

INNOVATIVE TECHNOLOGY

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Summary Report

Innovative Grouting and Retrieval

Subsurface Contaminants
Focus Area



Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

October 1998

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INNOVATIVE TECHNOLOGY

Summary Report

Innovative Grouting and Retrieval

OST Reference # 63

Subsurface Contaminants
Focus Area



MASTER

Demonstrated at
U.S. Department of Energy
Idaho National Engineering
and Environmental Laboratory
Idaho Falls, Idaho

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INNOVATIVE TECHNOLOGY

Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at <http://em-50.em.doe.gov> under "Publications."

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SECTION I

SUMMARY

Technology Summary

Innovative grouting and retrieval (IGR) technology provides an innovative and cost-effective approach for full-pit and hot-spot retrieval of buried transuranic (TRU) waste sites and in situ disposal of buried waste with improved confinement. The technology was developed with private-sector participation, including AGECEC of Richland, Washington and Geocon of Monroeville, Pennsylvania, in conjunction with the support of the U.S. Department of Energy (DOE) Office of Science and Technology (OST). It is now commercially available through vendors.

Problem

At shallow burial sites containing TRU wastes (such as at the Idaho National Engineering and Environmental Laboratory [INEEL] where there is approximately 2 million ft³ of TRU waste comingled with 6 to 8 million ft³ of soil), there is a need for in situ stabilization or hot-spot/total removal. Grouting the waste can provide long-term in situ stabilization or, for removal operations, agglomeration of contaminants and fine soil particles that decreases the chance of contaminant spread during inherently dusty retrieval operations.

How it Works

Innovative grouting technology

- minimizes spreading of contamination by agglomerating the soil particles containing plutonium/americium particulates into nonaerosolizable particles;
- minimizes worker risks and exposure;
- is more effective in controlling the spread of contamination than common mining practices such as directed air flow, misting, and fixant sprays;
- eliminates further treatment because the grouted, rubberized waste is ready for shipment to the Waste Isolation Pilot Project (WIPP);
- reduces capital expenditures, operating costs, and containment structure requirements; and
- is an estimated five times faster than the baseline technology of removal, packaging, and storage.

Advantages over the Baseline

Cost savings of approximately 90 percent of the costs for the baseline technology of retrieval, packaging, and storage can be realized (see Section 5, Cost) by using innovative grouting techniques for either stabilization or retrieval purposes.

The main disadvantage to using innovative grouting is that contaminated grout returns must be managed; however, this can be accomplished.

Demonstration Summary

During the summer of 1994, a full-scale, proof-of-principle demonstration of innovative grout/retrieval technology was performed at INEEL.

During the summer of 1995, a demonstration of two innovative subsurface stabilization technologies was performed at INEEL. The first technology involved creating a stabilization wall by jet grouting Portland



cement in the interior of a buried waste pit to support hot-spot retrieval. The wall allowed near-vertical digging in the waste pit when removing the hot spot, thereby reducing the amount of material retrieved to get the hot spot. The second technology addressed creating a stabilized monolith out of a waste site by jet grouting a two-component acrylic polymer. This stabilized monolith could be used for both hot-spot retrieval with enhanced contamination control and encapsulation and stabilization of buried waste for in situ disposal. For the second demonstration, two different simulated pits were grouted with different formulations of the acrylic polymer, one a hard, durable material for long-term encapsulation and the other a softer, easily retrievable material for interim storage and eventual retrieval.

During the summer of 1996, a variety of grouting materials were injected into simulated buried waste pits including TECT, a proprietary iron oxide-based grout; WAXFIT, a proprietary paraffin-based grout; type H cement; Hermitite forming grout; and water-based epoxy. During these studies, a full-scale permeameter was also grouted and the resultant hydraulic conductivity was measured. The WAXFIT material was especially well suited to aid in hot-spot or full-pit retrieval. Once injected, the relatively inexpensive material permeated all waste materials, including cloth, paper, and wooden debris. This pre-encapsulation locked up the contaminants, making retrieval easier by lowering the requirements for the ancillary contamination control apparatus.

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at <http://em-50.em.doe.gov> under "Publications." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST Reference # for innovative grouting and retrieval is 63.



SECTION 2

TECHNOLOGY DESCRIPTION

Technology Background

The innovative grouting and retrieval technique involves jet grouting of the buried waste and application of expansive grout (demolition grout) followed by remote excavation using a bridge crane-mounted system. This technique is uniquely qualified for routing and retrieval of TRU waste from shallow land burial. It is also considered an effective dust-control technique.

Innovative grouting technology for creation of a U-shaped stabilization wall to support hot-spot retrieval involves jet grouting a Portland cement mixture in the interior of a buried waste pit. The wall allows near-vertical digging in the waste pit when removing the hot spot, thereby reducing the amount of material retrieved to remove the hot spot.

Innovative grouting for creating a stabilized monolith out of a waste site is accomplished by jet grouting a two-component acrylic polymer. This stabilized monolith can be used for both hot-spot retrieval with enhanced contamination control and encapsulation and stabilization of buried waste for in situ disposal. Depending on the application, different formulations of the acrylic polymer may be used: one a hard, durable material for long-term encapsulation and the other a softer, easily retrievable material for interim storage and eventual retrieval.

Figures 1 and 2 show the jet grouting and excavation equipment that can be used in each of the preceding applications. Figure 3 shows the application of demolition grout, which is used in the innovative grout/retrieval technology application.

