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**REPORT FOR
SLOT CUTTER PROOF-OF-PRINCIPLE TEST
BURIED WASTE CONTAINMENT**

SYSTEM PROJECT

DE-AC07-97ID13505

Submitted to:

U.S. Department of Energy
Idaho Falls, Idaho 83415

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[Signature]

MASTER

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21 May 1998
Revision 1

pg 1 final

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ABSTRACT

Several million cubic feet of hazardous and radioactive waste was buried in shallow pits and trenches within many U.S. Department of Energy (U.S. DOE) sites. The pits and trenches were constructed similarly to municipal landfills with both stacked and random dump waste forms such as barrels and boxes. Many of the hazardous materials in these waste sites are migrating into groundwater systems through plumes and leaching. On-site containment is one of the options being considered for prevention of waste migration.

This report describes the results of a proof-of-principle test conducted to demonstrate technology for containing waste.

This proof-of-principle test, conducted at the RAHCO International, Inc., facility in the summer of 1997, evaluated equipment techniques for cutting a horizontal slot beneath an existing waste site. The slot would theoretically be used by complementary equipment designed to place a cement barrier under the waste. The technology evaluated consisted of a slot cutting mechanism, muck handling system, thrust system, and instrumentation. Data were gathered and analyzed to evaluate the performance parameters.

SUMMARY

This report describes the Slot Cutter Proof-of-Principle Test conducted at the RAHCO International, Inc., facilities located in Spokane, Washington, during the period of 17 June to 3 July 1997. The test objective was to demonstrate the capability of a RAHCO-designed Slot Cutter System to cut a nominal 1-ft horizontal slot in soil materials similar to those expected at DOE sites. In addition, the effectiveness of the muck handling system was observed and several operating parameters including advance rate, cutting horsepower, and cutter tool wear were measured.

The test facility, as illustrated in the figure below, was designed to allow the excavation of a 1-ft horizontal slot (nominally 15-ft wide and approximately 40-ft long) in four engineered soils. This facility consisted of a concrete slab, cutterhead rails, engineered soils, and a soil-retaining box 16 ft-8 in. wide X 41 ft-8 in. long X 20-ft high. The engineered soils consisted of cemented sand, cemented sand and cobbles, cemented sand and boulders, and natural clay. These materials were placed in four zones on the concrete slab. The soil-retaining box, suspended approximately 30 in. above the concrete slab, was filled with natural sand to simulate the overburden loading on the engineered soils.

Test Facility Layout

Test Results:

1. The test facility performed well. However, the moisture content of the engineered soils was higher than anticipated. This caused periodic plugging of the cutterhead and reduced the effectiveness of the vacuum muck handling system.
2. The 5-in., minidisc cutters were effective in excavating three of the engineered soils, particularly the sand-cobbles and sand-boulders. In the wetter soils, the spacing and pattern of the minidisc cutters was inadequate to allow for effective muck clearing and resulted in partial plugging. The spacing pattern of the cutters also caused overloading of the minidisks in the boulder zone. This resulted in some minidisc bearing and seal failures. In the natural clay material, minidisks proved inefficient.
3. The cutterhead tended to pitch upwards against its guide tracks when cutting in the sand-boulder material. This resulted in a slight upwards drift in the slot.
4. Several cam followers attached to the cutterhead failed. This failure was attributed to excessive tolerances in the fitup of the cutterhead to the beam that resulted in severe impact loads on the cam followers as the cutterhead advanced. Initial observations also indicated that the cam follower bearing seals may have been inadequate.
5. The vacuum muck handling system proved effective at transporting loose muck and small rock chips. However, it was not effective at handling damp or heavy muck or large rock fragments. The vacuum system was not used in the sand-boulder zone, but large rock chips produced in this material would suggest that the vacuum system would not be effective.
6. The remaining test hardware including cutterhead drive, thrusting system, and the power units performed as expected.
7. The instrumentation worked adequately, but the system did experience partial failures. The string pots, used for monitoring the position of the cutterhead, failed and were replaced by optical limit switches. The winch drive flowmeter provided intermittent data on start-up and during the cobble zone. However, it was adjusted and performed satisfactorily for the other zones.
8. Advance rates through the engineered soils varied considerably and were affected primarily by the minidisc manufacturer's recommended limitations on the depth of penetration and tool speed. Originally, the test goal was to achieve an average 10-fph advance rate through the different materials. This speed was easily achieved in the sand and the sand-cobble zones, but actual advance rate in the sand-boulder zone was approximately 1.3 fph.

Conclusions:

This test established that the Slot Cutter System is fully capable of successfully cutting a slot in materials expected at DOE sites. Further design efforts will focus on the following:

1. Repositioning the minidisc cutters to avoid material plugging and improve muck handling. Repositioning should reduce individual cutting tool impact and improve cutting speed in hard materials.
2. Improving the minidisc seal design and adding a method of single point or automated bearing relubrication to compensate for grease loss that occurs during the cutting of hard materials.
3. Adding the ability to adjust the cutterhead to allow correction in the slot path.
4. Improving or replacing the method of using cam follower rollers to transfer load from the cutterhead to the cutterhead beam.
5. Improving the manufacturing tolerance of the cutterhead-to-cutterhead beam fitup.
6. Changing the external muck handling system to a mechanical conveying method, but retaining negative pressure ventilation for dust control.
7. Improving the cutterhead position sensor system to provide a more reliable and robust method of monitoring cutterhead location.
8. Modifying the winch drive hydraulic system to provide better tension control of the cutterhead drive rope.
9. Modifying the hydraulic thrust system to improve thrusting position control.

SECTION 1.0

INTRODUCTION

Several million cubic feet of hazardous waste have been buried in shallow pits and trenches in U.S. DOE complexes. The pits and trenches were constructed similar to municipal landfills with both stacked and random dump waste forms such as barrels and boxes. The waste sites may contain particulate radioactive materials; transuranic waste; heavy metals; and/or volatile organic compounds such as trichloroethylene, carbon tetrachloride, and cutting oils such as REGAL oil. Many of the waste containers may be breached, leaking, or even unrecognizable because of deterioration.

The waste configuration described is similar to the waste located in DOE sites throughout the United States. In response to the need to contain these sites, the DOE's Office of Technology Development has initiated a comprehensive program to develop and demonstrate advanced containment technologies that support DOE's environmental objectives. Technologies that are successfully developed will result in the transfer of scientifically sound, demonstrated technologies that can be developed in various environmental programs throughout the DOE complex.

In Fiscal Year (FY) 97 a slot cutter system was developed and demonstrated as a component of the environmental stabilization technology. The culmination of this and the underground barrier placement system technology will be the development and demonstration of a Buried Waste Containment System (BWCS) designed to contain existing buried waste.

1.1 PURPOSE & SCOPE OF TEST

1.1.1 PURPOSE

The overall objectives of this proof-of-principle test were to explore and verify the method for effectively cutting a horizontal slot suitable for barrier placement below the ground surface.

This report describes the results of a Slot Cutter Proof-of-Principle (POP) Test conducted at the RAHCO International, Inc., facilities in Spokane, Washington, during the period of 24 June to 9 July 1997. The data from this demonstration will eventually be used to assist in the development of an operational machine that will cut a horizontal slot beneath a waste site and fill the excavated slot with an appropriate, impermeable barrier material.

1.1.2 SLOT CUTTER PROOF-OF-PRINCIPLE SCOPE

The Slot Cutter POP Test was conducted in four engineered soils as described in Table 1: cemented sand, cemented sand and cobbles, cemented sand and boulders, and natural clay.

TABLE 1
ENGINEERED SOILS

	ZONE #1	ZONE #2	ZONE #3	ZONE #4
Soil Material Type	Cemented Sand	Cemented Sand-Cobbles	Cemented Sand-Boulders	Natural Clay
Rock Type	None	Basalt Cobbles 6-in., Maximum	Basalt Boulders 40-in., Maximum	None
Maximum Material Strength	Tested at approximately 300 psi	Tested at approximately 17,000 psi	Tested at approximately 17,000 psi	N/A
Rock Distribution	None	Approximately 80% by Volume	Approximately 60%by Volume	None
Average Moisture Content	12%, Estimated	10%, Estimated	5%, Estimated	10%, Estimated

The POP test objectives were to:

- Verify the ability to make a horizontal slot suitable for a cast-in-place barrier system.
- Demonstrate that the cutterhead design is capable of penetrating four types of engineered soils.
- Evaluate the ability of the material (muck) removal system to clear the slot and convey the muck away from the slot operating area.
- Demonstrate that the thrust system has satisfactory force to advance the cutterhead and beam and that it can be controlled.

