planned compaction rates is already at or near to 10^{-7} cm/sec. The slight decrease in permeability is not considered a significant performance enhancement on the OSDF.

Cost

Current cost estimate for completion of one cell in the OSDF is about 12 million dollars. That includes constructing the cell, placing the waste, and constructing the cap. One cell contains about 350,000 cubic yards of material. If brickmaking technology reduces the volume of soil by 130,000 cubic yards, then it saves about half of one cell, or 6 million dollars.

An estimate of the capital costs for the two 90-ton per hour extrusion systems is 10 million dollars.The operating costs for the two extrusion systems are estimated to be 4 million dollars per year. The costs are considered to be additional since the equipment and personnel for standard impacted soil placement and compaction are still required and any potential placement savings are more than offset by the special hand compaction required around the brick cubes to minimize differential settlement of the capping system.

Based on these gross estimates, the implementation of an extrusion system in the OSDF would cause a large increase in cost, and the cost savings originally contemplated cannot be realized.

Implementability
Since the technology used to process, extrude, and handle soil is readily available, the implementability of the brickmaker system at the FEMP would not be difficult. The design of the handling and stacking of the extruded soil would be similar to that planned for debris; although larger equipment may be required.

V. RECOMMENDATIONS

The brickmaker technology evaluation indicated that the schedule would not be impacted and the implementability of the technology is not prohibitive, but the cost of implementation is great and the performance improvement is minimal. As a result of this evaluation, the brickmaker technology will not be further studied in conjunction with the OSDF.

ATTACHMENT A

Depth: 1.5-4.5 ft (See Note 2)

Description: Brown CL

Compaction Method: ASTM D 698 Method A

Lab: Advanced Terra Testing, Inc.

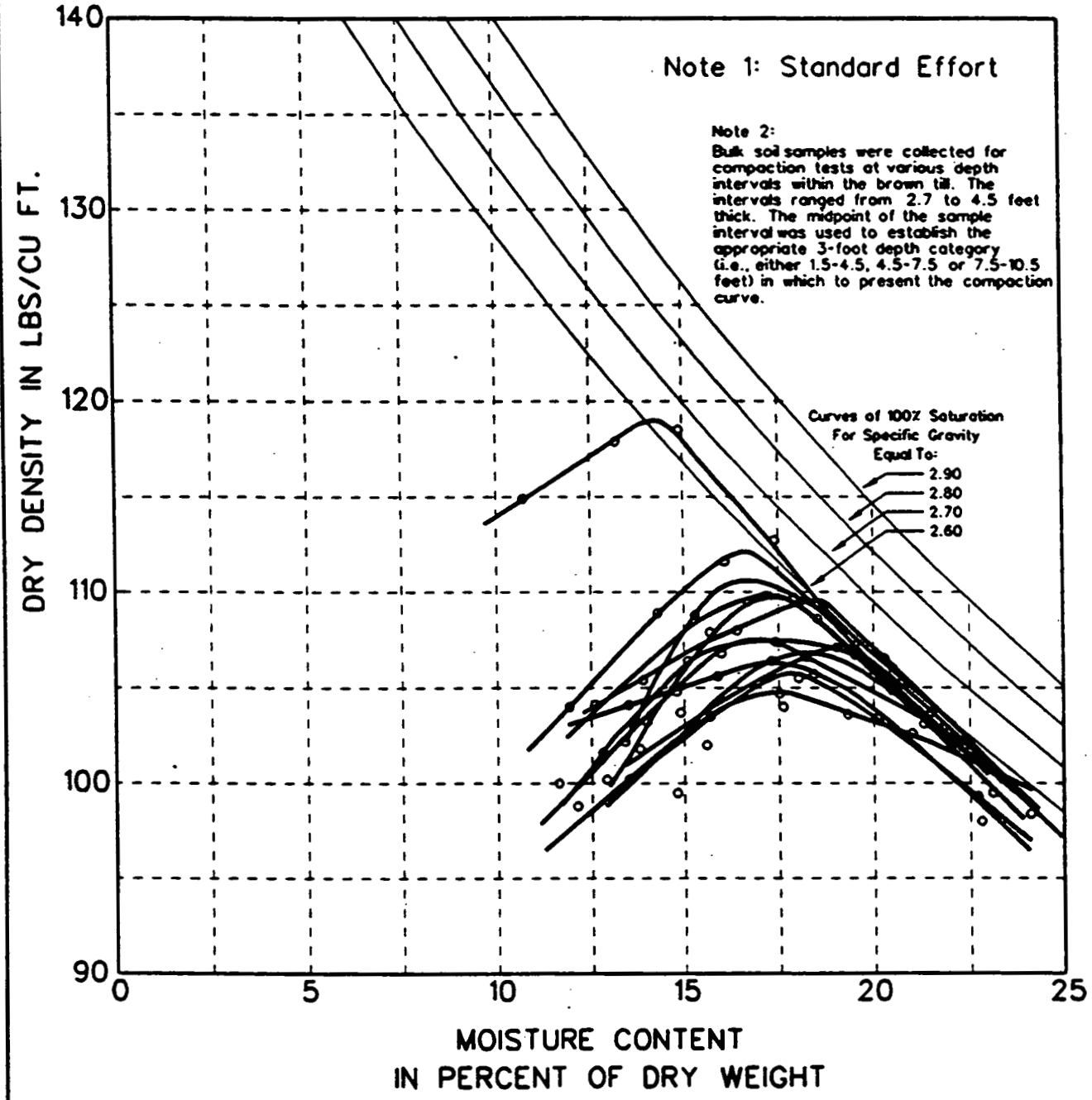

Figure A-1 - Summary of Standard Proctor Compaction Curves, Brown CL Bulk Samples, Depth 1.5 - 4.5 Feet

DRAFT REV. A
GEOCHEMICAL BARRIER REPORT

Fernald Environmental Management Project

Soil Remediation Project

May 1996

2502-E8-003

EXECUTIVE SUMMARY

In the Record of Decision for the Fernald Environmental Management Project (FEMP), Operable Unit 2 (June 1995) the FEMP agreed that engineering evaluations will be performed during the Remedial Design process if an emerging technology "...is developed that may significantly reduce the volume, toxicity, or mobility of waste." the FEMP specifically identified "geochemical barriers" as one of the two key technologies having potential benefit to uranium stabilization in the planned On-Site Disposal Facility (OSDF). Geochemical Barriers are defined here as any distinctly separate body of permeable reactant designed to selectively extract contaminants from mobile groundwater or leachate.

The FEMP conducted an investigation of the development status of this technology, finding it to be in a relatively immature state of R&D for radiological contaminants. Experiments on many chemical complexing agents have been performed in the last decade and continue by industry, academic and government laboratories. Although fundamental physical and chemical characteristics are understood concerning the mechanics of either precipitation or sorption barriers, very little is known relative to actual effectiveness, field placement and long-term cost/performance benefits.

The FEMP performed an evaluation of the utility of these technologies based on the Fernald 10-year remediation schedule, cost, performance and implementability. These criteria, driven by the Phase I OSDF design package lead the FEMP to conclude that the number of uncertainties surrounding chemical barrier placement cannot be answered with an adequate degree of confidence to warrant incorporation of barrier technology at this time.

However, commercially available phosphate rock has been shown in preliminary laboratory tests to be relatively effective in stabilizing uranium through a combination of sorption and precipitation mechanics. The use of phosphate rock will be evaluated by the FEMP during the cell design phase, as an alternative medium to the limestone pea gravel currently planned for the leachate collection system.

During the remainder of the Remedial Design Process, the FEMP will continue to monitor the progress of outside R&D efforts being performed for potential incorporation of geochemical barrier technologies into the design of subsequent stages of the OSDF.

I. INTRODUCTION

In the Record of Decision for Operable Unit 2 (June 1995) for the Fernald Environmental Management Project (FEMP), the FEMP agreed that engineering evaluations will be performed during the Remedial Design process if an emerging technology "...is developed that may significantly reduce the volume, toxicity, or mobility of waste." The FEMP specifically identified "geochemical barriers" as one of the two key technologies having the potential benefit of protecting the underlying Great Miami Aquifer from vertical contaminant migration out of the planned on-site disposal cell. This report supplements a separate evaluation submitted to EPA on the second key technology, "soil stabilization". Geochemical Barriers are defined for use at the FEMP as any distinctly separate body of permeable reactants designed to selectively extract contaminants from vertically mobile groundwater or leachate. Two specific barrier applications are being considered:

a) placement of reactants as a basal member of the multi-layer cell liner; and
b) replacement of limestone pea gravel in the leachate collection system with phosphate rock having uranium extraction capability.

This report summarizes the FEMP investigation of the Geochemical Barrier development efforts being conducted by private sector and government-funded laboratories. Methods consisted of interview of key personnel, literature review, and laboratory tests on Fernald soils. The FEMP recognizes that additional R&D may exist in the private sector which has not been identified, but does not expect to find technology development progress beyond that presented in this report. The investigation was performed to determine the state-of-the-art and to evaluate the potential benefit of incorporating geochemical barrier technology into the planned disposal cell at the FEMP. This report also presents a description of the technology, general summary of development efforts and results, and the evaluation criteria used to reach recommendations relative to remediation plans at the FEMP.

II. TECHNOLOGY REVIEW

Reactive chemical barrier methods being evaluated for the capture of mobile contaminants consist of either the precipitation of insoluble solid compounds or ion-exchange sorption. The concept of installing a semi-permeable, or chemically restrictive barrier was originally intended as an injection method to remediate VOC-contaminated aquifers. The installation of a geochemically restrictive barrier was first field tested in 1993 by the University of Waterloo at Borden Air Force Base in Ontario, Canada. A vertical cut-off trench barrier was successfully installed there using zero valent iron to degrade organic contaminants in groundwater.