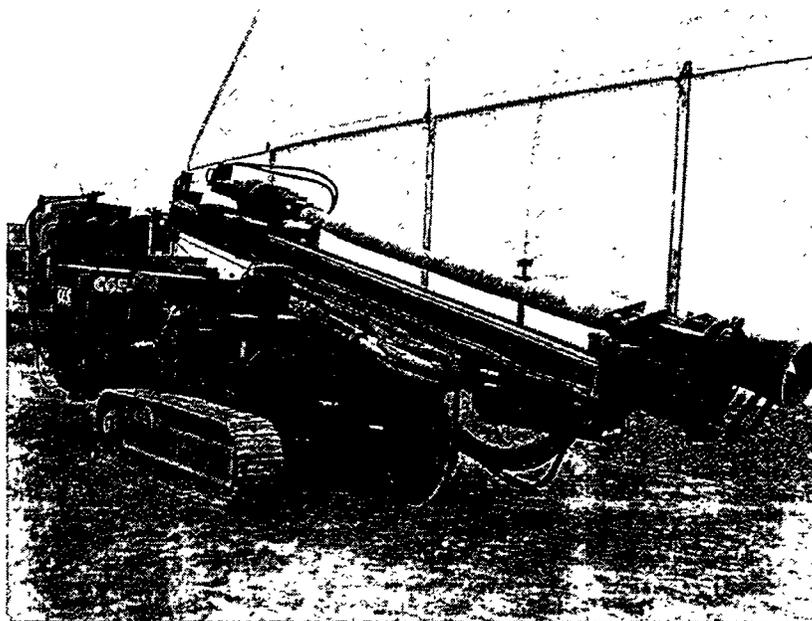


Figure 1. The CASA Grande drill system.



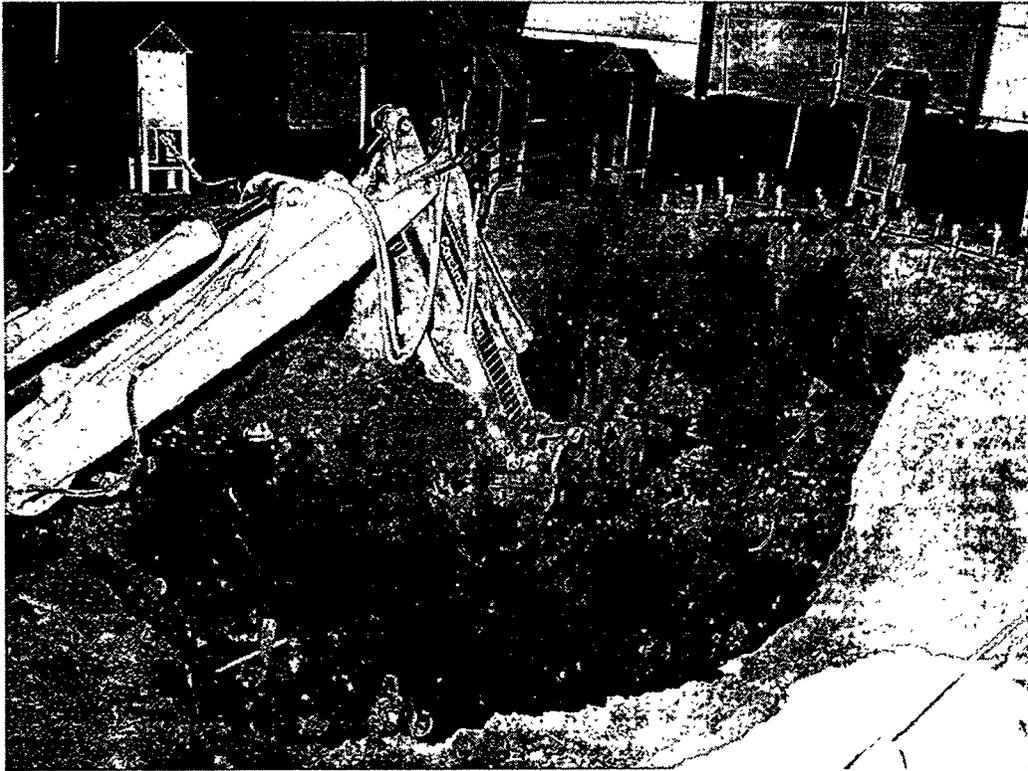


Figure 2. Excavation of monolith.

Jet Grouting

Jet grouting is accomplished using the CASA GRANDE drill system (see Figure 1) and a high-pressure positive displacement pump. The drill system drives through the soil/waste matrix and injects grout at a nominal 6000 psi at the bottom of the drill stem as the drill stem is withdrawn from the drill hole at a rate of 5 cm/6 s.

Demolition Grouting

The contaminants are locked in a monolith by the jet-grouting process. Immediately following jet grouting, thin-walled, spiral-wrapped tubes are inserted into the hole and allowed to set in place. The jet-grouted pit is allowed to cure, after which the demolition grout is introduced into the spiral-wrapped tubes (see Figure 3). As the demolition grout cures, it expands (through the thin-walled, spiral-wrapped tube) and fractures the soil/waste matrix in situ. For applications of "soft" grouts, the demolition grouting is not required.

Retrieval

Following stabilization with grout, retrieval equipment removes the debris (see Figure 2). The waste matrix is retrieved using a movable structure such as a bridge crane-mounted jack hammer, a shear, and a grapple, which can be controlled remotely.

The system usually requires a four member team. Secondary waste stream considerations include contaminated drill springs and contaminated bits, as well as various cloths and blotter paper; all in all, secondary waste stream generation is minimal.



Figure 3. Grouted pit with spiral-wrapped tubes.