Each of the objectives were fulfilled.

SECTION 2.0

TECHNICAL DESCRIPTION

2.1 TEST FACILITY DESCRIPTION

The test facility (as illustrated in Figure 1 and Photos 1 and 2) was designed to allow the excavation of a horizontal slot, nominally 1-ft thick by 15-ft wide, over a 40-ft distance in four engineered soils. This facility consisted of a concrete slab, cutterhead rails, engineered soils, and a soil-retaining box 16 ft-8 in. wide X 41 ft-8 in. long X 20-ft high. The engineered soils as described in Figure 2 consisted of cemented sand, cemented sand and cobbles, cemented sand and boulders, and natural clay. Photo 3 shows some of the in-place boulders before addition of the cemented sand. These materials were placed in four zones on the concrete slab. The soil-retaining box, suspended approximately 30 in. above the concrete slab, was filled with natural sand to simulate the overburden loading on the engineered soils.

Figure 1 Test Facility Layout

2.2 TEST HARDWARE DESCRIPTION

2.2.1 SLOT CUTTING MECHANISM

The slot cutting mechanism (see Photos 4, 5, and 6) consisted of a cutterhead beam, a cutterhead, and cutterhead drive components. The cutterhead beam spanned across the slot and acted as a guide rail and an earth shield for the traveling cutterhead. The thrusting system (hydraulic cylinders) connected to the ends of the main beam. The cutterhead was approximately 40 in. in length and consisted of 15 each, 5-in.-diameter minidisc cutters attached to a box weldment. The minidisks' function was to break up the soils so that the muck could be removed from the slot. The cutterhead stroked back and forth across the slot, cutting a vertical face wall nominally 12.0-in. high. The cutterhead was equipped with a muck scraper at each end of the box. The scrapers were used for removing face cuttings from the slot. The cutterhead drive used two hydraulic motors operating two wire rope drums (winches). One winch system at a time pulled the cutterhead across the slot using a 1-1/8-in.-diameter wire rope, while the other winch was set to maintain wire rope drag tension at a minimum. The winch systems automatically exchanged tasks to reverse the cutterhead for its next cut on the return pass.

Photo 4 Slot-Cutting Mechanism after Test Completion

Figure 3 Test Instrumentation & Data Collection

discharge. Observations were noted on the ability to pick up heavy muck components and to draw surrounding muck into the transfer hose. A summary of the test data taken and methods used is shown in Table 2.

TABLE 2 DATA COLLECTION MATRIX					
Test Parameters	Data Type/ Units	Data Source	Data Accuracy	Sampling Method	Sampling Rate
CUTTERHEAD					
Cutter Tool Loading	Radial & Normal Force/lbs	Colorado School of Mines	Unknown	Unknown	Unknown
Cutter Wear	Visual	Photos, Log Notes	NA	Direct Observation	At End of Test
Self-Clearing of Muck	Visual	Photos, Log Notes	NA	Direct Observation	Once per Zone
Depth of Cutter Tool Penetration	Distance/in.	Indirect, from Advance Cylinder Data	± 0.04 in.	Real Time Analog	10/20 Hz
Speed	fpm	String Potentiometer	± 0.075 fpm	Real Time Analog	10/20 Hz
CUTTERHEAD DRIVE					
Operating Pressure	psi	Transducer	± 25 psi	Real Time Analog	10/20 Hz
Flow	gpm	Flowmeter	± 2.0 gpm	Real Time Analog	10/20 Hz
ADVANCE CYLINDERS					
Distance	in.	Temposonic®	± 0.04 in.	Real Time Analog	10/20 Hz
Force	lbs	Transducer	± 25 psi	Real Time Analog	10/20 Hz
MUCK HANDLING					
Chip Size	Range/in.		± 0.25 in.	Grab Sample	Twice per Zone
Moisture Content	%	Offsite Lab Test	$\pm 2\%$	Grab Sample	Twice per Zone
Vacuum System	Vacuum/in.-Hg Volume/cu ft	Transducer	± 0.16 in. Hg	Real Time Analog	10/20 Hz
Cutterhead Scraper Performance	Visual	Photos, Log Notes	NA	Direct Observation	At Significant Occurrences

3.2 TEST EXECUTION

At its most fundamental level, the test program was simply the thrusting of a cutterhead and crossbeam through a test bed made of engineered soils that replicated consolidated soil, consolidated soil and cobbles, consolidated soil and boulders, and clay.

The test travel distance through the test bed is 31 ft: 9.33 ft of cemented sand, 9.33 ft of cobble soil, 9.33 ft of boulder soil, and 3 ft of clay (see Figure 2). There was a 9-ft checkout zone of various soil materials that was used before the test. The effects of consolidation was achieved by using a low-strength concrete mix of 1-1/2 sack cement (per cubic yard) that primarily contained sand and pea gravel as the aggregate. This particular mix is used in the Spokane area as an artificial backfill soil when digging or drilling in slumping ground. The use of cemented sand as the matrix was expected to give equal or greater compressive strength than the natural and consolidated soils chosen for waste sites. Ultimately, the use of basalt boulders in the test bed provided the most stringent test.

The test bed included the soil-retaining box to simulate actual weight bearing soil. The cutterhead beam was placed at the east end of the soil-retaining box atop a pair of guide rails (see Figure 1). Two 12-in.-bore hydraulic cylinders were attached to the cutterhead beam and latched to the guide rails. The cylinders moved the beam and cutterhead west through the engineered soils, relatching themselves to the next pin bar on the guide rails each time their stroke was used up. The hydraulic thrusting cylinders had a stroke of 60 in. Each cylinder's stroke was monitored by the internal linear displacement transducers (Temposonic®). Both hydraulic cylinders had pressure transducers to monitor cylinder force requirements. The hydraulic cylinders' stroke increment was set by programming the PLC to move the desired penetration depth per pass of the cutterhead. The control system allowed adjustments to the thrusting penetration and cutterhead speed to match cutting difficulty.

The test was performed in approximate 6-min-long stages with brief shutdowns in between for data filing. The software used for data logging was limited in its incremental data capacity and required downloading periodically to transfer data to a permanent file.

3.2.1 SAND ZONE TEST

The typical operating cycle for the sand zone began with the cutterhead in its park position a few inches outside the south end of the slot. A signal to turn was issued through the PLC to the cutterhead's hydraulic winch drives. By the time the full length of the cutterhead had entered the slot, the cutterhead speed had been quickly ramped up to the maximum preset for the test. After the cutterhead had traversed the slot width and started to exit out the north side of the slot, it passed an optical limit switch that signaled the PLC to begin the slow down speed ramp after a preset time delay. The cutterhead would then come to a controlled stop with its full length a few inches clear of the north end of the slot. After a momentary, preset delay at full stop to allow the crossbeam to advance, the cutterhead was then accelerated back into the slot. Upon reaching the south side, the stop process was repeated similar to the north side process. The stop on the south (home) side was always momentary unless a longer stop was needed for equipment

nominal penetration distance could be controlled real time from the PLC by automatically reading the cylinders' linear transducer position output and sending stop signals to the cylinders' hydraulic control valves. Posttest review of the computer data showed the response time of the hydraulic controls was not as rapid as desired and that there was some drift beyond the nominal penetration stroke goal. The result was that the penetration depths overran the 1/4-in. distance, but remained less than 1/2 in.

Photo 7 Cutterhead in Sand Zone

During the testing it was necessary to adjust the hydraulic controls manually for the winch drives to improve the balance in the handoff of drive tension from north travel to south travel and vice versa. Too abrupt a handoff with a distinct gap between tension cycles would cause jerking and whipping of the slack side wire rope. Adjusting too far the other way to increase the tension overlap would cause the slack winch to pull back excessively on the drive winch. In a few cases peak horsepowers were generated that were not due to actual cutting conditions, but were caused by the excess drag of the slack side winch. Because this tuning was a manual operation done by trial and error, it was difficult to obtain a perfect balance under all operating conditions.

An electrical junction at the flowmeter used to measure hydraulic flow (and therefore winch speed and horsepower) became disconnected during the course of the sand zone test. Because this data was not used for real time control of the winches, the loss of the data signal was not apparent until data processing after completion of the sand zone test.