Although research on barrier technologies concentrated on organic contaminants, the technology was expanded to include the extraction of RCRA metals. Research on radionuclide extraction has only recently begun, and candidate installation alternatives now include cut-off wall trenches and landfill liners[1,2].

Experiments are being conducted by a number of organizations to test reactants primarily in the lab, although several field and pilot tests are also being performed to determine the extraction effectiveness of various reactants. Chemically active compounds showing the most promise for radionuclide extraction research include:

- Amorphous ferric oxyhydroxide, $Fe(OH)^3$ or AFO
- Chemical and industrial grade phosphate sources
- Hydrated lime, $Ca(OH)^2$
- Ferrous sulphate, $FeSO_4$
- Zero valent iron compounds (iron filings, steel wool, etc.)

Examples of relevant R&D activities on geochemical barrier extraction of radionuclides include:

1. In early lab tests, the DOE Environmental Sciences Lab (ESL) at Grand Junction conducted batch and column tests using a layer of $FeSO_4$ overlying a layer of $Ca(OH)_2$ to simulate a liner for the Monticello uranium mill tailing repository[3]. These chemicals were selected from a large variety of materials screened for their ability to remove uranium and molybdenum from groundwater. Results showed that $Ca(OH)_2$ was effective at removing uranium (treated with 0.75g/L @ Ph 10.9) and $FeSO_4$ was effective in the precipitation of molybdenum.

ESL showed that decreased Eh and increased pH are responsible for the precipitation of uranium. With the dissolution of $FeSO_4$, dissolved Fe^{2+} contacts $Ca(OH)_2$ producing a sharp rise in pH, while the Eh of the fluid is lowered as Fe^{2+} is oxidized to Fe^{3+}. The $Ca(OH)_2$ layer continues to dissolve, maintaining the high pH and continuing to precipitate $CaUO_4$; dissolved uranium decreased from 30.0 to as low as .070 mg/L. Precipitation is controlled primarily by the iron and lime system dynamics.

ESL concluded that...

> "Other considerations for chemical barrier that need to be evaluated include: (1) the effect of high pH and high calcium concentrations produced by $Ca(OH)_2$; (2) the degeneration of $Ca(OH)_2$ by reactions with silicates to form calc-silicates and with carbonate to form calcite; (3) the effect of chemical changes on permeability and mechanical strength; and (4) the oxidation of $FeSO_4$ to ferric oxyhydroxides."

In 1992-93, ESL conducted a series of lab tests and a survey of radiological barrier

research activities using hydrated lime, fly ash, barium chloride, calcium phosphate, titanium oxide, peat, lignite, ferrous sulphate and ferric oxyhydroxide.

In 1992[4], ESL noted that the pH values of the treated pore fluids varied from 2.18 to 12.65 depending on reactant used; maximum extraction efficiency for each reactant was shown to be pH and concentration dependent. However, phosphate extracted uranium over a wide range of pH. Although ESL concluded that the reactants tested are capable of extracting uranium with varying efficiencies, none of the work addressed criteria for the longevity of either the barrier or the resulting uranium compounds.

The 1993 ESL report, "Chemical Barriers for Controlling Groundwater Contamination"[5], still accurately represents the 1995 state-of-the-art for radionuclide contamination. ESL notes that,

> "The potential risks of using chemical barriers must be evaluated as well as the potential benefits. The technology for chemical barriers is not well developed. Field experiments and actual usage will be needed before it can be reasonably certain that lab data and model concepts will predict accurately the performance desired at a site...Rates for many reactions of interest to chemical barriers are not well known. No generalizations can be made comparing reaction rates in precipitation versus sorption barriers."

In concluding remarks, ESL adds,

> "Most of the chemical barrier research performed to date has focused on evaluating the extraction potential of select industrial materials using lab testing on a variety of groundwater compositions, contaminant types and pH ranges. More efforts are required to develop accurate predictive models, evaluate flow patterns at specific sites, and integrate chemical barriers into large-scale remediation designs."

2. Sandia and Pacific Northwest National Labs are conducting a lab and pilot-scale R&D barrier project at the DOE Uranium Mill Tailing Remedial Action (UMTRA) site in Durango CO. The objectives are to investigate the possibility of utilizing zero valent metallic iron (steel wool, shavings, etc.) compounds to treat the uranium-contaminated aquifer. Metallic iron immobilizes uranium by chemical reduction and subsequent precipitation. When iron is treated with minor amounts of catalyzer such as copper, the rate of reduction is noticeably increased. For samples with 200 ppb uranium, concentration decreased to below detection (0.5 ppb) after 24 hours. Samples with 4500 ppb uranium were reduced appreciably within 24 hours and after 4 days were below detection limit. During the tests, the pH did not vary from 7.7. No work was done to determine optimal volumes, lifespan or redissolution potential.

Marozas, et al, 1995[6], conclude,

> "...Laboratory results have verified that metallic iron materials can remove uranium from water derived from uranium mill tailing operations...Long-term performance of these materials in the field will be tested in the pilot study, and evaluations made on efficiency and cost...Before reactive barriers can be accepted as a reliable and efficient method...field studies such as the Durango pilot are needed to provide efficiency, longevity, and control information to environmental scientists, engineers, regulators and site owners".

3. The EPA Remediation Technologies Development Forum (RTDF) - Permeable Barriers Work Group first met in March 1995 with its industry partner, the DuPont Company. The RTDF joined with the DOD Strategic Environmental Research and Development Program (SERDP) to conduct field tests at Dover AFB, the fifth site in the National Test Site Program. The Forum was organized as a vehicle to address the common groundwater remediation objectives of industry and government. The primary focus of this newly formed group is on organic contaminants and emplacement techniques. However, the "inorganics subgroup" plans to monitor and report on developments of heavy metals extraction techniques proposed and being investigated at Pacific Northwest Lab, Sandia, Savannah River, Durango, Portsmouth, West Valley, etc. All potential chemical reactants are being considered, whether commercially available or not. Much of the work involves limited pilot projects or field tests on site-specific aquifer issues. The key objectives of the field tests are to define appropriate chemical reactants and emplacement techniques. At the EPA/DOE/DuPont sponsored National Containment Workshop in August 1995, identified topics of uncertainty which included:

- Conceptual advantages of reactive barriers;
- Containment-reactant combinations being researched;
- Verification of long-term, low operating cost;
- Advantages, limitations, stage of development of issues;
- Construction/depth limitations.

In May 1995, Rust Geotech prepared an unpublished summary of current barrier development efforts for the RTDF, "Research on Permeable Barriers"[1]; and in April 1995, the EPA Technology Innovation Office published "In Situ Remediation Technology Status Report: Treatment Walls"[2]. These documents are kept in the Fernald Soil Remediation Project files.

4. The Technology Evaluation Task Force of the DOE Innovative Treatment Remediation Demonstration Program (ITRD at Sandia N.L.) investigated the potential for funding the accelerated development of radionuclide barrier technology. The Task Force identified active bench scale lab testing on heavy metals at Pacific Northwest Lab, Sandia, Grand Junction and Johns Hopkins Univ., noting the preliminary field

tests on radionuclides which have been conducted at several uranium mine tailings (UMTRA) sites. In the unpublished minutes of the October 1995 meeting[7], the Task Force concluded,

> "...it is not appropriate for the ITRD to fund barrier development, given our charter to provide impetus to technologies that are ready for full-scale field testing".

However, the technology is,

> "...worthy of continued research, but the results will probably not be available for inclusion into the engineered containment facility (at Fernald)".

5. In mid-1995, M.K. Fergusen began on-going lab and field tests on uranium contaminated soils at the Weldon Springs Removal Action Project using zeolites, wood chips, phosphate and peat. The objectives are to evaluate the incorporation of a geochemical barrier as the uppermost layer in disposal cell liner design. Batch tests are being run for 106-day periods to identify leach water contaminant concentrations using two site wasteform types: sludge and soil stabilized with a cement fly-ash; and rad-contaminated soils with an average 820 pCi/g uranium.

In verbal communication, Fergusen noted that testing on the rad-soils showed a strong relationship between decreasing uranium in the leachate as pH rose from 7 to 10.5. The sludge leachates appear to enhance the solubility of uranium in the rad-soils; the carbonate in the soils is likely binding with uranium generating soluble anionic complexes.

Initial test results on the selected reactants, combined into a layer with clean soil in varying ratios, showed that phosphates and peat were more effective at precipitating uranium in contaminated soil. Fergusen is continuing the tests to quantify the optimal reactant and treatment ratios and to evaluate the capacity of these mixes to attenuate uranium. No work is being planned to determine the mechanical properties or longevity of the created barriers.

6. Under the FEMP direction, Oak Ridge National Lab (ORNL) and the Alliance of Ohio Universities (Ohio State Univ. in this project) conducted multiple batch equilibrium and column tests using Fernald uranium-contaminated soil[8,9]. OSU used blended and layered reagent-grade phosphate which included: hydroxyapatite, monobasic and dibasic calcium phosphate, diammonium phosphate and powdered fluoro-apatite phosphate rock. Position of the layers were varied from top to bottom of the columns. ORNL used commercially available fertilizers in the form of rock phosphate, calcium phosphate and diammonium phosphate. Each lab reports that the reactants were effective at removal of uranium from leach solutions, with varying efficiencies. Controlling factors were reactant permeability, leachate U-concentration,

system pH and flow rate.