SECTION 3

PERFORMANCE

Demonstration Overview

Innovative Grouting and Retrieval

Innovative grouting and retrieval was demonstrated in 1994 at INEEL on a simulated waste pit, 10 × 10 × 10 ft, loaded with 55-gal cardboard and steel drums, and 4 × 4 × 4 ft cardboard boxes full of simulated waste and rare-earth tracer designed to simulate TRU contaminant. The pit was built prototypical of pits found in the INEEL Subsurface Disposal Area using backfilled lake-bed soil. A large weather shield was erected over the site, and air samplers were used for all major portions of the demonstration. The first phase involved jet grouting using the CASA GRANDE jet-grouting apparatus. The second phase involved application of demolition grout. The third phase involved using a standard backhoe with a thumb attachment to retrieve the waste.

- Jet-Grouting Phase

Thirty-six grout holes emplaced 24 yd³ (648 ft³) of Portland cement into the pit in a jet-grouting action (at nominally 6000 psi). Based on the data, the total voids accessed by the grout (648 ft³) equalled about 67 percent of the physical volume (972 ft³) based on the dimensions of the pit. This fact indicates that intense mixing of soil and Portland cement occurred under the jet-grouting action and that the "soilcrete" mix readily accessed voids in the waste forms. The jet grouting was accomplished by first driving the injection bit into the waste and withdrawing the bit in 5-cm increments while slowly rotating the bit. The withdrawal rate was nominally 5 cm/6 sec. The hole spacing was 24 in on a triangular basis, and the process took about 40 min to drill and jet-grout each hole. The hole spacing was based on a series of predemonstration field trials in compacted INEEL soil in which up to 28-in-diameter soilcrete columns were created. After each jet-grouting operation, a bottom-sealed, 2-in-diameter, spiral-wrapped tube was placed into the drill hole and allowed to cure in place. During the jet-grouting operation, soilcrete and some waste in the form of sludge came to the surface of the pit (in gallon quantities for some holes). Although this material contained the rare-earth tracer, no airborne spread of the tracer was found above background on the air samplers spaced systematically around the pit. No distinguishable upward movement of the soil was observed during the jet-grouting phase.

- Demolition Grout Phase

The application of BRISTAR as a demolition grout failed to fracture the waste as planned. The grout did not expand upon curing because of a temperature gradient in the monolith with up to 60°F higher temperatures in the middle regions of the monolith than on the edges (see Table 1, Appendix A). This axial temperature gradient was caused by the heat of hydration as the Portland cement cured. The temperature was maintained by the surrounding insulating properties of the soil. As a result, matching the correct BRISTAR product with the correct temperature to achieve fracturing was difficult. The grout appeared to expand at the near-surface positions that, however, were the cooler positions. A separate application of the BRISTAR product in several holes drilled directly into the monolith produced fracturing. For this case, the temperature of the pit was more uniform and lower than the postgrouting value. A nondust-producing technique alternative to the demolition grout would have been to use a hydraulic rock splitter in the spiral-wrapped tubes to fracture the monolith.

- Retrieval

Although the monolith was not fractured by the demolition grout, the standard backhoe bucket with a thumb attachment in the below-grade orientation was successful in removing the monolith. The



monolith was removed in just under 5 hours. Grouted boxes containing metal pipe, wire, and plate steel caused the most difficulty in retrieval, and a larger backhoe or front-end loader would have greatly facilitated the process. The general soilcrete mix was easy to break off with the backhoe in 1 × 2-ft portions. One of the waste materials that caused the most tracer spread was computer paper (6-in-thick portions). Removal of computer paper resulted in tracer spread because the grout-encased paper easily disintegrated when retrieved, leaving the computer paper intact with visible tracer on the paper. Other waste forms such as pipes and wood also separated from the grout during retrieval; however, a layer of grout existed on the surface, and the pipes were completely filled. If the waste pit contained all intact metal drums, this process probably would result in completely grouted drums, including the space between the drum and the drum liner. One such specimen of a metal drum originally containing plastic pipe was completely full of grout and was sectioned for display.

- **Dust Control/Contamination Control**

- Airborne dust and tracer concentrations were measured for all major phases of the demonstration, including the grouting and retrieval phases. In addition, concentrations were established for baseline retrievals of soil only and general static background. The air-sampler filters were analyzed for praseodymium using inductively coupled plasma/mass spectroscopy (ICP-MS) and reported as micrograms of tracer per gram of soil per cubic foot of air on the filter or parts per million per cubic feet of air. In addition to the air sampling, during the grouting phase, smears of the drill stem and samples of the soils were analyzed for concentration of tracer. Table 2 in Appendix A summarizes the air monitoring data for the grouting phase tests (G-3 through G-7), background, Baseline Retrievals 1 and 2 (BR-1 and (BR-2), and retrieval tests (R-1 through R-5).
- Background concentrations of dust and praseodymium oxide during periods of no activity were approximately 5.12E-08 g/L and 3.02E-03 ppm/ft³ of air.
- During grouting activities, airborne tracer was at or below background values within 95 percent confidence levels. In addition, the dust loading was, on average, only about a factor of two above background values. Table 3, Appendix A, represents the analysis of surface smears and sludge material taken during the grouting phase. These data show that, for the drill stem smears, the tracer (praseodymium) concentration is at reported background levels (3 to 5 ppm); however, the sludge material and other surface materials are much higher than background (221 ppm). Because a large source of tracer exists in the demonstration area (based upon the surface material results), with the airborne concentration remaining at near background, this result indicates that the sludge was locked in a grouted matrix and was not aerosolizable.
- The retrieval was accomplished both with overburden in place and with overburden removed, and, leaving the overburden on, promoted both dust and tracer spread during retrieval. Retrieval with the overburden in place resulted in dust removal over the baseline retrieval case of between 30 percent and 40 percent, which compares unfavorably with conventional contamination-control cases using misting and fixants where 70 percent dust removal was achieved. However, when retrieval was performed with the overburden removed, a 90 percent dust-removal rate was achieved. During retrieval with the overburden on, the airborne tracer concentration was 4,000 times background; with the overburden removed, the tracer concentration was only 1.35 times background. The overburden fell into the pit displacing air, causing entrained particulate from the debris in the bottom of the pit to travel to the air monitors, which indicated contaminant spread. Tables 4 and 5, Appendix A, summarize the dust and tracer concentration levels during the retrieval phase.