During the periodic, brief shutdowns for computer data transfer, routine inspections were made of the minidisc cutters. It was found that the bearing caps (hubcaps) would turn loose even

though they were installed with thread locking compound. Discussions with the minidisc vendor made it apparent that the caps were designed for one directional rotation as is typical for tunnel boring machines, but the reversing operation of the slot cutter eventually worked against the cap's thread direction to loosen them. The vendor recommended a very light tack weld to hold the caps tight. Approximately two thirds of the way through the sand zone, a cutter disc (Position #1) stopped turning. It was removed from service and replaced. Inspection of the cutter showed that it had seized due to loss of lubrication and not due to loading-related failure of the bearing. Temperature of the cutter discs was at ambient. This was generally checked by manually feeling the discs, but was also verified by use of an infrared thermometer. The mild disc operating temperatures indicated that the grease was not melting off. Further discussions with the vendor indicated that some of the minidisc cutters on the cutterhead had an older design of bearing seal that under certain conditions would allow the bearing grease to very slowly leak out. The slow rate of loss would not be apparent on the cutter surface and therefore we should relubricate all the cutter bearings every few feet of advance, depending upon the working conditions. Because the cutters came with grease ports, it was a reasonably simple task to temporarily remove the port plugs and regrease all the cutters. The duration of some periodic data transfer shutdowns was extended to accomplish this.

The cutting and forming of the slot and the clearing of the muck from the slot in the sand zone test proceeded smoothly. The actual, active cutting time was approximately 40 mins to advance almost 8 ft. The test distance through cemented sand was less than the nominal 9 ft-4 in. test zone. More than a foot of the sand test zone had been used earlier in completing the cutterhead checkout trials.

3.2.2 COBBLE ZONE TEST

Testing in the cemented sand-cobble zone proceeded similarly to the cemented sand zone. Qualitative observations of torque demands on the cutterhead winch drive indicated that slot cutting in cobbles on the average was not very different than the sand zone. Penetration depth per pass was not changed from the sand zone test.

The rocks chips produced by the minidisc cutters were generally small and resembled primitive arrowheads due to the fracture nature of the basalt. Occasionally, a larger piece of basalt cobble would pull out of the cemented sand matrix and be mucked to the sides. In all cases the removal of muck from the slot face proceeded well. At the end of each slot pass, the muck in this cobble zone self-cleared from the cutterhead better than the pure cemented sand of the previous zone. Apparently, the rock fragments counteracted the packing tendency of the damp sand. The air blast was used again, but it mainly served to blow the last clumps of sand from the minidisks and to keep the apertures of the optical limit switches clear.

A subtest for transporting muck away from the slot and crossbeam area was performed at the beginning of the cobble zone test. A large, industrial vacuum truck was brought to the test site and attached to a temporary shroud on the north side of the cutterhead crossbeam. This shroud was ducted downwards to attach to a 6-in.-diameter hose going to the vacuum truck. As the muck was brought to the north end of the slot by the cutterhead, it was deposited in this shroud

near the hose duct. The vacuum truck was operated at approximately one-half atmosphere equivalent of vacuum. During this subtest the vacuum system was not adequate to pull all the muck from inside the shroud to the hose duct. Muck remained behind to build up in the shroud with each pass of the cutterhead. Removing a windowed inspection port in the shroud allowed muck to be forced down the hose duct manually. Cobble fragments and cemented sand particles were carried well by this direct feeding method, but it was not a practical way to use the vacuum system. Removing the hose from the shroud and inserting it directly into the pile of open muck on the north side produced adequate muck pick up, but the hose had to be kept in direct contact with the material and moved frequently to maintain high air velocity (this is the standard method for using an industrial vacuum system manually). Continued testing of the vacuum muck transport system was abandoned and the shroud removed from the crossbeam. Later observations in the boulder zone of occasional 6-in.-plus-sized pieces of rock fragments indicated that vacuum muck transfer would not be suitable for all the possible operating conditions.

The electrical junction at the flowmeter used to measure hydraulic flow to the winch continued to have problems by not making a solid connection. Because of this problem, the winch hydraulic flow data was unknowingly not logged through the cobble zone.

Unscheduled maintenance shutdowns were not made during the cobble zone test. Periodic regreasing of the cutter bearings was continued. Cutter discs were not warm to the touch and recorded temperatures were only slightly higher than during the sand zone test. The subjective quality of the completed slot was excellent throughout the boulder zone test. The actual, active cutting time was approximately 45 mins to advance 9 ft-4 in.

3.2.3 BOULDER ZONE TEST

From the cutter disc vendor's recommendations and the brief experience with boulders during checkout, it was planned that the boulder zone test would use small cutter disc penetrations on the order of 1/16 in. It was also planned that when beginning the test, the cutterhead would make two passes before advancing forward the nominal 1/16 in.; and then later try advancing alternate sides (see-saw fashion) after each cutterhead pass to test progressive engagement of the cutter discs into the hard rock. Because of the observed impact as the cutterhead engaged the boulders at the beginning of the boulder zone, the test team chose to go to the alternating advance method sooner than scheduled. Subsequent to this plan change, it was also decided to reduce the penetration depth by about one-half (down to a nominal 1/32 in.) to reduce the shock further. Cutterhead travel speed was also reduced. Forward advance rate was therefore less than during the sand zone and the cobble zone. Under these conditions the actual cutting and mucking of test material proceeded well (see Photo 8). Muck did not build up on the cutterhead and the air blast was used primarily, as in the cobble zone, to keep the apertures of the optical limit switches clear.

The use of boulders to replicate actual rock under a waste pit could be considered to be a more severe condition than solid rock. The mass and the intermittent nature of the boulders in the cemented sand matrix created multiple impact points somewhat analogous to driving on a potholed road. The winch drives on the cutterhead required careful tuning to optimize the slack

side wire rope tension and reduce whipping of the ropes during impacts. Occasionally, the hydraulic control system for the cutterhead crossbeam advance would allow overtravel that resulted in excessive cutter penetration and shock on the cutterhead to the point of sometimes stopping the cutterhead in midpass. This would require reversing the advance cylinders slightly to pull the cutterhead back and then restarting the cutterhead. The hydraulic hoses to the winch drives were observed to flex and jump noticeably throughout the operating cycles in the boulder zone.

Photo 8 Cutterhead in Boulder Zone

As the boulder zone test proceeded it was observed that the path of the forming slot tended to drift upwards at times. Apparently, the fitup clearances between the cutterhead and the crossbeam allowed the cutterhead to pitch up or down slightly whenever it worked into the uneven face of a boulder. An upward pitch would result in an upward path of the slot. A downward pitch and downward slot path would be canceled by the reaction of the guide beams. In one situation, the rise upwards was severe enough to cause the cutterhead top discs (gauge discs) to begin to contact the steel structural member at the bottom of the soil retaining box. During this time the cutterhead crossbeam lifted off the guide rails at each end (but without serious consequences). To redirect the slot downwards, steel shim bars were temporarily added to the top edge of the cutterhead where they could slide against the top flange of the crossbeam and reduce the upward cutterhead pitch. The shims' thickness was increased sequentially to avoid a sudden, large increase in cut requirements for the bottom cutter discs. During this process of gradually steering the cutterhead back down, the top discs (Positions #14 and #15)

continued to make contact with the steel retaining box on the south side (the side that included a large rock during this part of the test). No damage was caused to the steel structural member, but a modest thump could be heard each time the cutterhead swept by. The friction from the shim contact caused significant wear on the shims and a temperature increase around them in the top of the cutterhead. The edge of the crossbeam flange did not receive excessive wear, probably due to the intermittent contact by the moving cutterhead for any one spot on the beam.

Before the conclusion of the boulder zone test, the #14 and #15 cutter discs suffered bearing seizures and were removed from service. At the time of failure, the cutterhead was working against the bottom of the retaining box; this impact was the likely cause of bearing failure. The disc cutters were not replaced. The top cutters were not needed for the restearing procedure and new ones would have been at risk for premature failure. The #14 shaft was damaged beyond reuse. The #15 shaft was still in good condition, so a protective steel sleeve was fitted over it to finish out the test zone. Before the conclusion of the boulder test zone, two more cutter discs failed in the #9 and #10 positions. These were among the lead positions that take the most load from advance cutting. These cutters were replaced before proceeding. Some parts of the cutter rims were worn flat (see Photo 9). Apparently the cutters' high resistance to rotation as the bearings failed caused them to drag instead of roll across the boulders.

Photo 9 Worn Disc Cutters in the Boulder Zone

During the course of the test, a hydraulic line to an oil cooler came loose from its fitting and had to be reattached. This was most likely due to the aforementioned shock loading on the winch drive hydraulic system.