ORNL additionally concluded that water soluble forms of phosphate blended with soils were more effective at forming stable compounds than layered insoluble forms. Ohio State (OSU) was unable to determine the form of uranium solids with X-ray diffraction, and therefore unable to determine long-term solubility. In personal communication each noted that many unknowns exist relative to the actual placement of phosphate barriers at Fernald. If DOE elects to continue funding, work would be directed at less complex soil-reactant blending techniques or on phosphate rock as a pea gravel alternative in the leachate collection system.

In addition to their laboratory tests, OSU prepared a summary of the state-of-the-art of geochemical barrier technology development[10]. OSU notes that of the many sorbent materials tested historically, lignite, peat, titanium oxide, iron oxides, and zeolites have proven to be the more effective barriers, however:

> "...each material has an optimum solution pH range and fluctuation causes uranium to remobilize back into solution. Since the chemical variations of leachate in the proposed (FEMP) landfill are unknown, sorption barrier materials are not recommended for long-term containment of uranium..."

OSU states that as precipitation barriers:

> "...Hydrated lime and fly ash generate calcium uranate...which is stable only at pH values above 11, and changes in landfill environment over time could decrease effectiveness...and allow uranium to redissolve into the leachate."

> "...Zero valent iron and organic carbon precipitate uranium by reductive precipitation, but long-term reliability in a landfill is unknown...changes in the redox state over the life of the landfill could decrease effectiveness and remobilize uranium."

> "...Calcium phosphate (hydroxyapatite) and phosphate rock are able to precipitate UO_2^{+2} over a wide pH range...hydroxyapatite is more effective but being pure reagent grade chemical at $100K per cubic yard is not cost effective...before phosphate rock can be used as a chemical barrier, analytical work must be done to quantify its effectiveness..."

7. GeoSyntec Consultants prepared an independent, unpublished review of R&D development efforts on geochemical barriers[11] for the Naval Facilities Engineering Command. GeoSyntec also assembled a compendium of published articles on techniques used to retard the migration of radionuclides for the FEMP; this compendium addresses techniques more related to the FEMP soil amendment investigation and is discussed in that parallel report to EPA.

The technology review conducted for the Navy by GeoSyntec concentrated on shallow vertical barrier techniques to protect aquifers in coastal and estuarine areas from landfill-leakage of VOC's, pesticides, explosives, chemicals and soluble radioactive compounds. These high-permeability geographic areas are subject to high water tables and tidal flux, which accelerate pollutant migration. The investigation concentrated primarily on grout barrier and slurry/cut-off wall techniques which have been well developed and are in use by the construction and landfill disposal industries. These techniques are more appropriate to short-term aquifer protection (relative to FEMP time requirements), and highly mobile situations requiring on-site monitoring, maintenance and operational controls. As a result, this investigation provided no new insights to the horizontal barrier needs of the FEMP.

8. Using results achieved by the DOE Subsurface Science Program, Pacific Northwest Laboratory will begin a feasibility test in FY96 to evaluate in situ redox manipulation to control the mobility of toxic metals. The test will use dithionite injection to reduce sediment from ferric to ferrous iron, creating a permeable barrier. Mobile chromate passing through the barrier will be reduced by the ferrous iron to highly immobile iron chromium hydroxide. If successful, technology development may be expanded to include radionucles.

III. TECHNOLOGY EVALUATION CRITERIA

In order to determine the viability of incorporating any emerging technology into the Fernald Soil Remediation Project (SRP), four primary criteria were selected. In order of priority, these criteria are:

1. Schedule - under the accelerated 10-year remediation option at the FEMP, the application of proven new technologies must be integrated into field operations in time to realize a quantifiable benefit to remediation.

2. Cost - the use of new technologies must not appreciably add to the approved baseline cost. Higher cost may be justified if dramatic reductions in risk are achievable versus conventional methods.

3. Performance - the technology must reliably produce a quantifiable reduction in volume, mobility or toxicity of FEMP radiological waste.

4. Implementability - defined here as: the availability of commercial equipment or materials, delivered to the FEMP on a scale necessary to meet remediation requirements; compatibility with existing remediation conditions and operations; acceptability of stakeholders and regulators; and use of chemicals that are non-hazardous to remediation personnel

and the environment.

Using the criteria above, the FEMP performed an evaluation of the applicability of Geochemical Barrier technologies to the FEMP OSDF, which is presented in Section IV below.

IV. CONCLUSIONS

Schedule

The FEMP has concluded that the R&D work currently being performed will not provide quantifiable results on candidate geochemical barrier-liner materials for inclusion in the first OSDF design package. Due to the anticipated further reduction in federal R&D funding and limited capabilities in the private sector, the FEMP believes that this technology may not mature to the point of even limited field application on radionuclide contamination within 5 years.

However, results of testing on rock phosphate should be completed in time to replace limestone pea gravel during construction of the leachate collection system if warranted. Disposal cell construction is scheduled to begin in April 1997.

Cost

Since definitive answers to chemical reactant dynamics, treatment ratios and operational issues cannot be provided by October 1996, costs for materials, required application equipment, and labor can only be roughly estimated for comparison and evaluation. It must be noted that at this time, data on compressive strength and compatibility with the existing liner design are not available for the candidate reactants.

The table below compares estimated installation costs for candidate industrial-grade barrier materials in each stage of the disposal cell; additional costs include material, equipment and labor time, shipping, G&A, fee, etc. Except for AFO and phosphate rock, the FEMP assumes that structurally competent barrier materials are commercially available. Using semi-quantitative performance data, the FEMP assumes for this report that the barrier will be placed as an additional (basal) 6-inch member of the liner.

Modeling studies by RUST Geotech indicate that 300 tons of powderized AFO, disced into the lower 6 inches of the basal clay liner, would effectively extract uranium from leachate; this design would require only a minor increase in labor and equipment costs.

If determined to be an effective media for extraction of uranium from leachate, phosphate rock will simply replace limestone pea gravel in the leachate collection

system; no additional application costs will be required above baseline. However, net material costs above the limestone baseline include construction of a rail receiving facility at or near the Fernald site.

Barrier Cost Per Disposal Cell Stage

	QUANTITY	MATERIAL	EQUIPMENT	LABOR	TOTAL
$Ca(OH)_2$	6150 yd^3	$375 K	$12,300	$7700	$395 K
$FeSO_4$	"	$800 K	"	"	$820 K
Fe^0*	"	$6,345 K	"	"	$6,365 K
AFO	300 tons	$125 K	$5000	$3000	$133 K
PO_4rock●	190 K yd^3	$5250 K	n/a	n/a	$5,250 K

* Granular steel shot
● installed in leachate collection system vs limestone pea gravel; material cost shown is net increase above limestone baseline and includes construction of a rail receiving facility.

Performance

During the remainder of 1996, work on barrier technologies by various organizations will continue to concentrate on determining basic chemical interactions in the lab. Operational methods, field performance and long-term results will not be known in the foreseeable future.

R&D to date has assumed equal leachate flow through the liner, contacting all of a homogeneous barrier. However, preferential leakage along vertical fractures through the cell and liner, with minimal exposure to the barrier is more probable. Other unknown performance issues for candidate reactants which are critical to engineering design and decision making include:

- Service life of candidate barrier media using estimated leachate uranium concentrations, flow-through leak rates and barrier thicknesses.
- Compressive strength to support cell overburden.
- Required thickness of barrier material.
- Design criteria for either a precipitation or sorption barrier.
- Effects on reactants by varying the disposal cell characteristics, eg. pH, Eh, CEC, Redox, etc.
- Relative operational effectiveness of possible reactants, eg. ferric oxyhydroxide(AFO), phosphates, zero valent irons, hydrated lime, ferrous sulphate.
- Long-term solubility of formed complexes.

- Possible precipitation of other RCRA metals due to chemical reactions, and resulting effects on the barrier.
- Potential effects of chemical reactions on the physical characteristics (eg. density, permeability, solubility, etc.) of the underlying carbonate-rich glacial tills.
- Relative affinity of other leachate constituents competing with the candidate barrier for uranium.

Initial ORNL and OSU lab tests confirm prior work showing the affinity of rock phosphate for soluble uranium. The FEMP plans to conduct additional engineering evaluations to determine the performance efficiency of rock phosphate as an alternative material in the leachate collection system.

Implementability

It is not possible at this time to select a specific reactant(s) based on proven performance, nor to quantify treatment ratios and design emplacement protocols. Therefore, evaluation parameters cannot be quantified to determine the implementability of geochemical barrier methods by June 1996. As stated above, parameters include availability, acceptability, compatibility, and hazardous nature of reactants. The table below summarizes these parameters for selected candidate barrier materials.

If phosphate rock proves to be a feasible alternative to limestone pea gravel in the leachate collection system, DOE will be able to quickly evaluate the actual implementability of this commonly used and easily emplaced commercial material for cell construction. Material transportation, either by rail and/or truck, will need to be discussed with stakeholders.

Implementability of Candidate Barrier Materials

	Available	Acceptable	Compatible	Hazardous
$Ca(OH)_2$	yes	probably	unknown	no
$FeSO_4$	yes	probably	unknown	unknown
Fe^0	yes	probably	unknown	no
AFO	yes	probably	unknown	no
PO_4 rock	yes	yes	yes	no

V. TECHNOLOGY DEVELOPMENT PLAN

1. Driven by an accelerated 10-year remediation schedule, the FEMP will not attempt to incorporate a geochemical barrier in Phase I of the OSDF. Although increased costs are minimal, the number of engineering uncertainties surrounding chemical barriers cannot be answered with an adequate degree of confidence to warrant incorporation of this technology into this stage of the OSDF.