Waste Pit Hot-Spot Retrieval by Wall Stabilization Technique Using Jet Grouting (Portland Cement)

The wall demonstration involved creating a U-shaped wall by jet grouting Portland cement (1:1 water/Portland by mass) in the existing INEEL cold test pit near the Radioactive Waste Management Complex (RWMC). This cold test pit was constructed similar to the actual TRU pits and trenches in the



Subsurface Disposal Area at RWMC. A variety of waste disposal practices were simulated, including random dump and stacked orientations of the containers in shallow land burial. For this demonstration, the wall spanned two zones of the cold test pit representing random dump drums and random dump drums and boxes. The U shape was thought to be sufficient to demonstrate all features of a four-sided wall. The demonstration consisted of a jet-grouting phase and a stabilization evaluation phase.

- **Jet-Grouting Phase**

For the jet-grouting phase, 52 holes were jet grouted in three days to create the wall. The sides of the U-shaped wall were three holes wide on a triangular pitch, and the back of the wall was two holes wide. The wall was nominally 30 ft along the back of the U, and the sides of the U extended about 8 ft. A total of 24 yd³ of Portland cement was used, for an average of about 0.46 yd³/hole. Each hole was approximately 9 ft deep, which is the depth of the waste. This operation was accomplished with a minimum (less than 2.5 gal) of grout returns for each hole. A typical jet-grouting operation involved driving the drill stem into the waste and jet grouting at 6,000 psi while removing the drill stem in discrete increments.

- **Stabilization Evaluation Phase**

- In stability testing, the wall supported a 98,000 lbm trackhoe excavator in an excavation position on the wall without collapse or structural damage.
- Excavation of the wall showed that the three-hole-wide side walls produced a wall nominally 6 ft thick and the two-holes-wide back wall produced a wall of about 4 ft thick.
- The jet grouting of Portland cement resulted in a solid wall with no visible voids in the wall.
- The 2-ft triangular pitch matrix was sufficient to create a solid wall using the following injection parameters: two revolutions of the drill stem/step, 5 cm withdrawal/step, and 4 to 6 seconds on each step.
- Examination of the wall showed that the grout mixed with the soil and formed a soilcrete material that in turn filled some of the voids. Other voids were filled with the neat Portland material. Striations of clay soil pockets in the wall were estimated at between 10 percent and 20 percent of the volume of the wall.
- Thin tendrils of easily excavated grout extended into the ungrouted interior positions formed by the wall. These tendrils were about 2 in thick and extended 2 ft into the waste.

Jet-Grouted Polymer for Waste Stabilization or as Interim Technique Before Retrieval

The demonstration of using jet-grouted polymer as an interim storage technique before retrieval or as in situ disposal has shown a positive proof of concept. Two simulated buried waste pits were jet grouted using a dual concentric annulus drill stem. The pits were constructed the same as TRU pits and trenches in RWMC and represented a random dump drum region. The simulated waste containers (55-gal cardboard and metal drums) contained cloth, paper, metal, wood, and sludge similar to that received from Rocky Flats at INEEL. The concept of interim storage followed by retrieval was demonstrated in one pit, and long-term encapsulation was demonstrated in the other. The polymer was an acrylic polymer from 3M Company, Inc., consisting of two comonomers (equal portions of Part A and Part B) with benzoyl peroxide and amine additives to start the polymerization process. The polymer forms a high-molecular-weight material that has excellent durability characteristics. Two different formulations of the polymer were used, one to produce a hard, durable material for long-term encapsulation and the other to form a soft, "eraser-like" material for ease of retrieval and enhanced contamination control during retrieval.

For the soft polymer pit, 15 holes were jet grouted into a pit 4.5 x 9 x 6 ft deep. The injection techniques for jet grouting a two-component polymer were first developed in field trials. During these field trials, the injection parameters were set as follows: the JET5 SCHWING pump injected the B part at 1,000 psi. The withdrawal step was 3 cm, with two revolutions/step and 2 seconds on a step. Mixing of the two



components occurred outside the dual concentric annulus drill stem in the waste/soil matrix. The main cutting force of the jet grout occurred with the A part at 6000 psi with the 1000-psi B part simply mixing with the A part.