After observing the cam follower bearing rollers in the muck, an examination of the followers was done. More than half of the followers required replacing. These were found to have lost the bearing seal that led in turn to grease loss and bearing failure. It is also possible that some of the bearings failed due to impact loading (see Photos 10 and 11). The quantity of replacements

required exceeded available spares. Delivery time of the replacements resulted in a several day shutdown before the boulder zone test could be completed.

Photo 10 Cam Followers during Boulder Zone

Photo 11 Worn Cam Followers

Muck handling out of the slot was done without problems. The subjective quality of the completed slot was excellent throughout the boulder zone test. The actual, active cutting time was approximately 6.67 hrs to advance 9 ft-4 in.

3.2.4 CLAY ZONE TEST

For the clay zone test, the cutterhead penetration was increased to the method and approximate settings used for the sand and cobble zones. The travel speed of the cutterhead was left below 200 fpm from the end of the boulder zone test.

The nature of the moist, sticky clay did not generally allow the minidisc cutters to rotate. Therefore, the fracture-type cutting action was absent and the cutterhead as a unit acted more as a bulk scraper. The cutterhead quickly packed with clay, but continued to scrape and muck clay material to the open sides of the slot (see Photo 12). This created a suitable slot; but, as expected before the test, the minidisks are not the most efficient tool for soft, nonbrittle materials. There were no cutter tool temperature considerations during this test.

Photo 12 Cutterhead in Clay Zone

The clay test zone was planned for 3 ft of advance travel. With about 7 in. remaining in the zone, the test was stopped. This was a result of the clay not being stable and crumbling away as the end of the retaining box was approached. The cutterhead beam thrust controls were adjusted to advance the beam rapidly and continuously so that it simply pushed forward through the remaining clay.

No equipment failures occurred. Mechanically, this test could be considered *easy going*.

A summary of the primary parameters observed during all four test zones is shown in Table 3.
A diagram of the overall test operations is shown in Figure 4.

TABLE 3 TEST PERFORMANCE MATRIX				
Major Components	Sand Test #1	Cobbles Test #2	Boulders Test #3	Clay Test #4
Average Cutter Face Travel Speed	322 fpm	322 fpm	219 fpm	159 fpm
Average Penetration Advance	0.3085 in.	0.3041 in.	0.0326 in.	0.2932 in.
Average Advance Rate	10.2 fph	13.8 fph	1.5 fph	8.0 fph
Average Advance Thrust Pressure	1208 psi	1083 psi	3070 psi	3331 psi
Average Peak Cutter Winch Power per Pass	60 hp	51 hp	69 hp	1 hp
Peak Cutter Disc Temperature	75°F	85°F	160°F	75°F
Cutter Disc Wear	Over Complete Test: 0.5% Average on Diameter			

Start Test Approx. 18:40 PM

Day 1 24-June-97

Day 2 25-June-97

Day 3 26-June-97

Day 4 1-July-97

Day 5 8-July-97

Day 6 9-July-97

Finished Test Approx. 4:40 PM

Approx. Test Zone Cutterhead Operating Tim

Sand Zone	0.374 Hours
Sand\Cobble Zone	0.325 Hours
Sand\Boulder Zone	6.050 Hours
Clay Zone	0.310 Hours

Figure 4 Test Operations

SECTION 4.0

TEST RESULTS

4.1 EQUIPMENT/SYSTEMS EVALUATION

4.1.1 TEST FACILITY PERFORMANCE

The test facility consisted of the systems and equipment used to support the slot cutter test. The major components of this system were the soil retaining box, test bed, and the PLC. Table 4 lists the component evaluated, the requirements for that components, any issues related to meeting the requirements, and a subjective evaluation of the equipment's performance.

The test facility, with minor exceptions, performed as expected and supported all of the required test objectives.

TABLE 4 TEST FACILITY PERFORMANCE			
Scale: 1 = Unacceptable; 2 = Fair; 3 = Acceptable; 4 = Good; 5 = Excellent			
Component	Performance Rating (1-5)	Performance/Functional Requirements	Issues & Problems
Soil-Retaining Box	5	Support the sand overburden	• None
Test Bed	4	Provide a reasonable simulation of possible sub-surface excavation conditions	• Excessive moisture in cemented sand matrix and intermittent positioning of boulders may both represent more severe conditions than typical in the field
Programmable Logic Controller (PLC)	5	Provide automated oversight and control of test process	• None

4.1.2 TEST HARDWARE PERFORMANCE

The test hardware included the slot cutting mechanism, the thrusting system, the muck handling system, and the instrumentation. Table 5 lists the hardware subcomponents, the requirements for those components, any issues related to meeting the requirements, and a subjective evaluation of the equipment's performance.

TABLE 5
TEST HARDWARE PERFORMANCE

Scale: 1 = Unacceptable; 2 = Fair; 3 = Acceptable; 4 = Good; 5 = Excellent

Component	Performance Rating (1-5)	Performance/Functional Requirements	Issues & Problems
Slot Cutting Mechanism:			
Cutterhead	4	Cut engineered soils and provide a uniform slot	<ul style="list-style-type: none"> • Arrangement of disc cutters hindered clearing muck • Bearing seals and manual lubrication system not suited to demands of job • Will require a choice of designs for clay versus rocky soils
Cutterhead Beam	4	Support the cutterhead and have minimal deflection and distortion	<ul style="list-style-type: none"> • In conjunction with the cutterhead, the fitup was too loose and nonadjustable
Cutterhead Winch Drive	5	Pull the cutterhead back and forth	<ul style="list-style-type: none"> • None
Cutterhead Power Unit	4	Provide adequate power in a uniform, controllable manner	<ul style="list-style-type: none"> • Hydraulic controls were difficult to adjust for drive rope slap reduction
Thrust System:			
Thrust Cylinders	5	Advance cutterhead beam and provide penetration into the slot	<ul style="list-style-type: none"> • None
Thrust Guide Rails	4	Guide the cutterhead beam and support the thrust cylinders	<ul style="list-style-type: none"> • Design of the inchworm method of relocation did not easily allow backing up
Thrust Power Unit	4	Provide adequate power in a uniform, controllable manner	<ul style="list-style-type: none"> • Hydraulic controls intermittently allowed overtravel in thrust cylinders
Muck Removal System:			
Cutterhead Scrapers	5	Convey muck from the face of the slot to the open slot ends	<ul style="list-style-type: none"> • None
Vacuum Muck Removal	1	Convey muck from the slot ends to a remote location (truck hopper)	<ul style="list-style-type: none"> • Required <i>hand feeding</i> of muck directly into the vacuum inlet • Was not suited to large rock in the muck
Instrumentation:			
Various Instruments	3	Convert physical data to electronic data and store data for later analysis	<ul style="list-style-type: none"> • Stringpot position sensors were not suitable • Optical position sensors required frequent cleaning • Hydraulic flowmeter electrical connection • Data logging method required periodic interruptions

Overall, the 5-in. diameter minidisc cutters performed well and as planned within the context of the following observations. Temperatures at the disc rims were higher for the boulder zone, but were not excessive (see Charts 1 and 2). Excavation performance in the first three engineered soils was satisfactory. Because the minidiscs are designed to fracture brittle soils, they were inefficient in natural clay. Lubrication cycles were often not frequent enough in the more severe cutting conditions. Some minidisc cutter bearing seals were not robust enough in design. Loss of lubricant became a factor in cutter tool failures. Impact also had an effect in the case of cutter discs that singly caught the full force of initial cutting. An example is the cutter in Position #1 that engaged rocks (cutting from south to north) without being paired up with a second cutter to share and balance loads. Wear on the disc rims was generally less than 0.050 in. on the diameter. In the cases of excessive wear, the bearings had first seized, followed by little to no rotation of the disc resulting in flat spots on the rims (see Charts 3 and 4). Damp muck did not always drop clear of the cutterhead because of the cutter disc pattern and the close mounting of the discs. This was particularly noticeable in the middle of the cutterhead. The cutter pattern is similar to a flattened X and, at the middle point, formed the equivalent of a catch basin to hold up the muck.

The slot created by the cutterhead appeared uniform and very suitable for injection of barrier material. Direction of the slot tended to drift upward at times when cutting the tops of large boulders. Generous manufacturing tolerances in the fitup of both the cutterhead and the cutterhead beam resulted in pitching up of the cutterhead.

This cutterhead pitching may have also resulted in uneven loading of the cam followers on the back of the cutterhead and contributed to their failure (see Chart 5). The cam followers were subject to loss of lubrication similar to the cutter discs.