2. During the remainder of the Remedial Design process, the FEMP will continue to closely monitor barrier development efforts through interaction with EPA/RTDF and DOE/OTD. If cost-performance data and application protocols are identified, the FEMP will evaluate the relative benefits of incorporating a geochemical barrier in the design of subsequent stages of the OSDF and field operations methods.

3. Phosphate rock has initially proven to be relatively effective in stabilizing uranium. The FEMP will perform or supervise an engineering evaluation of this alternative medium to the limestone pea gravel which is currently planned for the leachate collection system. Results are anticipated to be available by January 1997. During the evaluation period, the FEMP will work closely with the Florida Phosphate Institute, the Alliance of Ohio Universities, commercial suppliers, and pertinent National Labs to determine the cost-performance factors which will justify use of phosphate rock pea gravel in the leachate collection system.

REFERENCES

1. Morrison, S.J.; Spangler, R.R., 1995. Research on Permeable Barriers. Rust Geotech, Environmental Sciences Laboratory, Grand Junction Projects Office for the RTDF Permeable Barriers Working Group. Unpublished.

2. U.S. Environmental Protection Agency, 1995. In Situ Remediation Technology Status Report: Treatment Walls. OSWER Technology Innovation Office, EPA 542-K-94-004.

3. Spangler, R.R.; Morrison, S.J. 1991. Laboratory Scale-Test of a Chemical Barrier For Use at Uranium Mill Tailings Disposal Sites. *Environmental Restoration '91,* Pasco WA., Conference Proceedings, pp. 739-744.

4. Morrison, S.J.; Spangler, R.R., 1992. Extraction of Uranium and Molybdenum From Aqueous Solutions: A Survey of Industrial Materials for Use in Chemical Barriers For Uranium Mill Tailings Remediation. *Environmental Science Technology,* v.26, No. 10, pp. 1922-1931.

5. Morrison, S.J.; Spangler, R.R., 1993. Chemical Barriers for Controlling Groundwater Contamination. *Environmental Progress,* v.1, pp. 175-181.

6. Marozas, D.C.; Dwyer, B.P.; Cantrell, K., 1995. Reactive Barrier Treatment of Groundwater at Uranium Mill Tailings Sites - Pilot Demonstration, Durango CO. *International Containment Technology Workshop,* Baltimore MA; unpublished proceedings

7. Peters, G., 1995. Innovative Treatment Remediation Demonstration Minutes. *October 1995 Task Force Meeting,* Cincinnati OH.

8. Francis, C; O'Dell, D., 1995. Immobilization of Uranium Transport in Soils Using Phosphate Amendments. Oak Ridge National Lab Interim Report to the FEMP Soil Remediation Project

9. Traina, S.J.; Logan, T.J.; Fuller, B., 1995. Potential Use of Phosphates for Insitu Immobilization of Uranium in Contaminated Soils. Ohio State University Contract Report to the FEMP Soil Remediation Project; unpublished

10. Traina, S.J.; Fuller, B.A., 1995. State-of-the-Art Status Report Geochemical Barriers. Ohio State University Contract Report to the FEMP Soil Remediation Project; unpublished

11. GeoSyntec Consultants, 1994. Subsurface Landfill Barriers (SBIR Topic N93-130). Prepared for the Naval Facilities Engineering Command; unpublished

DRAFT REV. A
PHYSICAL SEPARATION REPORT

Fernald Environmental Management Project

Soil Remediation Project

May 1996

2502-ES-004

EXECUTIVE SUMMARY

In support of the selected remedy, the Fernald Environmental Management Project (FEMP) agreed to perform engineering evaluations on physical separation techniques which would assess their viability for application to the Operable Unit 5 remedy. It may be possible for physical separation to achieve some cost-effective waste minimization. Although OU5 bench-and-pilot-scale treatability testing indicated that chemical leaching techniques (soil washing) were effective, application to FEMP soil became cost prohibitive when compared to the per cubic yard incremental cost savings associated with soil placement in the On-Site Disposal Facility (OSDF). As a result of these findings, physical separation was evaluated for the decontamination and reuse of existing site gravel, in construction applications.

An assessment was performed of physical separation techniques, applied to recycling and reuse of gravel. Five technology evaluation criteria were used to determine the viability of incorporating physical separation processes in the Fernald Soils Remediation Project (SRP). In order of priority, these criteria are quantity, schedule, cost, performance and implementability. Many technical uncertainties exist for the on-site treatment of gravel with respect to these criteria. Also, only 60,000 cubic yards of gravel have been identified during the remedial investigations, and this material will be generated sporadically over a period of 7 to 8 years. This would necessitate interim storage of gravel until enough is available for processing. Therefore, based on results of the evaluation, the recommendation is to not further consider any physical separation treatment of gravel on site.

I. INTRODUCTION

The objective of this report is to provide a technical review and status report of physical separation technology for its potential application to gravel re-cycling at the FEMP. As part of this review, physical separation is evaluated using criteria that is relevant to the CERCLA process as well as cost and schedule constraints associated with the remedial activities at the FEMP. A conclusion is drawn as to the implementability of physical separation as a support remediation option, and a recommendation is made for a proposed path forward.

The identification and initial screening of technologies applicable to soil were presented in the Feasibility Study Report (FS) for Operable Unit 5 (OU5) (June 1995). Selected process options were evaluated based on effectiveness, implementability and relative cost, and were retained as either "primary" or "secondary" processes. Under the general response action category of soil treatment and physical/chemical remedial technology subcategory, physical separation was retained as a support process option that could potentially reduce the size of the OSDF. Soil washing was subsequently deleted as a support option, due to excessive operational costs.

Physical separation is described in the FS as an "ex situ process to minimize waste through volume reduction by physically separating out size fractions of soil containing minimal contamination". Referenced as an emerging technology in the FS, physical separation was considered to be an implementable technology requiring equipment that is readily available and requires a minimum number of operators to run the system. It was also considered to require low capital cost as well as low operation and maintenance cost. However, it was noted that additional engineering studies (treatability studies) were necessary to determine the extent of its effectiveness as a support process option. In the Record of Decision (ROD) for OU5 (January 1996), the FEMP agreed to continue to examine and apply this emerging technology pertaining to treatment of on-site gravel, provided these methods are demonstrated to be cost effective and implementable.

II. TECHNOLOGY REVIEW

Physical separation techniques have been the focal point of most soil washing processes. Similar process have been used in the solution mining and mineral extraction industries for many years to remove contaminants from soil. The basis for this process is particle separation by size and/or density characteristics.

The initial objective of any physical separation process is to divide soil aggregates into single-grain compositions of clay, silt, sand and gravel. This reduction is accomplished by either mechanical means (e.g., high pressure water or mixers) and/or chemical dispersing agents (e.g., sodium salts). This initial step is the basis for separating the coarse-size fraction of the soils (e.g., sand and gravel) from the finer particles of soil (e.g., silt and clay). The second objective of physical separation is to dislodge radiological contaminants from the surfaces of gravel by force and/or abrasive processes. High-pressure water washers (hydraulic shearing) and attrition scrubbers are two types of equipment to aid in these physical separation processes. Physical separation operations in soil washing may also include screening, centrifugation, froth flotation, hydrogravimetric separation (including hydrocyclones, mineral jigs and spiral classifiers), and multigravity separation.

Physical separation processes were investigated as part of the OU5 soil washing treatability study. An initial review of the literature on the use of soil washing for removing radionuclides was conducted in 1991 in support of the "Treatability Study Work Plan for OU5: Soil Washing". This review indicated that the cost-effective application of soil washing to radionuclide-contamination might be feasible. Therefore, the FEMP conducted an extensive investigation into the application of soil washing as an effective remedial alternative for soil. The investigation began with a characterization study by Oak Ridge National Laboratory (ORNL) of uranium contamination at the FEMP. Subsequent bench-scale testing was conducted by IT

Corporation.

Based on the findings from the bench-scale physical separation and chemical extraction testing, a combined approach was developed for pilot-scale testing. The initial configurations of two separate soil washing pilot plants were based on the fundamental designs of current soil washing systems within the United States.

The data from this pilot-scale testing indicated (on a conservative basis) that greater than 80 percent of the soil could be treated to a residual total uranium concentration of 100 mg kg^{-1} or less with a mobility of less than 1 mg L^{-1} total uranium. The application of soil washing to FEMP soil became cost prohibitive when compared with per cubic yard cost of placing soil in the OSDF. As a result of these findings, physical separation was directed at the recycling and reuse of gravel in the OU5.

III. TECHNOLOGY EVALUATION CRITERIA

Four primary evaluation criteria were used to determine the viability for using physical separation for the treatment of gravel. In order of priority, these criteria are schedule, cost, performance and implementability.

Schedule
The application of physical separation for gravel treatment must be compatible with scheduled field operations. Benefits associated with gravel recycling and reuse must be in a timely manner so as to realize a qualifiable and/or quantifiable benefit to the remediation effort. The primary impact on the schedule is the availability of gravel for excavation versus the need for gravel, e.g., haul-road construction, interim storage areas, cell construction, etc.

Cost
The cost of any physical separation treatment must not appreciably add to the approved baseline for remediating gravel. Higher cost may be justified if dramatic reductions in volume, toxicity or mobility are achievable. Cost must take into account the savings associated with any volume reduction as well as savings derived from recycling and reuse of indigenous materials.

Performance
Any physical separation process must achieve a performance level in: a) reliably producing a quantifiable process that recycles and reuses indigenous resources within the FEMP, b) eliminating the need to import additional construction materials, and c) reducing the amount of material ultimately going into the disposal facility.