- **Results**

- Retrieval with a standard backhoe of the soft polymer pit inside a weather shield showed an enhanced dust control over retrieval involving standard mining techniques. During earlier retrieval demonstrations, only a 70 percent reduction in dust spread occurred when misting sprays and fixants were used. However, when the soft polymer pit was retrieved, a 91 percent reduction was observed (see Table 6, Appendix A).
- The soft, "eraser-like" polymer was easy to remove and behaved similarly to wet clay.
- The polymer material did not successfully eliminate the spread of a rare-earth tracer material that had been placed in each container in the pit to simulate the plutonium oxide in actual TRU pits. A two-order-of-magnitude increase in tracer occurred on air-monitoring filters during the retrieval over the background values (see Table 6, Appendix A). This increase was thought to be the result of the fact that one of the metal containers was not penetrated by the drilling activity during jet grouting, and this container was punctured during the retrieval and potentially spread the fine, micron-sized tracer material around the pit.
- Eighteen holes were jet grouted into the hard polymer pit (constructed identically to the soft polymer pit), and evaluation analyses were performed. Durability tests were also performed on laboratory samples of INEEL soil, and the hard polymer was mixed at 33 percent polymer and 67 percent soil. The durability tests included hydraulic conductivity measurements, resistance to immersion in water, resistance to immersion in a saturated aqueous solution of trichloroethylene (TCE), resistance to immersion in alkali, and resistance to wet-dry cycling.
- Destructive examination using a backhoe showed that the acrylic polymer material resulted in a cured, stabilized monolith with no voids. In addition, the hard polymer was easily fractured with a standard backhoe, and the pit could be removed in large, cohesive chunks of soil/waste/polymer.
- The compressive strength caused by water immersion changed from a base-case average of 20.7 MPa to 19.6 MPa after 90 days for a negligible effect. For wet-dry cycling, the average compressive strength was 22.9 MPa. For base-resistance tests (pH = 12.5), the compressive strength changed from the base case of 20.7 MPa to 16.2 MPa after 90 day's immersion for a 20 percent reduction in strength. The effect of solvent TCE on the waste form showed a negligible change in compressive strength after 90 d of immersion (see Figure A.1 in Appendix A).
- The hydraulic conductivity of the soil/polymer mix was measured to be 2.8E-12 cm/second.

In Situ Stabilization

It has been demonstrated that a variety of grouting materials can be jet grouted to form monoliths out of the buried waste. The monoliths can be considered interim in situ storage before retrieval or for permanent disposal in situ.

- **Results**

- TECT grout is easily jet grouted and forms a dense, high-compressive strength >2000 psi soil/waste/grout monolith.
- WAXFIT is easily jet grouted, and before solidification considerable permeation to all waste material occurs. This resultant monolith is easily retrieved with minimal contaminant/dirt spread.
- Neither INEEL-developed Hermitite forming grout nor water-based epoxy is jet groutable.
- Type H cement is jet groutable and forms an inexpensive solid monolith.



- Field-scale permeation studies show that the TECT and WAXFIT grouts had hydraulic conductivities less than $1E-7$ cm/second.



SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

- Innovative grouting and retrieval (IGR) technology can be applied to shallow land burial sites containing TRU wastes requiring hot-spot/total removal.
- IGR can be applied to waste-removal sites as an effective contamination-control technique.
- The IGR jet-grouting phase involving the injection of a 1:1 Portland cement/water by volume mixture, using a CASA GRANDE drill system, is effective at sites with fine, silty-clay soil structure.
- The demolition grout phase of IGR can be applied as an effective grouted monolith fracture mechanism if the monolith is within the correct grout application temperature ranges.
- Standard backhoe retrieval techniques can be applied to remove IGR grouted monoliths.
- Innovative grouting with acrylic polymers can be applied effectively to fine-grained soils using jet grouting to provide stabilization and encapsulation of a waste trench or as an interim storage/retrieval technique.
- Innovative grouting that uses jet grouting for injection of a Portland cement to provide a stabilized wall to support waste trench hot-spot retrieval can be applied effectively to fine-grained soils.

Competing Technologies

- The baseline technology against which IGR is compared is the physical removal, packaging, and storage of decontaminated soils. The cost section includes a cost comparison of IGR with this standard technique for an application involving TRU wastes at INEEL.
- An alternative technology involves first freezing the soil by introducing liquid nitrogen into the soil and then removing the frozen matrix using a remotely controlled bridge crane arrangement with a grapple, a shear, a jackhammer, and a special freeze tube break-out tool. This technology is effective in removing the soil/waste matrix; however, the complexity and costs associated with the liquid nitrogen are high.
- Grouting techniques alternative to the jet-grouting phase of IGR exist. Grout selection should be based on soil structure because some grouts and injection techniques are not effective in fine, silty-clay soils.
- Alternative technologies exist for waste trench hot-spot retrieval (e.g., the use of telerobotics and crane-mounted systems).
- Alternative waste trench stabilization techniques and materials exist, including in situ vitrification and various encapsulation technologies (frozen wall barriers, etc.).



SECTION 5

COST

Introduction

Information in this section was prepared from data provided by the principle investigator for this technology and the Environmental Restoration Program at INEEL responsible for approximately 2 million ft³ of TRU waste comingled with 6 to 8 million ft³ of soil in shallow land burial.

Cost Comparison

The baseline technology being used for this cost comparison is the physical removal, packaging, and storage of contaminated soils ($A < 10$ nCi/g) based on an approved EM-40 plan. In addition, a cost comparison is provided for the competing innovative technology of cryogenics. Costs were estimated for the remediation of 1 and 4 acres (except for stabilized wall/hot-spot retrieval) of contaminated soil.

All cost estimates for innovative grouting technologies assume the use of government-furnished equipment (CASA GRANDE system) available via the Applied Geotechnical Engineering and Construction spin-off company from Westinghouse Hanford Company. An additional equipment depreciation cost of \$42/hole grouted would be required for vendors with nongovernment-furnished equipment.