The cutterhead drive winches worked well during testing. Power to the winches was satisfactory. In a few cases the winch drives stalled due to overpenetration (by the thrust system) and due to a few hydraulic control miscues resulting in one winch pulling against the other winch instead of releasing tension. These were not significant from a power perspective. Uneven response time of hydraulic controls for the winches resulted in drive cable slap that was not always easy to tune out.

The thrust cylinders provided a surplus of force for advancing the slot during the test. There was no lack of thrust. There was a minor deficiency of control over the positioning of the cylinders. This resulted from a lag in response time of the hydraulic controls and some lack of attention to proper tuning for the controls. Backing the cutterhead beam up with the thrust cylinders (occasionally needed to reverse over penetrations) was somewhat tedious because of the one directional design of the inchworming latches. Temporary spacer bars had to be inserted behind each cylinder's forward clevis to hold it in the latched position while the cylinder would stroke out. Reversing was very infrequent, so this procedure was not a major problem.

Muck removal by the cutterhead scrapers from the slot worked very well during testing. At no time was residual material of any significant amount left in the slot. The performance of the vacuum muck removal system away from the ends of the slot was disappointing. As mentioned

before, the system had adequate power to convey smaller material placed directly into the transport hose, but could not draw material to itself from more than a few inches away. After completing the boulder zone test, it also became apparent that the larger, fractured boulder pieces mucked out of the slot would not have passed through the hose.

The instrumentation for the test worked satisfactorily enough to obtain adequate data. The failure of the stringpots and the intermittent electrical connection to the drive winch flowmeter caused the loss of some specialized, detailed data. However, there was enough overlap in data collection methods to compensate for this. The pauses to allow for data downloading after every six minutes of operation during the test were initially considered an unwelcome interference to the flow of the test. But as the test proceeded they provided a valuable opportunity to check out the mechanical systems periodically.

Material		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Ambient Temp °F
Sand Zone	Shaft																73
	Disc	73	73	73	73	73	73	73	71	75	71	71	73	73	73	71	
Sand-Cobble Zone	Shaft																78
	Disc	84	84	84	84	83	82	82	81	88	84	84	84	84	86	83	
Sand-Cobble Zone	Shaft																78
	Disc	83	85	82	82	81	83	82	81	83	84	84	84	83	81	81	
Sand-Boulder Zone	Shaft	114						137		146	160	130	137	120		125	81
	Disc	113		95		122		112	112	130	159	106	104	112	115	112	
Sand-Boulder Zone	Shaft	111								135	112	117	120	148			65
	Disc	98	92	95	98	103	111	97	91	149	128	85	104	115	132	125	
Sand-Boulder Zone	Shaft	120	106	110						140	133	132	116	126	127		67
	Disc	134	101	106	94	98	112	98	100	121	119	116	110	110	116	116	
Sand-Boulder Zone	Shaft									154	160	113	127	131	150		67
	Disc	126	122		111	112	128	132	119	132	130	115	122	114	139	111	
Sand-Boulder Zone	Shaft	128								188	172	170	144	165	123	289	67
	Disc		114	120			130		135		137	133	120	132		113	

Chart 1 Cutter Disc Operating Temperatures

SECTION 5.0

CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSIONS

This test established that the Slot Cutter System is fully capable of successfully cutting a horizontal slot and meeting the major test objectives. Table 6 lists the major objectives of the tests and a subjective evaluation of the performance.

TABLE 6 TEST OBJECTIVES EVALUATION		
Scale: 1 = Unacceptable; 2 = Fair; 3 = Acceptable; 4 = Good; 5 = Excellent		
Major Test Objective	Test Rating	Comments
Verify the ability to make a horizontal slot suitable for the cast-in-place barrier system.	5	<ul style="list-style-type: none"> • Good slot quality with uniform surfaces
Verify that the cutterhead design was capable of penetrating four types of engineered soils.	4	<ul style="list-style-type: none"> • Worked well in brittle soils • Was inefficient in soft, plastic soil (clay)
Demonstrate that the thrusting system satisfactorily advanced the cutterhead and beam and was controlled accurately.	4	<ul style="list-style-type: none"> • Excellent advance force and smoothness of operation • Overtravel suggests need for control design or software modification
Validate that the material (muck) removal system cleared muck from the slot and conveyed it away from the slot operating area.	4	<ul style="list-style-type: none"> • Muck removal in slot was excellent • Vacuum mucking of heavy materials was not satisfactory

5.2 RECOMMENDATIONS

From information gathered and lessons learned from the slot cutter test, the following design requirements should be incorporated into the operational equipment:

- Improve the minidisc cutter seal design and add a single point or automated bearing lubrication system to compensate for grease loss that occurs during the cutting of hard materials.
- Reposition the minidisc cutters to avoid material plugging and improve muck flow off the cutterhead.
- Add the capability to adjust the cutterhead pitch to maintain a horizontal slot path.

- Decrease the manufacturing tolerance of the cutterhead-to-cutterhead beam fitup; improve or replace the use of cam followers for load transfer to the beam.
- Change the external muck handling system to a mechanical conveying method, but retain negative pressure ventilation for dust control.
- Modify the cutterhead position sensor to provide a reliable and robust method of monitoring cutterhead location across the slot.
- Modify the winch drive hydraulic system to provide better tension control of the cutterhead drive cable.
- Modify the hydraulic thrust system to improve thrusting position control.

Buried Waste Containment System

FINAL REPORT

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1998
May

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**DESIGN & PROOF-OF-PRINCIPLE TESTING
OF A BURIED WASTE CONTAINMENT SYSTEM**

FINAL REPORT

Submitted to:

U.S. Department of Energy
Idaho Falls, Idaho 83415

Submitted by:

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21 May 1998

ABSTRACT

Several million cubic feet of hazardous and radioactive waste was buried in shallow pits and trenches within many U.S. Department of Energy (U.S. DOE) sites. The pits and trenches were constructed similarly to municipal landfills with both stacked and random dump waste forms such as barrels and boxes. Many of the hazardous materials in these waste sites are migrating into groundwater systems through plumes and leaching. On-site containment is one of the options being considered for prevention of waste migration.

This report describes the results of the preliminary design and proof-of-principle testing conducted to demonstrate technology for containing waste. The proof-of-principle tests, conducted at the RAHCO International, Inc., facility in the spring of 1997, evaluated equipment techniques for continuously constructing a horizontal slot and placing a cementitious barrier beneath existing waste. The technology evaluated consisted of a method for excavating materials, injecting a continuous barrier, and monitoring its placement to ensure a leak-proof containment. Data were gathered and analyzed to evaluate the performance parameters.

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LIST OF ACRONYMS

ASTM	American Society of Testing and Materials
BWCS	Buried Waste Containment System
DOE	U.S. Department of Energy
Est	Estimated
FCC	Face Centered Cubic
FY	Fiscal Year
LMITCO	Lockheed Martin Idaho Technologies Company
POP	Proof-of-Principle (Test)
PT	Pressure Transmitter
SBR	Styrene Butadiene Rubber
U.S. DOE	United States Department of Energy
USP	United States Pharmacopeia
ZT	Linear Transmitter

Figure 4 Barrier Placement Machine—Side View

SECTION 2.0

SYSTEM DESCRIPTION

As developed for this contract, the RAHCO International Buried Waste Containment System uses a specially designed, self-propelled, track-mounted Barrier Placement Machine (BPM) to cast-in-place an impermeable and durable grout barrier along the sides and below a buried waste site. During normal operation, the BPM excavates a trench along each side and a horizontal slot cut below the waste pit. Simultaneously, the machine continuously casts-in-place a grout barrier around the side slopes and bottom of the trench and in the 12-inch tall, horizontal slot cut below the waste pit. Soil material excavated from each side trench is conveyed to the rear of the machine where it is discharged into the barrier-lined trench—thus backfilling the trench. Soil material excavated from the slot cut is picked up and transported by a mechanical conveyor to a belt conveyor. Here, the soil is assayed and then discharged into the partially-filled trench.

The BPM is operated by a single operator located in a main operating cab. Three additional crew members are used to monitor the slot excavating process, the grout barrier placement process, and the installation of the long-term sensor systems. Vehicle control is achieved using a global positioning system (GPS) and RAHCO's proven machine control software. The RAHCO-designed BPM is capable of continuously excavating and simultaneously casting-in-place the grout barrier at speeds to 10 feet/hour on a 24-hour per day basis.

2.1 EQUIPMENT DESCRIPTION

The BPM can be grouped into three main assemblies: the barrier installation assembly, the multipurpose transporter, and the trench equipment.