Implementability
Physical separation must be supported by the availability of commercial equipment

and materials, delivered to the FEMP on a scale necessary to meet recycling requirements. Implementability is also governed by regulatory issues relative to disposition of gravel following treatment. Free release criteria, which may be based on final remediation levels (FRLs), must be established if the gravel is to be disposed outside a radiologically controlled area.

IV. CONCLUSIONS

The use of physical separation processes for treating gravel has been reviewed, resulting in the following conclusions. The estimate of total on-site gravel presented in the OU5 FS was approximately 170,000 cubic yards. A subsequent review of engineering drawings and specifications concluded that gravel was not used as fill underlying and surrounding building foundations or for utility ditches, as originally assumed. A 1985 site run-off characterization survey estimated total gravel volumes for both production and administrative areas. Gravel estimates for each area was further broken down into surface gravel and gravel under roads. In the production area, gravel estimates for surface areas and road foundations were 21,272 and 29,426 cubic yards, respectively. In the administration area, gravel estimates for surface areas and road foundations were 2,221 and 6,699 cubic yards, respectively. This totals 59,618 cubic yards of gravels with 8,920 cubic yards in the administrative area that may not require treatment prior to reuse. Although changes within the FEMP have evolved over the past 11 years, it is concluded that the addition and removal of gravel has not changed.

Schedule

Gravel will be generated as a materials component of planned site excavation, scheduled to begin in FY99 and be completed in FY2004. The primary uncertainties relative to the treatment of gravel are the quantity of gravel excavated during any particular time period, and the storage locations which may require double handling. Combined with the relatively small quantities noted in the previous section, the availability of gravel during any specific time period for cost effective treatment is not likely.

Cost

An internal cost estimate for physical separation was produced by FERMCO. Direct cost estimates were derived from individual remediation companies on costs associated with mobilization, set-up, operation and maintenance aspects for a separation system located at the FEMP. Indirect costs were determined by FERMCO for conducting any separation activity at the FEMP. For extrapolation purposes, two internal cost estimates were produced using total volumes of 20,000 and 200,000 cubic yards of material to be treated. However, these estimates assume material is stockpiled and available. Based on a 90% treatment efficiency, cost would range

from $670 to $450 per cubic yard, respectively. This cost includes contingencies and residual disposal.

The above cost estimates can be further extrapolated to a more simple physicochemical process for the singular treatment of gravel. A simplified physical separation process associated with gravel treatment was initially considered to be a cost-effective method for the recycling and reuse of gravel at the FEMP; the resulting treated gravel would be available for remediation activities during the FY96 and FY97. However, the additional indirect costs associated with conducting any treatment at the FEMP make even a simplified process expensive compared with the per cubic yard OSDF cost.

Performance

Any physical separation process must achieve a selected performance level. This may be accomplished by reliably producing a quantifiable recycled volume, and by eliminating the need to import additional construction materials during the remediation effort, which would increase the amount of material ultimately going into the OSDF.

The performance effectiveness of a physical separation process for gravel has not been quantified. Previous test results contain little data as to treatment effectiveness on the gravel fraction (2 millimeter to 3 inch diameter soil fraction). The gravel is calcarious and relatively porous and may be significantly different in the contaminant-solid phase matrix from the soil fraction (less than 2 millimeters). The absence of any characterization data on the gravel-contaminant matrix and any bench-scale test data on the effectiveness of the physicochemical treatment of the gravel fraction yields no conclusive determinations relative to performance effectiveness. Primary concern exists for the migration of uranium into the inner porous areas of the gravel aggregate, where it would be difficult or impossible to remove without actually crushing the aggregate. Another concern is soil mixed with the gravel, which may also be contaminated and require additional treatment.

Implementability

Physical separation techniques have been used extensively during the past four decades in the mining industry. The application of these processes to the treatment of soils over the past decade has resulted in the global availability and use of commercial soil washing systems. The use of physical separation processes for treatment of gravel requires an even more basic process than that necessary for the treatment of soils. There are a number of physical-separation-based commercial systems that could be delivered to the FEMP on a scale necessary to meet remediation requirements. However, the effectiveness of physical separation technology on the calcarious gravel at FEMP is unknown. Also, given the relatively small quantity (i.e., 50,000 - 60,000 cubic yards) of potentially impacted material and the sporadic excavation of the material over a 7 to 8 year period results in an order of magnitude higher cost than on-site disposal. There are no existing off-site treatment facilities

currently permitted to remediate gravel materials. Transportation costs to and from any facility are dependent on distance.

V. RECOMMENDATIONS

An assessment of the use of physical separation for the recycling and reuse of gravel has been performed. Many uncertainties exist for the on-site treatment of gravel with respect to quantity, cost, performance and implementability. Based on these uncertainties, the recommendation is to not further consider the physical separation-treatment of gravel, either on or off site.

DRAFT REV. A
SOIL STABILIZATION REPORT

Fernald Environmental Management Project

Soil Remediation Project

May 1996

2502-ES-001

EXECUTIVE SUMMARY

On-property disposal emerged as the preferred remedy for contaminated soil and sediment that meet a Waste Acceptance Criteria (WAC) of 1030 ppm total uranium, from the detailed evaluation of alternatives in the Operable Unit 5 Feasibility Study. The preferred remedy was selected for reasons of: long-term reliability; lowest short-term risks; relatively low overall costs; and employment of proven technologies. Soil and sediment exceeding the WAC for on-property disposal would be shipped for offsite disposal.

In the Record of Decision for the Fernald Environmental Restoration Site (FEMP), Operable Unit 5 (January 1996), the FEMP agreed to:

- "Continuation of efforts to examine and apply, where practical, emerging technologies pertaining to treatment of soil and sediment...Engineering studies will be performed on soil amendment with phosphate additives to assess the viability for application to the selected remedy.

- Continuation of efforts to examine and apply, where practical, throughout the duration of remedial activities, new methods or technologies to mitigate environmental releases occurring as a result of the implementation of remedial actions."

The FEMP specifically identified soil stabilization as one of the two key technologies having potential benefit for leachate control in the On-Site Disposal Facility (OSDF). Soil stabilization is defined here as any chemical compounding or ion exchange mechanism designed to immobilize uranium contaminants in the soils being placed in the disposal cell.

The FEMP conducted an investigation of this technology, finding it to be in a relatively immature state of R&D for radiological contaminants. Continuing experiments on many chemical complexing agents have been performed during the last decade by the environmental services and uranium solution mining industries, and academic and government laboratories. Fundamental physical and chemical characteristics are fairly well understood concerning the mechanics of forming stable compounds. However, only a partial understanding exists of actual effectiveness, field application techniques and long-term cost/performance benefits.

The FEMP also evaluated the utility of these technologies based on schedule, cost, performance and implementability. This evaluation, combined with an accelerated 10-year remediation schedule requiring Phase I soil placement by March 1998, leads the FEMP to conclude that phosphate technology may have merit at the FEMP. However, the technology is too immature for incorporation into the Phase I OSDF design. The FEMP will continue to monitor this technology for possible future uses.

During the remainder of the Remedial Design Process, the FEMP will attempt to initiate engineering evaluations of candidate techniques through various avenues within the DOE technology development complex. The FEMP will seek to influence and/or continue to monitor the progress of outside R&D efforts being performed, for possible amendment of the soils being placed in the disposal cell. The FEMP will also attempt to assess the potentially stabilizing conditions generated within the cell by the combined reducing environment, natural and man-made organics, ferrous demolition debris, and native clay soils. Technical performance, application procedures and cost justification must be determined by September 30, 1997 to impact Phase I of the soil excavation/placement schedule.

I. INTRODUCTION

From the detailed evaluation of alternatives in the Operable Unit 5 Feasibility Study, on-property disposal emerged as the preferred remedy for contaminated soil and sediment that meet Waste Acceptance Criteria (WAC) of 1030 ppm total uranium. The preferred remedy was selected for reasons of: long-term reliability, lowest short-term risks; relatively low overall costs; and employment of proven technologies. The soil and sediment exceeding the WAC for on-property disposal will be shipped for offsite disposal. Incremental costs of approximately $40 per cubic yard of soil placed in the cell compare to $674 per cubic yard for offsite shipment.

The proposed final remediation levels for soil and sediment are based upon restrictive risk assessment levels to undeveloped park users. The preferred remedy adopts the ALARA concept by applying available hand-held field radiological detection instruments to guide excavation and identify any isolated locations of higher contamination. Toward this end, the more restrictive ALARA goal of 50 ppm total non-leachable uranium is established rather than the remediation level of 80 ppm uranium in FEMP soil and sediment. For leachable uranium forms, a remediation level of 20 ppm total uranium was established. Treated soil and sediment meeting these guidelines could have restricted on-property use and not be placed into the disposal facility. EPA established a level of 5 ppm total uranium for treated soil to be used as unrestricted backfill.

The FEMP made a formal commitment that extends over the entire period of remediation to evaluate innovative technologies that are environmentally acceptable and have cost-effective potential for immobilizing radiological contaminants in the soil and sediment to be placed into the on-property disposal facility. In the Record of Decision for Operable Unit 5 (January 1996) for the Fernald Environmental Restoration Site (FEMP), the FEMP committed to:

- "Continuation of efforts to examine and apply, where practical, emerging technologies pertaining to treatment of soil and sediment...Engineering studies

will be performed on soil amendment with phosphate additives to assess the viability for application to the selected remedy.

- Continuation of efforts to examine and apply, where practical, throughout the duration of remedial activities, new methods or technologies to mitigate environmental releases occurring as a result of the implementation of remedial actions."