Baseline Technology (Physical Removal, Packaging, and Storage)

The estimated remediation cost was \$200M for the first acre of TRU waste-contaminated buried waste. Remediation of each additional acre was estimated to cost \$35M. Therefore, the cost to remediate the 4-acre TRU waste-contaminated site was estimated as \$305M. The costs for waste treatment, interim storage, and pilot-scale demonstration are not taken into account. Of significance is the high cost associated with compliance with mixed waste regulations dealing with conventional ex situ treatment.

Innovative Grouting and Retrieval

Estimated remediation costs for the first acre for this technology was \$19.1M, including the following:

- grouting and waste management;
- excavation; and
- project management, secondary waste management, D&D equipment.

Costs of \$15M/acre were estimated for each additional acre remediated, bringing the total cost to \$64M for a 4-acre site.

In Situ Waste Trench Stabilization/Disposal (Jet Grouting with TECT)

In this option, the pit is left as the disposal site for the waste for permanent disposal. This cost does not include the cost of any caps or the design and testing of a cap. It includes the stabilization and containment costs, and the secondary waste is assumed to be classified as low-level waste.

- Grouting - 14,000 holes at \$250/hole = \$3.5M;
- Secondary waste management - crew of two for 3 person-years at \$125K/person-year = \$375K;
- Grout material - \$5/gal at 57 percent voids, which is equivalent to 1.85E6 gal of grout = \$9.2M;
- Management - 10 percent of total costs = \$1.3M;
- Profit - 6 percent of total costs = \$0.78 M; and
- Grand total (for 1-acre site) = \$15.1M.



Interim Storage/Retrieval Option (Jet Grouting with WAXFIT)

This estimate is based on the jet grouting of a waste pit with a soft polymer and subsequent pit excavation. This estimate also does not reflect any permitting or delays caused by agreements between DOE, U.S. EPA, and the state. For the full pit retrieval, an acre-sized pit 10 ft deep is grouted and retrieved. These costs do not include costs of interim storage, treatment, or disposal of retrieved waste.

- Grouting - 14,000 holes at \$250/hole = \$3.5M;
- Secondary waste management - crew of two for 3 person-years at \$125K/person-year = \$375K;
- Retrieval Capital - \$4M (\$2M remote retrieval system; \$2M weather shield), engineering estimate only;
- Retrieval Operations - three-person crew at \$500/d/person at 200 yd³/d = \$127K;
- Grout material - \$5/gal at 57 percent voids, which is equivalent to 1.85E6 gal of grout = \$9.2M;
- Management - 10 percent of total costs = \$1.7M;
- Profit - 6 percent of total costs = \$1.03 M; and
- Grand total (for 1-acre site) = \$19.9M.

Cost Results

Technology	Cost for 1-acre site (\$M)	Cost for 4-acre site (\$M)	Cost savings over Baseline Technology (\$M)
Baseline (retrieval, packaging, and storage)	200	305	N/A
Grouting/Retrieval	19	64	241
Trench Stabilization (Jet Grouting with TECT)	15	N/A	185
Interim Storage/Retrieval (Jet Grouting with WAXFIT)	20	N/A	180



SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

For any retrieval option of TRU waste, contamination control is mandatory to avoid personnel uptake and lengthy delay times for decontamination. Innovative grout and retrieval technology minimizes the spread of contamination, resulting in fewer regulatory issues (decontamination, etc.).

For any stabilization technology, such as the use of polymeric grouts, which leaves the waste in an in situ monolith, the primary consideration is the leachability of the contaminants.

The grouting of TRU waste followed by monolith fracture and removal and waste trench jet grouting with soft polymers for interim storage followed by retrieval minimize dust evolution and eliminate the need for elaborate contamination-control schemes, which reduce process and removal operation times and decontamination periods.

Hot-spot retrieval, supported by jet-grouted (Portland cement) wall stabilization, allows near-vertical removal, thereby minimizing the amount of waste removed.

Waste trench stabilization by jet grouting with hard acrylic polymers eliminates required retrieval, transport, and storage, thereby eliminating dust evolution and worker hazards associated with removal and transport, and minimizes decontamination activities.

Safety, Risks, Benefits, and Community Reactions

Worker Safety

The potential exposure of site personnel is greatly reduced because of inherent contamination control in that the contaminants and soil particles are agglomerated into a soilcrete mixture or an "eraser-type" material (soft polymer) that is not easily aerosolized.

Waste trench stabilization with the hard polymer minimizes the potential for worker contamination because dust evolution associated with required waste removal and waste handling and transport are eliminated.

Some workers may require full-face respirators when working with acrylic polymers.

Community Safety

The potential exposure to the surrounding community is greatly reduced because of agglomeration of dust and contaminant particles into a soilcrete mixture or a soil/polymer material. In addition, the stabilization of the contaminant by grouting reduces the possibility of community exposure during transport to a permanent disposal facility.

The in situ stabilization of a waste trench by jet grouting with a hard polymer material eliminates the possibility of community exposure during transport to a permanent disposal facility. Grouted waste trench monitoring will ensure that the contaminants are stabilized and are not migrating to present hazards to the surrounding community.



Environmental Impacts

The injection equipment for jet grouting of the waste and the excavation and process equipment will require decontamination. However, because of reduced dust levels as a result of the process, surface process equipment is not expected to become as contaminated.

Socioeconomic Impacts and Community Perception

- This technology will have a minimal impact on the labor force and the economy of the region.
- The reduced probability of contaminants being spread during removal and transport for grout/removal technology and the in situ encapsulation of wastes for waste trench stabilization with grout should receive the general support of the public.