2.1.1 BARRIER INSTALLATION ASSEMBLY

The barrier installation assembly includes the equipment required to place the grout barrier material and the long-term sensor components and also the equipment required to excavate the slot below the waste site. The list of these systems, beginning from front to back in the direction of BPM travel, is: the thrusting system, the horizontal slot cutter, the slot muck handling system, the barrier material mixing and delivery system, slot barrier material distribution system, the side trench slipforms, the void detection system, and the sensor deployment equipment (see Figure 5).

The thrusting system provides the force to pull the horizontal slot cutter into the face of the advancing slot and to overcome the drag of the surrounding soil on the equipment that places the grout barrier. Rather than transferring this force from near the bottom of the trench upward to the crawler tracks under the multipurpose transporter, the force is instead transmitted directly back into the soil around the bottom of the trench. Large, horizontally placed hydraulic cylinders in each side trench thrust against precast, reinforced concrete columns placed horizontally in the

Figure 5 Barrier Installation Assembly—End View

bottom of each trench. These thrusting blocks are interlocked to each other and extend under the lined and backfilled trench behind the advancing BPM. New concrete column blocks are lowered down through the trench shields to the floor of the trench. Each trench has a double system of thrust blocks and cylinders mounted side-by-side in a staggered fashion to provide overlapping, continuous force. The thrust force from the cylinders is transferred into a stirrup-shaped, steel thrust beam that surrounds the cylinders and extends back to connect to the slot equipment. This horizontal thrust beam with the thrust cylinders is supported vertically by the surrounding trench shields. However, it is not restrained horizontally by the shields in order that its advance motions can be separate from the shields' inchworming-type of advance.

The slot cutting system consists of a hollow cutterhead beam, a cutterhead, and cutterhead drive components. The cutterhead beam spans across the slot and acts as a guide rail and an earth shield for the traveling cutterhead. Upper and lower horizontal steel plates provide structural strength to the beam and form shields to support the ground and keep dirt from collapsing the slot behind the cutterhead. The shields extend outward from the back of the beam forming a cavity that will enclose a grout distribution and injector system. The thrusting system connects to the ends of the main beam. The cutterhead consists of small-diameter minidisc cutters attached to a nominal 40-inch-long box weldment. The minidiscs' function is to break up rocky soils so that the muck can be removed from the slot. Cutterheads using cutter tools other than minidiscs can be easily installed to match soil conditions such as clay or sands without large, hard rocks. The cutters are installed in a radial pattern that skews outward at the top and bottom of the box so that they will cut a slot wider than the beam's frame members. The cutterhead is contained in a channel shape in the front of the cutterhead beam and strokes back and forth across the slot, cutting a vertical face wall nominally 12.0-inches high. The cutterhead is equipped with a muck scraper at each end of its box weldment. The scrapers are used for removing soil cuttings from the slot. The cutterhead drive uses hydraulic motors operating two wire rope drums (winches). The winch systems alternate in pulling the cutterhead from one side to the other across the slot face. The motors are variable speed so that the cutter speed can be adjusted to match soil conditions. (See Figure 12 in Section 3.0 for a similar cutting system used in proof-of-principle testing.)

The slot muck handling system serves to remove the soil cuttings (muck) from the slot area and transfer them to a conveying system in the multipurpose transporter that is above ground level. A mechanical elevator-type conveyor is located in each trench at the ends of the slot beam. Small buckets attached to an endless conveying chain pick up the muck at the bottom of the trench out of a shallow bin into which the cutterhead's muck scrapers have dropped the muck. The buckets raise the muck to the top of the trench and then discharge it onto a conveyor belt. At that point, the muck becomes part of the material transfer conveyors that include assaying equipment as necessary. The slot muck handling elevator is enclosed in a metal box for its full height. The inside of this box is kept at a lower air pressure than normal atmospheric pressure to prevent the discharge of dust that may be contaminated by waste pit leakage into the slot area.

The slot barrier material mixing and delivery system begins with storage and mixing of grout raw ingredients in a continuous grout dispenser and finishes with the pumping of the grout to the barrier distribution equipment. A system is installed on each multipurpose transporter above

ground level. The continuous grout dispenser is an adaptation of a commercially available unit and consists of receiving hoppers and tanks for short-term storage of raw materials, a continuous mixing auger, and a grout pump. Dry, raw materials are delivered by pneumatic conveyor and liquid materials are pumped, both from a nearby bulk transport truck. A process control computer oversees the blending of the raw materials in the mixing auger. The speed and length of the mixing auger are designed to provide the proper mixing time before discharging the fresh grout into the hopper of the pumping unit. The size of the mixing and pumping units is kept small enough to prevent long residence times for the fresh grout. This is important when relatively rapid-setting grouts may be used for barrier materials. The grout from each grout dispenser is pumped through transfer pipes and hoses to the adjacent side of the slot barrier material distribution system and to the appropriate side trench slipform.

The slot barrier material distribution system injects grout into the horizontal slot cut by the slot cutter. It consists of a specially designed injector and a grout purge mechanism. The grout injector is located within the cavity of the shields at the back of the slot cutter beam along the full width of the underground slot. Grout flows into both ends of the injector from each of the grout dispensers located on the multipurpose transporters above each side trench. The grout injector is a pipe-shaped conduit with a series of holes along its length facing out into the slot behind the beam. A special shutter-type mechanism is used to open and close the individual holes, or injection ports, as indicated by the void detection system to permit fluid grout to fill every area behind the slot beam as it advances. A header wall extends from the injector unit upwards and downwards to the top and bottom of the slot. Shields extend to the rear from the top and bottom of the header wall to prevent grout from backflowing into the area around the outside of the slot beam and to also support the overburden load while the grout barrier is taking its initial set. The grout purge mechanism consists of dump valves that can be used to empty grout lines and a mechanical plug that travels through the injector pushing grout ahead of it. The plug has a head end that conforms to the shape of the injector interior. It is pulled through the injector by a wire rope that is stored through the length of the injector conduit. By closing off the shutters over the holes it will also be possible to provide a final liquid flush of the injector conduit.

Side trench slipforms are located adjacent to the ends of the slot equipment at the tail end of each trench shield unit. Each trench slipform consists of a consolidator and a troweling pan. The consolidator is a vertical, reciprocating bar with paddles. It is located behind the shield at the head of the troweling pan and parallel to the work trench outer wall. It moves the grout downwards along the trench wall and floor and consolidates it to eliminate any voids. The speed and duration of consolidator strokes are adjustable to meet control demands from the barrier void detection system. The troweling pan is a smooth, curved steel plate that extends parallel to the outer wall and floor of the work trench at an offset distance equal to the desired barrier thickness. It slides over the surface of the grout barrier, forming and smoothing the barrier surface. Grout is pumped from the grout dispensers into the consolidator region at a point near the top of the slipform.

The barrier void detector system consists of a series of pressure sensors located along the injector header wall in the slot and along the leading edge of the trench slipforms. If a void

forms in the barrier, the resulting pressure drop in the area of the void will be detected by at least one of the sensors in the sensor array. An electronic signal from the sensors is sent to a programmable logic controller (computer) that monitors for excessive deviations and automatically controls the flow of fresh grout to the appropriate locations.

The sensor deployment equipment installs the permanent, long-term sensor devices into the slot and side trench barrier spaces as the grout is being injected. These sensor devices consist of fiber optic strands and flexible plastic tubes placed in a grid pattern throughout the containment barrier as shown in Figure 6. Transverse sensor devices are kept on storage reels on the multipurpose transporter above one side trench. These are pulled down through a pair of conduits that run along the head walls of the trench slipforms and slot barrier injector and back up to the multipurpose transporter above the other side trench. The sensor devices are automatically cut to the proper length above the height of each of the trench edges. At the proper interval in the advance of the BPM, the sensor devices are pushed out through side seals in the conduits into the fresh, liquid grout. Sensor devices for the longitudinal direction are anchored at the starting end of the containment barrier and pulled out of guide ports in the advancing headwalls of the slot grout injector and trench slipforms. The guide ports are fed the running length of the sensor devices through guide tubes in the slot beam and trench slipforms that lead up to storage reels on the multipurpose transporter.

2.1.2 MULTIPURPOSE TRANSPORTER

The above ground, visible part of the BPM is called the multipurpose transporter (see Figure 7). There are two multipurpose transporters, one for each side trench around the waste site. Each multipurpose transporter is made up of a main frame, crawler track assemblies, power packages, the operator's cab that contains the guidance and computerized control systems, and miscellaneous support equipment. Each transporter is physically disconnected from the other, except at the slot beam below ground. The control system keeps them operating in unison.