The determination of whether an innovative technology should be implemented depends largely on reliability and cost-benefit factors. Additionally, there are other factors which cannot be easily reduced to quantitative economic terms. These "irreducible factors" include schedule impact, technical performance, and implementability for minimizing the potential for hazardous leachate to escape into the environment from the disposal facility.

The FEMP specifically identified "soil stabilization" in the OU5 ROD as one of two key technologies having the potential to immobilize uranium contamination in the planned on-site disposal cell. This report supplements a separate evaluation to EPA on the second key technology, "geochemical barriers". Soil stabilization is defined here as any chemical compounding or ion exchange mechanism designed to immobilize uranium contaminants in the soils being placed in the disposal cell.

Commercial techniques for immobilizing contaminants in soils are commonly used in the environmental industry for VOC/SVOC contamination but have not been well developed for heavy metals or radionuclides. This report presents an overview of emerging technologies with potential for reducing leachability of uranium from the OSDF. The fundamental concept is to form stable uranium compounds, through the addition of chemical reactants during placement of soil and sediment in the facility. Application of amendments may be incorporated by the FEMP during waste placement, if proven to be cost-effective for immobilizing radiological contaminants. The selection and acquisition of a technology is necessary by March 1998 to favorably impact Phase I of the soil placement schedule.

This report summarizes the FEMP investigation of uranium stabilization development efforts being conducted by private sector and government-funded laboratories; methods consisted of interview of key personnel, literature review, and laboratory tests on Fernald soils. Although the FEMP committed to an evaluation of phosphate amendments, other potentially effective reactants were also considered. The FEMP recognizes that additional R&D may exist which has not been identified, but does not now expect to find technology development progress beyond that presented in this report. The investigation was performed to determine the state-of-the-art and to evaluate the potential benefit of incorporating uranium stabilization techniques into the OSDF. This report also presents a description of the technology, a general summary of development efforts and results, and the evaluation criteria used to reach

recommendations relative to remediation plans at the FEMP.

II. TECHNOLOGY REVIEW

Laboratory experiments are being conducted by several organizations to test the ability of various chemical additives to form stable uranium compounds. No field or pilot tests to determine application processes or the relative effectiveness of various reactants have been identified. Most current research and relevant published literature is directed at the installation of geochemically restrictive barriers for groundwater remediation, versus the ex situ addition of chemical stabilizers to contaminated soils. Although treatment techniques vary, chemical complexing processes are common to each. A discussion of chemical barrier R&D activities, with document references, is presented in the Draft Geochemical Barrier Report, May 1996.

Orthophosphate from various sources is the primary reactant under consideration for use at the FEMP. Other chemically active candidate compounds targeted primarily for radionuclide immobilization and barrier research include:

- Hydrated lime
- Amorphous ferric oxyhydroxide (AFO)
- Calcium Phosphate
- Other zero valent iron compounds.

As with geochemical barrier R&D, fundamental physical and chemical characteristics are understood concerning the mechanics of either precipitation or sorption complexes. However, only a partial understanding exists relative to actual effectiveness, field placement techniques and long-term cost/performance benefits.

Although the majority of R&D activities are focused on the installation of geochemically restrictive barriers as noted above, a lesser effort is being directed specifically toward chemical immobilization of radionuclides. Many of the same reactants are being considered. Document references listed in the FEMP barrier report to EPA are also included in the Selected Bibliography of this report. The status of pertinent soil stabilization R&D is summarized in the following paragraphs.

1. With support of the USEPA Superfund Innovative Technology Evaluation Program (SITE), Sevenson Environmental Services Inc., developed and patented a non-pozzolan, heavy metals stabilization process with the tradename "MAECTITE", which has been used at several Superfund sites. This process uses dehydration and chemical bonding principles to react with leachable nuclides. New minerals are formed which are insoluble, hard and stable for geologic time frames in landfill or soil covered environmental conditions.

In 1995, Sevenson began an independent R&D effort to apply their proprietary process to uranium contaminated soils from Fernald. Batch tests were run on various mixtures followed by leaching with distilled water, TCLP tests and ANSI 1312 testing methods. Initial results were presented to the FEMP in a confidential informal report. Several of the leach tests resulted in 100 percent reduction of soluble uranium, to non-detectable limits in comparison to untreated soil. No attempt was made to determine the nature of the uranium complexes formed or the relationships with the surrounding soil matrix. Based on current knowledge, bulking should not be a problem. The cost for Sevenson's treatment ranges from $11 to $20 per ton.

2. The IDM Environmental Corp., in association with SOLUCORP Industries recently contracted the University of New Mexico (UNM) to test their commercial heavy metals stabilization process, Molecular Bonding Systems (MBS), on radionuclide contaminants. MBS, a process using a proprietary mixture of chemicals, creates insoluble metal sulfide complexes with no curing time. Waste materials are screened and crushed, and mixed with powdered reagents in a closed hopper pug mill; water is added to catalyze the reaction. Engineered controls on off-gas Hydrogen Sulfide are required. Preliminary results on treatment effectiveness are not available at this time. In verbal communication, IDM estimates the cost for MBS treatment to be approximately $50/ton.

3. As summarized in the FEMP barrier report, Oak Ridge National Lab (ORNL) and Ohio State University (OSU) conducted multiple batch equilibrium and column tests using Fernald uranium-contaminated soil (items 7 & 8 in attached bibliography). OSU used batched reagent-grade phosphates: hydroxyapatite, monobasic and dibasic calcium phosphate, diammonium phosphate and powdered fluoro-apatite phosphate rock. ORNL used commercially available fertilizers in the form of rock phosphate, calcium phosphate and diammonium phosphate. Each lab reported that the reactants were effective at removal of uranium from leach solutions, with varying efficiencies. Controlling factors included matrix permeability, leachate U-concentration, system pH and flow rate.

ORNL concluded that water soluble forms of phosphate blended with soils were more effective at forming stable compounds than separated layers of insoluble rock phosphate. Preliminary results indicated that hydroxyapatite and dibasic calcium phosphate were most effective at immobilizing uranium. OSU was unable to determine the form of uranium solids with X-ray diffraction, and therefore unable to determine long-term stability. In personal communication, each noted that many unknowns still exist relative to the actual placement of phosphate barriers at Fernald.

4. In 1995, Argonne National Laboratory (ANL), began research to determine the effectiveness of biophosphorous treatments on uranium contaminated soils. ANL summarized the results of initial investigations[1] using phytic acid, an organophosphorous complexant which decomposes while releasing phosphates.

Phytic acid is isolated from beans and leafy vegetables and is used commercially as a nutrient source for microorganisms, and as a metal chelating and precipitation agent. However, manufacturing capacity is limited and cost for food-grade acid is excessive. Released phosphates transform actinide ions to less soluble, thermodynamically stable mineral phases. ANL lab work has concentrated on thermodynamic calculations, modeling, and dissolution experiments on selected actinides. ANL notes that,

> "...the basis of this work is the introduction of phosphate into the subsurface environment in a controlled manner. The phosphate is delivered preferentially to the polyvalent metal ions to be mineralized...or to concentrate the metal ions. The ideal vehicle for phosphate introduction appears to be a water soluble organophosphorous complexant which can be delivered as a dissolved species or aqueous slurry. This compound would slowly decompose and release phosphate to react with the polyvalent actinide ions, generating microcrystalline actinide phosphate solids. Alternately,...co-precipitation with phosphate mineral phases of ubiquitous polyvalent metal ions may be the principle mechanism for immobilization."

In summary of the initial results:

> "These experiments demonstrate a significant reduction in the solubility of trivalent and hexavalent f-elements on phosphate addition, even in the presence of 1:1 citric acid complexes... it appears that phosphate immobilization can significantly reduce the potentially mobile concentrations of tracer amounts of trivalent actinides...Actinide-phytate compounds are insoluble, and europium and uranyl phytates are converted to phosphates within a month at 85 degrees C...with a projected reactant lifetime in the absence of microbiological effects of 100-150 years, phytic acid remains an active catalyst until used up...we are at the stage in which we must begin testing the method on true soil samples."

Soil samples from the Plant 1 Pad at Fernald were sent to ANL in early February for testing. The FEMP will use test results and the future availability of industrial-grade acid to evaluate the need for further lab/field testing.

5. GeoSyntec Consultants assembled a compendium of published articles for the FEMP on techniques used to retard the migration of radionuclides[2]. The bibliography search conducted for Fernald is shown in Attachment A. GeoSyntec investigated published reports of laboratory studies dealing with radionuclide:

- migration through compacted bentonites with added carbon steel, through hydroxyl-phosphate amended backfill, and through salt-bentonite mixtures;
- sorption onto a variety of naturally occurring clays (alumino-silicates) and

other iron-rich minerals; and

- behavior in a wide range of redox conditions.

The GeoSyntec report is an excellent summary of lab work addressing the principles underlying radionuclide stabilization. However, the practical concerns of engineering design are not yet able to be addressed. The research to date indicates that the naturally occurring clays in the native glacial tills at Fernald may provide an adequate medium for the sorption of soluble uranium species.

6. At the request of the FEMP, the Technology Connection Program (EM-50) at ANL performed a computer search of companies providing contaminant stabilization services (Attachment A). The FEMP inquiry showed that the majority of these companies specialize in the mechanical treatment techniques for immobilizing VOC/SVOC contaminants. However, several companies do provide services and chemicals for the stabilization of heavy metals (noted by * in Attachment A), and are willing to apply their patented technologies to radionuclide contaminants. However, reliability, longevity, and cost-performance has not been established. As part of the commitment to investigate the utility of radionuclide soil stabilization, the FEMP will work with select industry leaders to encourage development of cost-effective radionuclide treatments.