SECTION 7

LESSONS LEARNED

Implementation Considerations

Grouting

- When grouting a pit, use an alternating pattern of grouting. The alternating pattern involves spacing the grout holes such that in any one day no adjacent hole that is within 24 in of another hole would be grouted, thus ensuring no ejection of grout or material from adjacent holes.
- When grout is applied, any indication of soilcrete returns up the drill stem containing waste material should result in an accelerated withdrawal rate until the returns stop emanating from the drill hole.
- When grout is applied, the entire top surface of the pit should be treated with at least two coats of calcium lignosulfonate dust suppressant to reduce dust spread during operations.
- When grout is applied to the first hole, a tendency may exist to place multiple yards of grout in that hole (filling easily accessible voids in the bottom of the pit). This result is desirable, but care must be given not to "float" the waste out of the pit by observing the surface of the pit for expansion.
- The use of "thrust blocks" greatly reduces grout return management.

Demolition Grout

- A longer time should be allowed to "cure" the pit before applying the BRISTAR demolition grout. This may take up to one month before the large axial temperature gradient in the pit is reduced.
- Monolith temperature can be monitored accurately using a digital readout "hanging" thermocouple in the spiral-wrapped tubes.

Retrieval

- Moisture control in the soils and soilcrete waste mix throughout the retrieval area is the key to contaminant control. The use of misting sprays, fixants, and dust suppressants greatly reduces the spread of dust.
- The retrieval of the grouted monolith in the below-grade (dig face) mode should be performed with a large-scale remote excavator with dexterous Balderson thumb and a companion shear for removing metal debris. The excavator should be used in the top-down mode.
- If the "wall" is used in a hot-spot retrieval zone, the interior of the wall should be excavated with a strong contamination control strategy. At a minimum, this strategy would involve misting systems, fixants, and ventilation. In addition, retrieval equipment should include a variety of tools, including large- and small- scale shears for use on loose wire and cable. It may be practical to use the relatively cheap wall materials in combination with a more expensive in situ stabilization material such as the acrylic polymer.
- In actual field applications of a wall, a grout plant with quality control features on the grout should be used, thus avoiding down time for the grouting equipment. Specifically, the grout plant should be devoid of small gravels that cause problems with high-pressure pumps.



Technology Limitations/Needs for Future Development

- A technique for early detection of a plugged nozzle should be developed.
- A long time is required to "cure" the pit before applying the BRISTAR demolition grout. A curing period of approximately one month may be required before the large axial temperature gradient in the pit is reduced.
- Accurate monolith temperature sensors need to be developed.
- More development and testing is needed with "demolition" grouts, various temperature requirements, and monolith axial temperatures.
- Long-term durability studies should be performed on any blends of materials developed to reduce the cost of grouting.
- Monitoring systems should be developed to ensure complete encapsulation in a hot site for in situ waste trench stabilization technology.
- Cheaper blends of acrylic polymer should be devised to reduce the cost of this type of grouting.
- Future development should devise polymers with less odor threshold because of the obnoxious smell (nonhazardous).
- A secondary waste management system should be devised for the jet-grouting operation to handle grout returns. In addition, provisions should be developed for hot applications, including health physics support and procedures for handling potentially radioactive returns in the grout returns.

Technology Selection Considerations

Retrieval and disposal of TRU waste buried in shallow land burial is being considered as a remediation option. The concept of removing selected hot spots and applying a cap to the buried waste is also a consideration. Conventional retrieval technology using off-the-shelf remote excavators for either full-pit or hot-spot retrieval can create considerable dust. The application of innovative grout and retrieval technology should be considered as an alternative technology option to minimize the spread of dust and contamination.



APPENDIX A

TABLES

Table 1. Contact temperature of the bottom of pit (°F)

Hole	7/12/94	7/14/94	7/18/94
1	94	82	71
2	83	78	78
3	68	72	76
4	81	70	70
5	91	81	82
6	111	112	108
7	135	122	112
8	128	122	120
9	88	81	82
10	70	73	73
11	80	78	76
12	78	70	71
13	100	85	85
14	98	90	84
15	89	90	86
16	106	98	101
17	112	108	104
18	78	70	74
19	78	79	75
20	80	80	80
21	119	108	102
22	84	80	80
23	78	77	78
24	111	100	100
25	72	74	76
26	82	82	84
27	103	92	92
28	140	108	110
29	102	94	90
30	82	78	80
31	75	72	76
32	74	78	78
33	77	80	82
34	107	90	90
35	114	120	118
36	96	87	85