The main frame of a multipurpose transporter supports all the other equipment systems, either directly or indirectly. It consists of a box-type, truss frame chassis that spans a side trench and extends lengthwise to support a trench excavator at the frame's front, through a series of trench shields in the middle, and finally to the barrier equipment at the back.

The main frame is carried on four heavy-duty crawler tracks, one located at each corner. The crawler tracks are hydraulically driven and are capable of very slow, creeping speeds. Each crawler track is attached to the main frame by a vertical suspension column. This column has the ability to raise or lower the transporter main frame to maintain a precise working elevation. Steering cylinders are provided at each suspension column to rotate the crawler tracks around the vertical suspension axis, in this way allowing the transporter to make precise course corrections.

The BPM is powered by diesel engines that primarily drive hydraulic pumps and secondarily drive electrical generators. Two power packs are located on each transporter frame. The forward unit powers the forward tracks, the trench excavators, the conveyors, and an electrical

PROJECTION VIEW OF SENSOR GRID

HALF CROSS SECTION VIEW

Figure 6 Installation of Long-Term Sensors

Figure 7 Multipurpose Transporter—Side View

Figure 8 Trench Equipment—Side View

side trenches. The slot equipment is then placed in the cross trench on the concrete starting block and attached to the thrust system within the shields. Backfill is placed around the excavator and shields and any temporary cribbing is removed from the side trenches. Temporary bridge structures are put over the cross trench in two places to permit the multipurpose transporter to travel over the cross trench. With the subsurface equipment in place, the crawler track-mounted multipurpose transporter is driven into place and attached to the trench excavator and moveable shields.

2.2.2 NORMAL OPERATION

During normal operation, the BPM's crawler tracks advance the complete equipment assembly forward at an average speed matched to the slot cutterhead's ability to penetrate through the particular soils encountered at the jobsite. The left and right transporters are kept in proper relative position to each other by adjusting crawler speeds and steering. The positioning input comes from the GPS electronics. As this advance takes place, the trench excavators are removing the side trench soil and placing it on the conveyor belts within each transporter frame. The moveable shields follow behind the trench excavators, moving in their inchworm fashion and shoring the work trench walls. As the shields move, they advance the trench slipforms that are placing the barrier along the trench outer walls and floors. While the trench slipform's longitudinal motion is mechanically independent of the slot slipform's motion, the two systems are kept in a synchronized relationship by the automated control system.

Placement of the trench barriers and the slot barrier is done simultaneously to form a monolithic structure and to facilitate embedment of the long term sensors. As noted in the equipment description section, the barrier grout is mixed on the BPM using raw materials stored offsite and delivered by bulk transport trucks. Mixed grout is pumped down to the slot as slot excavation proceeds. The thrusting system pulls the slot equipment forward. If an overly large void space is encountered in the slot, the void detection system may call for the thrusting system to slow or stop to allow a sufficient quantity of grout to be fed into the void before continuing to advance. Periodically, the permanent transverse sensor strands and tubes are pulled through the trench and slot barrier slipforms and put into place. The longitudinal permanent sensors strands are anchored at the starting block in the cross trench and fed through the slipforms continuously.

Forward travel of the BPM will be affected during normal operation by stops and starts for maintenance and particularly during slow slot excavation when it may be more advantageous to place barrier material in batches with all forward motion halted after a period of slot excavation. (Preliminary testing of barrier grouts indicates that these stop/start joints will perform satisfactorily. See this report's section on proof-of-principle testing.)

Problems may occur during barrier placement operations that will also require the shutdown of the operation. Should this occur, the barrier installation assembly must be purged of grout before it can set up. As previously described in the equipment section, the ends of the grout injection mechanism are opened into bypass lines and a grout purge plug is inserted into one end of the injector. The plug is pulled through the injector, forcing the grout out the other end of the injector where it is collected. When the problem is corrected and barrier placement is to

resume, the cutter is started and allowed to advance slightly to open a space between the injector and set grout. Placement of fresh grout then resumes.

Continuing with normal operation, the excavated soil from the trenches and slot are carried on conveyor belts to the rear of the BPM and discharged into the lined work trenches. The excavated material from the trenches is kept separate from the slot's excavated material by independent conveyor belts. This allows the slot material to be assayed separately and to be placed first at the bottom of the trenches onto the new barrier. This puts it in close proximity to its original location. The potentially more benign trench material is then backfilled over the top.

2.2.3 END BARRIER PLACEMENT

At the end of the waste pit, barrier placement is stopped. The BPM is disassembled and removed from the work trenches. The terminal cross trench for the waste pit is now excavated and prepared, the starting cross trench is prepared, and end walls for both are placed using conventional construction methods.

2.2.4 FINISHING/DEMobilIZATION

After completion of the end barriers, a dozer and grader will come in to grade the backfill around and over the trenches and compact it as required by site authorities. Additional cover soil is brought in to profile the top of the site and a cover cap is put in place, again as required by site authorities. Coordinated with this work, the long-term sensor leads are connected to a centralized monitoring point adjacent to the waste site. The sensor tubes are given a curb to anchor them, and caps are placed over the tubes.

Demobilization is begun on the BPM by dismantling it into its major subsystems to the extent needed for shipment to the next job. If the next job requires over-the-highway transport, then the dismantling will be greater than needed for another job at the same site. As part of this dismantling, the equipment is thoroughly inspected for contamination. Because the BPM components will be designed and surface finished to simplify decontamination it is expected that most components (and possibly all components) will be reusable, with the exception of excessively worn or damaged parts.

SECTION 3.0

PROOF-OF-PRINCIPLE TESTING

Two proof-of-principle (POP) tests were performed as part of the contract awarded to RAHCO International. For the first test, RAHCO was required to design and conduct a Slot Cutter POP test to verify that a horizontal slot could be excavated in the variable soils expected at DOE sites using a specially designed slot cutter. For the second test, RAHCO was required to design and conduct a Grout Barrier Placement POP test to verify that a 12-inch-thick, subsurface, grout barrier could be cast-in-place in soils expected to occur at DOE sites, including that the barrier placement equipment could be purged of grout during shutdowns and that the cold joints (start/stop joints) would demonstrate adequate adherence between the old and new faces.

3.1 SLOT CUTTER POP TEST

The Slot Cutter Proof-of-Principle Test was conducted at the RAHCO International, Inc., facilities located in Spokane, Washington, during the period of 17 June to 3 July 1997. The test objective was to demonstrate the capability of a RAHCO-designed Slot Cutter System to cut a 1-foot horizontal slot in soil materials similar to those expected at DOE sites. In addition, cutting tool efficiency and effectiveness of the muck handling system were to be observed and several operating parameters including advance rate, horsepower, and cutter frame loading were to be measured.

The test facility, as illustrated in Figures 9 and 10, was designed to allow the excavation of a nominal 1-foot horizontal slot, approximately 15-feet wide and 40-feet long, in four engineered soils. This facility consisted of a concrete slab, cutterhead rails, engineered soils, and a soil-retaining box 16 feet-8 inches wide X 41 feet-8 inches long X 20-feet high. The engineered soils as described in Table 1 consisted of cemented sand, cemented sand and cobbles, cemented sand and boulders, and natural clay. These materials were placed in four zones on the concrete slab. A photo of the boulders and cobbles prior to placement in the test facility is shown in Figure 11. The soil-retaining box, suspended approximately 30 inches above the concrete slab, was filled with natural sand to simulate the overburden loading on the engineered soils.

TABLE 1—ENGINEERED SOILS

	ZONE #1	ZONE #2	ZONE #3	ZONE #4
Soil Material Type	Cemented Sand	Cemented Sand-Cobbles	Cemented Sand-Boulders	Natural Clay
Rock Type	None	Basalt Cobbles 6-in., Maximum	Basalt Boulders 40-in., Maximum	None
Maximum Material Strength	Estimated 1,000 psi	Estimated 25,000 psi	Estimated 25,000 psi	N/A
Rock Distribution	None	Approximately 80% by Volume	Approximately 60% by Volume	None
Moisture Content	4.3%, Post Test	2.0%, Post Test	0.8%, Post Test	3.0%, Post Test

- Native Basalt Boulders
2'-5' in Size
- Native Basalt Cobbles
<8" in Size
- <25,000 psi
Compressive Strength

Figure 11 Cobbles & Boulders

The test hardware (shown in Figures 12 and 13) consisted of a slot cutting mechanism, a muck handling system, a thrusting unit, and instrumentation. During testing, the cutterhead, supported by the cutterhead beam, traveled horizontally across the slot and excavated the engineered soils. Disc-type cutting tools (minidisks), mounted on the cutterhead, penetrated to a depth of up to 1 inch per pass. Cutterhead travel was provided by a pair of opposing, diesel-powered, hydraulically-operated winches. The winches operated alternately to pull the cutterhead back and forth across the slot.