7. Several R&D projects are emerging from the DOE Subsurface Science Program which may provide immobilization opportunities in the near future:

a. At Brookhaven National Laboratory, selective anaerobic bacteria have been used to first solubilize uranium and toxic metals from waste and then to immobilize them as different compounds. A CRADA is being developed between ORNL and the Ogden Environmental and Energy Services Company to field test the process. The work has not begun as of this date.

b. Pacific Northwest Lab developed techniques for measuring and modeling uranium sorption to clay minerals. The techniques are being applied at the Pantex Plant in Texas, where uranium is a significant contaminant and clays are a dominant percentage of the native soils. Computer models are also being developed to predict contaminant migration and to test potential mitigation strategies. Results may be useful for modeling the immobilization conditions generated in the engineered disposal cell at Fernald.

III. TECHNOLOGY EVALUATION CRITERIA

In order to determine the viability of incorporating any emerging technology into the Fernald Soil Remediation Project (SRP), four primary criteria were selected. In order of priority, these criteria are:

1. Schedule - under the accelerated 10-year remediation option at the FEMP, the application of proven new technologies must be integrated into field operations in time to realize a quantifiable benefit to remediation.

2. Cost - the implementation of new technologies must not appreciably add to the approved baseline cost. Higher cost may be justified if dramatic reductions in risk are achievable versus conventional methods.

3. Performance - the technology must reliably produce a quantifiable reduction in volume, mobility or toxicity of FEMP radiological waste.

4. Implementability is defined here as: the availability of commercial equipment or materials, delivered to the FEMP on a scale necessary to meet remediation requirements; compatibility with existing remediation conditions and operations; acceptability of stakeholders and regulators; and use of chemicals that are non-hazardous to remediation personnel and the environment.

Using these criteria, the FEMP performed an evaluation of the applicability of soil stabilization technologies to the OSDF, which is presented in Section IV below.

IV. CONCLUSIONS

Schedule

DOE concludes that the R&D work currently being performed on one or more of the candidate reactants may yield favorable results prior to March 1998; however significant reductions in cost need to be realized to be viable at the FEMP. In any event, R&D progress will be monitored for possible inclusion in the subsequent stages of disposal cell soil placement.

Cost

Definitive answers to chemical reactant dynamics, effectiveness and operational issues have not yet been determined. However, the FEMP approximated the treatment quantities and costs for the most likely candidate reactants(table below), should any prove to be useful. It must be emphasized that treatment decisions cannot be based on cost alone. Solids will be dissolved or slurried and liquid application of a selected chemical will be incorporated into the planned dust and moisture control

process at no additional labor/equipment cost.

Candidate Reactant Treatment Rates and Costs

	MAECTITE	Bio-phosphorous	AFO*	Calcium-phosphate
rate/yd^3	1-2 gal	unknown	1.8#	6.0#
\$/yd^3	\$4-8	unknown	0.75	0.65

* amorphous ferric oxyhydroxide

Performance

During the remainder of 1996, work on soil amendment technologies by various organizations will continue to concentrate on determining basic chemical interactions in the lab. Operational methods, field performance and long-term results will be addressed in late 1996 or early 1997. Among others, unknown critical performance issues which must be determined prior to consideration include:

- Service life (stability) of amended soils, using candidate reactants at estimated uranium concentrations, flow-through leach rates and soil thicknesses.
- Required application methods and ratios.
- Effects on selected reactant and resulting compounds by varying the disposal cell soil characteristics, eg. mineralogy, pH, Eh, CEC, Redox, etc.
- Relative operational effectiveness of candidate reactants, eg. bio- or mineral phosphates, hydrated lime, AFO, etc.
- Impact of possible dissolution of other RCRA metals in the resulting leachate.
- Potential effects of leachate on the physical characteristics (eg. density, permeability, solubility, etc.) of the emplaced soils, underlying cell liner and native carbonate-rich glacial tills.
- Relative affinity of other native soil components or cell constituents competing with the reactants for uranium.
- Effects of leachate and precipitants on LCS.

Implementability

It is not possible at this time to select a specific reactant(s) based on proven performance, with quantified treatment ratios and engineered emplacement protocols. Therefore, parameters cannot be quantified to determine the implementability of various soil stabilization processes. As stated above, parameters include availability, acceptability, compatibility, and hazardous nature of reactants. The table below summarizes these qualitative parameters for the candidate stabilization materials.

Implementability of Candidate Reactants

	Available	Acceptable	Compatible	Hazardous
MAECTITE	yes	unknown	probably	no
Bio-Phosphorous	yes	probably	probably	no
AFO	yes	probably	probably	no
Calcium-phosphate	yes	probably	probably	no

V. TECHNOLOGY DEVELOPMENT PLAN

1. Driven by an accelerated 10-year remediation schedule requiring start of Phase I impacted soil placement by March 1998, the FEMP is using current technologies for design. However, the FEMP will also:

   - encourage industry or government-funded experiments using Fernald soils, or pilot field projects at Fernald (eg.Sevenson Environmental, etc.); and
   - if warranted, conduct or manage additional engineering evaluations to determine the performance efficiency of commercially available materials for use in a soil amendment process.

2. Research to date has proven that a wide variety of mineral complexes are capable of immobilizing soluble uranium in a reducing environment: alumino-silicates typical of the calcium and carbonate-rich native Ohio glacial clays; natural and man-made organic materials; and iron (either zero valent or compounds such as AFO). Since these materials comprise the bulk of constituents in the OSDF, there appears to be some inherent capability to immobilize uranium.

3. During the remainder of the Remedial Design process, the FEMP will closely monitor the results of uranium stabilization R&D through liaison with industry and government labs. When favorable cost-performance data and application protocols are identified, the FEMP will further evaluate the benefits of incorporating uranium stabilization in design and construction of the OSDF.

REFERENCES AND SELECTED BIBLIOGRAPHY

1. Jensen, M.P.; Nash, K.L.; Morss, L.R.; Appleman, E.H.; Schmidt, M., 1995. Immobilization of Actinides in Geomedia by Phosphate Precipitation. Argonne National Laboratory, Chemistry Division; unpublished

2. GeoSyntec Consultants, 1995. Articles Concerning Techniques Used to Retard the Migration of Radionuclides. Prepared for the USDOE, Fernald Environmental Management Project; unpublished

3. Morrison, S.J.; Spangler, R.R., 1995. Research on Permeable Barriers. Rust Geotech, Environmental Sciences Laboratory, Grand Junction Projects Office for the RTDF Permeable Barriers Working Group. Unpublished.

4. U.S. Environmental Protection Agency, 1995. In Situ Remediation Technology Status Report: Treatment Walls. OSWER Technology Innovation Office, EPA 542-K-94-004.

5. Morrison, S.J.; Spangler, R.R., 1992. Extraction of Uranium and Molybdenum From Aqueous Solutions: A Survey of Industrial Materials for Use in Chemical Barriers For Uranium Mill Tailings Remediation. *Environmental Science Technology,* v.26, No. 10, pp. 1922-1931.

6. Morrison, S.J.; Spangler, R.R., 1993. Chemical Barriers for Controlling Groundwater Contamination. *Environmental Progress,* v.1, pp. 175-181.

7. Marozas, D.C.; Dwyer, B.P.; Cantrell, K., 1995. Reactive Barrier Treatment of Groundwater at Uranium Mill Tailings Sites - Pilot Demonstration, Durango CO. *International Containment Technology Workshop,* Baltimore MA; unpublished proceedings

8. Peters, G., 1995. Innovative Treatment Remediation Demonstration Minutes. *October 1995 Task Force Meeting,* Cincinnati OH.

9. Francis, C; O'Dell, D., 1995. Immobilization of Uranium Transport in Soils Using Phosphate Amendments. Oak Ridge National Laboratory Interim Report to the FEMP Soil Remediation Project.

10. Traina, S.J.; Logan, T.J.; Fuller, B., 1995. Potential Use of Phosphates for Insitu Immobilization of Uranium in Contaminated Soils. Ohio State University Report to the FEMP Soil Remediation Project.

ATTACHMENT A

ARGONNE NATIONAL LABORATORY
9700 SOUTH CASS AVENUE, ARGONNE, ILLINOIS 60439 (708) 252-9848

2 February 1996

Mr. Richard J. Scheper
FERMCO, Inc.
P.O. Box 398704, MS-81
Cincinnati, OH 45239

Dear Mr. Scheper,

Enclosed is a working document prepared by the Department of Energy's EM-40 Technology Connection program. This document lists technologies for solidification/fixation/containment of soil and is derived from conversations you've had with Dale Pflug, Manager of the Technology Connection Domestic Program Office.

Technology Connection's charter is to identify, screen, and support implementation of currently available national and international environmental restoration technologies. The list we are providing you is a working document which includes some technologies which have not been screened. We understand that this list is acceptable for your use. Should you desire to have your inquiry reevaluated, perhaps to narrow the list down for a specific need, please do not hesitate to contact Dale Pflug at (708) 252-6682, or me at the number listed above.

Thank you for your interest in the Technology Connection program and this opportunity to partner with you. We look forward to working with you in the future.

Sincerely,

Phil Horstman
Project Coordinator
Technology Connection Program

Enclosure - Technology Connection Working Document

DOE EM-40, Technology Connection, Working Document

Solidification/Fixation/Containment; Developed for Mr. Richard Scheper, FERMCO, Inc.