Table 2. Average tracer and dust concentration

Test ID	Net mass of dust on filter (g)	Net $\mu\text{g Pr}^a$ (total average blank)	$\mu\text{g/g Pr}$ in dust	Flow rate (cfm)	Tracer concentration ($\mu\text{g/g Pr/cf-air}$)	Dust concentration (g/L-air)	Tracer concentration ($\mu\text{g/g Pr/cf-air}$) background corrected	Standard deviation (2 σ)	Dust concentration (g/L-air) background corrected	Standard deviation (2 σ)
G-3	0.1043	0.7346	7.03	16.06	4.66E-03	2.27E-07	1.63E-03	$\pm 1.41\text{E-}03$	1.76E-07	$\pm 6.29\text{E-}08$
G-5	0.0995	1.2079	10.81	16.30	3.85E-03	1.30E-07	8.23E-04	$\pm 2.37\text{E-}03$	7.83E-08	$\pm 4.47\text{E-}08$
G-7	0.2190	1.8392	8.34	15.21	2.27E-03	1.96E-07	-7.59E-04	$\pm 7.48\text{E-}04$	1.44E-07	$\pm 8.32\text{E-}08$
BKG	0.0274	0.1947	6.16	17.06	3.02E-03	5.13E-08	NA ^c	$\pm 9.59\text{E-}04$	NA	$\pm 2.28\text{E-}08$
BR-1	0.2359	2.5622	9.53	15.73	5.04E-03	4.66E-07	2.02E-03	$\pm 6.95\text{E-}04$	4.15E-07	$\pm 6.67\text{E-}09$
R-3	1.1014	170.5000	1665.50	12.89	1.44E+00	2.88E-07	1.44E+00	$\pm 6.29\text{E-}01$	2.36E-07	$\pm 8.75\text{E-}08$
R-4	0.0748	504.2500	6358.38	13.55	8.11E+00	3.17E-07	8.11E+00	$\pm 6.38\text{E+}00$	2.66E-07	$\pm 1.37\text{E-}07$
R-5	0.2033	41.9670	203.71	15.07	1.49E-01	4.87E-07	1.46E-01	$\pm 6.11\text{E-}02$	4.36E-07	$\pm 8.50\text{E-}08$
Br-2	0.6166	28.7000	45.33	13.53	1.12E-01	4.99E-06	1.09E-01	$\pm 3.35\text{E-}02$	4.94E-06	$\pm 7.42\text{E-}07$

^aPraseodymium.

Key: G = Grouting phase test; BKG = Background; BR = Baseline retrieval; R = Retrieval test

Table 3. Cement-soil type and smear samples for praseodymium by inductively coupled plasma/mass spectroscopy

Sample number	Sample description	¹⁴¹ Pr g/g (ppm)
1	G-3 surface grout	3.68
2	G-3-2 surface grout (second)	3.76
3	G-4 hole 6-post hole 7	221.00
4	G-6 surface grout 17	39.90
5	G-6-18	4.55
6	G-7-23 surface grout	38.60
7	G-7-24 surface grout	9.39
8	G-7-31 near surface	109.00
9	G-7-37	4.82
10	Smear G-3-1 drill stem	5.01
11	Smear G-3-1 drill stem 2	3.24
12	Smear G-6 hole 17 drill stem	5.50
13	Duplicate G-7-37	4.84
14	Matrix spike G-3-2	10.70
15	Matrix spike G-3-2	12.10
<i>Precision for duplicates</i>		
% Relative Percent Difference = 0.35%		
<i>Recovery of matrix spikes</i>		
Sample 1 = 106.1%		
Sample 2 = 130.3%		

Table 4. Summary of dust concentration during retrieval

Test	Configuration	Dust concentration (g/L)	Dust reduction (1-R/BR) * 100%
BR-1	Large tent (moist)	4.15E-7	—
R-3	Large tent (moist)	2.36E-7	46
R-4	Large tent (moist)	2.65E-7	36
BR-2	Small tent (dry)	4.94E-6	—
R-5	Small tent (dry)	4.36E-7	91
1993 Demonstration	No contamination control unit (baseline)	4.14E-7	—
1993 Demonstration	With contamination control unit	1.65E-7	60



Table 5. Summary of tracer spread during retrieval

Test	Configuration	Tracer concentration ^a ppm/ft ³ -air	Ratio of tracer concentration during retrieval and baseline retrieval (R/BR)
BR-1	Large tent (moist)	0.00201	—
R-3	Large tent (moist)	1.44000	7.16 ^b
R-4	Large tent (moist)	8.11000	40.34 ^b
R-5	Small tent	0.14600	1.35 ^c
BR-2	Small tent	0.10800	—

^aData corrected for background (0.00302 ppm/ft³-air).

^bUsed Baseline Retrieval 1 for ratio.

^cused Baseline Retrieval 2 for ratio.

Table 6. Summary of dust and tracer spread data - soft polymer pit

<i>Background values</i>	
Dust	8.42E-7 g/L-air
By tracer	0.0123 ppm/cf-air
<i>Overburden removal values</i>	
Dust	1.21E-5 g/L-air ±0.48E-5
By tracer	0.047 ppm/cf-air
<i>Retrieval phase</i>	
Dust	1.11E-6 g/L-air ±01.8E-6
By tracer	3.235 ppm/cf-air

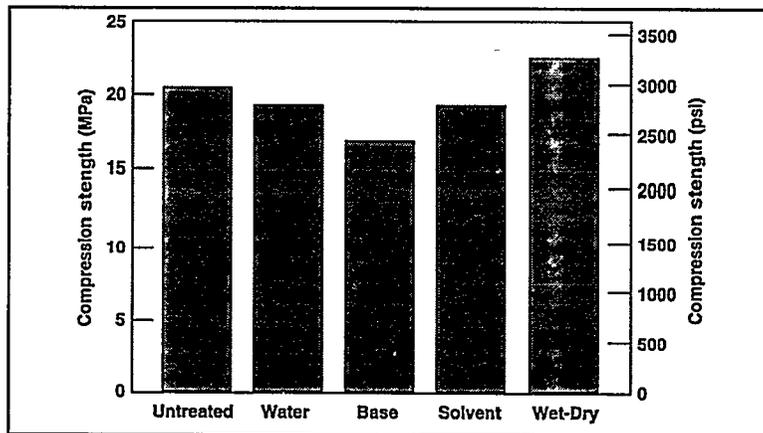


Figure A.1. Comparison of compressive strength after resistance testing.



APPENDIX B

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