Group	Company Name	First Name	Last Name	Work Phone	City	ST	Description
Tmix	AMAX Research & Development Center	Eddie	Chou	303/273-7200	Golden	CO	Water treatment & metals recovery
Tmix	Electro-Pyrolysis, Inc.	J. Kenneth	Wittle	610/687-9070	Wayne	PA	DC Plasma Arc melter. Developed by Electro-Pyrolysis
Tmix	Geosafe Corporation	James	Hansen	206/822-4000	Kirkland	WA	In situ vitrification [ISV]
Tmix	In-Situ Fixation Company	Richard	Murray	602/821-0409	Chandler	AZ	Deep in-situ remediation w/ bio. and/or stab.
Tmix	Layne-Western Company, Inc.	Greg	Aluce	414/246-4646	Pewaukee	WI	Cryogenic ground freezing in soils w/ sufficient water
Tmix	Svedala Industries/Kennedy Van Saun	Peter	Wilver	717/275-3050	Danville	PA	DC Plasma Arc melter. "Viable solution for radioactive
Ttal	ADTECHS Corporation/JGC Corp.	Dennis	Wilkie	703/713-9000	Herndon	VA	Heavy metal fixing w/ polmerization
Ttal	Bachy	M.	Gandais	33 1 47 142600	International	Fra	Deep soil mixing - in-situ immobilization. PNL file 6.01
Ttal	Bachy	M.	Gandais	33 1 47 142600	International	Fra	In-situ barrier
Ttal	Bio-Electrics, Inc.	Erich	Sarapuu	816/474-4895	Kansas City	MO	In-situ electro-thermal remediation
Ttal	Bio-Recovery Systems, Inc.	Tom	Powers	505/523-0405	Las Cruces	NM	AlgaSORB sorption process for heavy metals removal
Ttal	Brown & Root Environmental, Inc.	Ted	Bittner	713/575-4649	Houston	TX	Solidification/stabilization with micro matrix cement
Ttal	Brown & Root Environmental, Inc.*	Ted	Bittner	713/575-4649	Houston	TX	Jet grouting for special barriers
Ttal	Brown & Root Environmental, Inc.	Ted	Bittner	713/575-4649	Houston	TX	Aquifer re-isolation - closure of monitoring wells
Ttal	Brown & Root Environmental, Inc.	Ted	Bittner	713/575-4649 Petit	Houston	TX	Soilsaw - in-situ slurry wall formation
Ttal	C&E Consulting and Eng'g GmbH	Dr.	Glombitza	49 0371 887520	International	Ger	3D horizontal jet montan wax grouting
Ttal	C&E Consulting and Eng'g GmbH	Dr.	Glombitza	49 0371 887520	International	Ger	Sludge/dust immobilization
Ttal	C&E Consulting and Eng'g GmbH	Dr.	Glombitza	49 0371 887520	International	Ger	Groundwater
Ttal	CDS Research Ltd.	Zoller	Heratia	604-925-2860	International	Can	Cryogenics; Freeze barriers
Ttal	Chemfix Technologies, Inc.	Phillip	Baldwin	504/831-3600	Metarie	LA	Chemical/physical treatment
Ttal	Colloid Environmental Technologies Company	Jeff	Ashton	708/392-5600	Arlington Heights	IL	SORBOND stabilization/solidification agents
Ttal	Contaminant Containment Consultants	Urban	Drew	27 12 46 7478	Pretoria	SA	Silicon rubber grout
Ttal	ECOSITE	Charles	Boulanger	418 872-3600	Quebec	Can	Injecsol - soil washing. Canadian
Ttal	EmTech Environmental Services, Inc.	Ray	Fundeburk	800/227-6543	Fort Worth	TX	Chloranan [tm] process - chemical treatment and immob.
Ttal	Envirogen, Inc.	William	Guarini	609/936-9300	Lawrenceville	NJ	In-situ biodegration of chlorinated organic solvents
Ttal	Envirotreat	Neil	McLeod	44 01384 288876	International	UK	Chemical immobilization
Ttal	Flowtex	Ingo	Sass	49 7243 336146	International	Ger	Horizontal jet grouting w/ montan wax
Ttal	Fluid Tech, Inc.	Dean	Rowsell	702/871-1884	Las Vegas	NV	Use of modified natural clays for in-situ immobilization
Ttal	Geo-kinetics	Robert	Clarke	510/254-2335	Orinda	CA	Electro-chemical barriers
Ttal	Geodur			41 42 32 2532	International	Swi	Customized immobilization mixtures

000049

2888

DOE EM-40, Technology Connection, Working Document

Solidification/Fixation/Containment; Developed for Mr. Richard Scheper, FERMCO, Inc.

Group	Company Name	First Name	Last Name	Work Phone	City	ST	Description
Ttal	Groundwater Technology, Inc. (form GeoCh	Jim	Rouse	303/988-8902	Lakewood	CO	ISF in-situ fixation and stabilization of radionuclides and
Ttal	GZA Geoenvironmental, Inc.	John	Balco	617/969-0700	Newton Upper	MA	Hydrodynamic isolation
Ttal	Halliburton Services	Lindsey	Lee	713/676-3011	Fort Worth	TX	Micro Matrix SS - solidification & stabilization
Ttal	Heitkamp Umwelttechnik	Uwe	Blass	49 2348 7905 236	International	Ger	Solidification of radioactive soils
Ttal	Horsehead Resource Development Co., Inc.	John	Oyler	215/826-8858	Palmerton	PA	HRD Ecoloam (tm)
Ttal	International Waste Technologies	Jeff	Newton	316/269-2660	Wichita	KS	Solidification/Stabilization
Ttal	ITEX Environmental Services, Inc.	Stuart	Markussen	214 407 0550	Addison	TX	In-situ soil solidification and stabilization. Archon.
Ttal	McAlpine	Alan	Christie	44 1744 892481	International	UK	Asphaltic concrete
Ttal	Milligard Environmental Corporation	Jeff	Jacobs	313/261-9760	Livonia	MI	MecTool; patented deep soil mixing
Ttal	Moretrench Environmental Services, Inc.	Robert	Kunzel	201/627-2100	Rockaway	NJ	cryogenic barriers in subsurface
Ttal	Ogden Remedial Services	Gary	Smith	801/565-3705	Midvale	UT	FSSS; Fixation/Stabilization/Solidification
Ttal	Paurat Group	F.W.	Paurat	49 0281 94200	International	Ger	Immobilization by polyelectorlyte injection
Ttal	PQ Corporation	Michael	Kovacs	215/293-7449	Valley Forge	PA	silicate stabilizing agents
Ttal	Radian Corporation	Tony	Mellini	414/327-9955	Milwaukee	WI	In-situ fixation
Ttal	RKK, Ltd*	Christopher	Reno	206/653-4844	Arlington	WA	Cryocell Cryogenic Subsurface Frozen Barriers
Ttal	Robertson Barrier Systems Corp.	Rhino	Rhors	604 684 8072	International	Can	Robertson Barrier Liner - treatable high-security
Ttal	S.M.W. Seiko, Inc.	David	Yang	415/591-9546	Redwood City	CA	Soil-Cement Mixing Wall
Ttal	SCC Technology, Inc.	Osamu	Taki	415/592-3435	Belmont	CA	In-situ solidification/stabilization
Ttal	Sevenson Environmental Services, Inc.	Karl	Yost	219/836-0116	Munster	IN	CHROMTITE™ treatment process
Ttal	Sevenson Environmental Services, Inc.	Karl	Yost	219/836-0116	Munster	IN	MAETITE™ treatment/solidification process
Ttal	Sevenson Environmental Services, Inc.	Karl	Yost	219/836-0116	Munster	IN	Treatment/immobilization of soils and wastes.
Ttal	Slafon Corporation				Irvine	CA	micro encapsulation process
Ttal	Soletanche	Richard	Lours	33 47 764262	International	Fra	Impervious cutoff wall
Ttal	Soletanche	Richard	Lours	33 47 764262	International	Fra	Stabilization and solidification
Ttal	Soletanche	Richard	Lours	33 47 764262	International	Fra	Porous barrier
Ttal	Solucorp Industries, Ltd.	Richard	Lours	33 47 764262	International	Fra	Ecojol grout
Ttal	STC Omega	Noel	Spindler	201/368-7902	Saddle Brook	NJ	Molecular Bonding System-patented process that stabilizes
Ttal	Stock Equipment Company	Greg	Maupin	602/948-7100	Scottsdale	AZ	soil stabilization using silicate compounds
Ttal	Technical Minerals, Inc.	William	Phillips	216/543-6000	Chagrin Falls	OH	stabilization/solidification for mixed waste
		W.	Austin	601/944-4758	Jackson	MS	residue fixation/immobilization

2/2/96

000005

DOE EM-40, Technology Connection, Working Document

Solidification/Fixation/Containment; Developed for Mr. Richard Scheper, FERMCO, Inc.

Group	Company Name	First Name	Last Name	Work Phone	City	ST	Description
Ttal	VFL Technology Corporation	Russell	Pinkerton	610/918-1100	West Chester	PA	stabilization treatment technology
Ttal	VFL Technology Corporation	Richard	Patton	610/918-1100 VFL	West Chester	PA	Stabilization/Solidification
Ttal	Wastewater Technology Centre	Julia	Stegemann	905/336-4738	International	Can	stabilization formulations
Ttal	Wheelabrator Environmental Systems, Inc.	Chris	Ganotis	603/929-3438	Hampton	NH	HMS; heavy metals stabilization; lead & cadmium
Ttal	Wheelabrator Environmental Systems, Inc.	Tom	Peacock	603/929-3374	Hampton	NH	Waste-to-energy/ash stabilization of heavy metals

000051

288