The excavated muck was transported to the edges of the slot by scrapers attached to the cutterhead structure. During a portion of the tests, an industrial-capacity, truck-mounted vacuum system was used to remove the excavated muck from the end of the slot. A sealed cover with a vacuum inlet was placed over one end of the cutter beam and attached to the vacuum truck with a 6-inch hose.

Forward thrusting of the cutterhead was provided by two 12-inch-diameter hydraulic cylinders connected to the ends of the cutterhead beam.

Operating data was acquired by both visual means and by electronic instruments that transmitted information to a PLC (programmable logic controller). The PLC then transferred data to a computerized data logging station as shown in Figure 14. Table 2 lists the test data and acquisition methods.

Figure 12 Test

THRUST CYLINDER

CUTTERHEAD DRIVE

CUTTERHEAD

Figure 13 Test

Figure 14 Test Instrumentation & Data Collection

TABLE 2—TEST DATA & ACQUISITION METHODS

TEST DATA PARAMETERS	DATA TYPE/UNITS	DATA SOURCE	SAMPLING METHOD
Test Bed			
Rock Strength	Compressive/psi	Offsite Lab Test	Random Sample
Soil Cement Strength	Compressive/psi	Offsite Lab Test	Random Sample
Muck Handling			
Chip Size	Range/in.	Notes	Grab Sample
Moisture Content	Percent	Offsite Lab Test	Grab Sample
Vacuum System	Vacuum/in.-Hg Volume/cu ft	Transducer	Real Time Analog
Cutterhead Scraper Performance	Visual	Photos, Notes	Direct Observation
Cutterhead			
Cutting Tool Temperature	°F	Hand-Held Infrared Thermometer	Manual
Cutter Wear	Visual	Photos, Notes	Direct Observation
Self-Clearing of Muck	Visual	Photos, Notes	Direct Observation
Depth of Cutting Tool Penetration	Distance/in.	Indirect, From Thrust Cylinder Data	Real Time Analog
Speed	fpm	String Potentiometer (Optional.: Winch Flowmeter)	Real Time Analog
Winch			
Operating Pressure	psi	Transducer	Real Time Analog
Flow	gpm	Flowmeter	Real Time Analog
Thrust Cylinders			
Distance	in.	Linear Displacement Transducer	Real Time Analog
Force	lbs	Transducer	Real Time Analog

Table 3 lists the characteristics of the tests as performed through the four soil zones.

TABLE 3—TEST PERFORMANCE MATRIX				
Major Components	Sand Test #1	Cobbles Test #2	Boulders Test #3	Clay Test #4
Average Cutter Face Travel Speed	322 fpm	322 fpm	219 fpm	159 fpm
Average Penetration Advance	0.3085 in.	0.3041 in.	0.0326 in.	0.2932 in.
Average Advance Rate	10.2 fph	13.8 fph	1.5 fph	8.0 fph
Average Advance Thrust Pressure	1208 psi	1083 psi	3070 psi	3331 psi
Average Peak Cutter Winch Power per Pass	60 hp	51 hp	69 hp	1 hp
Peak Cutter Disc Temperature	75°F	85°F	160°F	75°F
Cutter Disc Wear	Over Complete Test: 0.5% Average on Diameter			

Test Results:

1. The test facility performed well. However, the moisture content of the engineered soils was higher than anticipated. This caused periodical plugging of the cutterhead and reduced the effectiveness of the vacuum muck handling system.
2. The 5-inch, minidisc cutters were effective in excavating three of the engineered soils, particularly the sand-cobbles and sand-boulders (see Figure 15). In the wetter soils, the spacing and pattern of the minidisc cutters was inadequate to allow for effective muck clearing and resulted in partial plugging. The spacing pattern of the cutters also caused overloading of the minidisks in the boulder zone. This resulted in some minidisc bearing and seal failures. In the natural clay material, minidisks proved inefficient.

Figure 15 Cutterhead

3. The cutterhead tended to pitch upwards against its guide tracks when cutting in the sand-boulder material. This resulted in an slight upwards drift in the slot.
4. Several cam followers attached to the cutterhead failed. This failure was attributed to excessive tolerances in the fitup of the cutterhead to the beam that resulted in severe impact loads on the cam followers as the cutterhead advanced. Initial observations also indicated that the cam follower bearing seals may have been inadequate.
5. The vacuum muck handling system proved effective at transporting loose muck and small rock chips. However, it was less effective at handling damp or heavy muck or large rock chips. The vacuum system was not used in the sand-boulder zone, but large rock chips produced in this material would suggest that the vacuum system would not be effective.
6. The remaining test hardware including cutterhead drive, thrusting system, and the power units performed as expected.
7. The instrumentation worked adequately, but it did experience partial failure. The string pot, used for monitoring the position of the cutterhead, failed and was replaced by optical limit switches. The flowmeter provided inaccurate data on start-up and during Test #2. However, it was adjusted and performed satisfactorily for the other tests.
8. Advance rates through the engineered soils varied considerably and were affected primarily by the minidisc manufacturer's recommended limitations on the depth of penetration and tool speed. Originally, the test goal was to achieve an average 10-feet/hour advance rate through the different materials. This speed was easily achieved in the sand and the sand-cobble zones, but the actual advance rate in the sand-boulder zone was approximately 1.3 feet/hour.

This test established that the Slot Cutter System is fully capable of successfully cutting a slot in materials expected at DOE sites (see Figure 16). Further design efforts will focus on the following:

1. Repositioning the minidisc cutters to avoid material plugging and improve muck handling. Repositioning should reduce individual cutting tool impact and improve cutting speed in hard materials.
2. Improving the minidisc seal design and adding a method of single-point or automated bearing relubrication to compensate for grease loss that occurs during the cutting of hard materials.
3. Adding the ability to adjust the cutterhead to allow correction in the slot path.
4. Improving or replacing the method of using cam follower rollers to transfer load from the cutterhead to the cutterhead beam.
5. Decreasing the manufacturing tolerance of the cutterhead-to-cutterhead beam fitup.

6. Changing the muck handling system to a mechanical conveying method, but retaining negative pressure ventilation for dust control.
7. Improving the cutterhead position sensor system to provide a more reliable and robust method of monitoring cutterhead location.
8. Modifying the winch drive hydraulic system to provide better tension control of the cutterhead drive rope.
9. Modifying the hydraulic thrust system to improve thrusting position control.

Figure 16 Test Complete

3.2 BARRIER PLACEMENT POP TEST

The Barrier Placement Proof-of-Principle Test was conducted during the period of 9 May to 30 May 1997 at the RAHCO International, Inc., facilities located in Spokane, Washington. The test objectives were to demonstrate the ability of a RAHCO-designed Barrier Placement System to cast-in-place a continuous barrier in a horizontal slot, demonstrate the ability to detect and fill voids in the barrier, establish the ability to purge the system of grout in the event of a shutdown, and to evaluate the effects of starting and stopping on the placed barrier.

The test facility, as shown in Figures 17, 18, and 19, was designed to allow the construction of a 10-foot-wide by 12-feet-long by 12-inch-deep test barrier. In the start position, the test fixture provided a chamber 10-foot wide by 1-foot long. The movable fixture increased the chamber length to a maximum 12 feet as grout was pumped into the placement chamber. The fixture travel speed was coordinated with the pumping rate to maintain a constant chamber pressure.

Figure 17 Test Facility, Hardware, & Instrumentation

Figure 18 Test Facility Operation

Figure 19 Test Facility

The test hardware consisted of a continuous grout mixer (Figure 20); concrete pump (Figure 21); grout distribution system (hose, injector, and slipform); and a void detection system (Figure 22).

Daffin 35F,
1973 8CY
Mobile
Concrete Mixer

Output:

5.5-6.0 cyh

Figure 20 Continuous Mixer

Schwing, 1996
Model BPL-500X-18R

Capacity: 0-75 cyh

Figure 21 Concrete Pump

Void Detection System:

10 Pressure
Transmitters (PT)

Vibration System:

5 Vibrators—
19,000 vibrations/min
or 205 lbs-force

Figure 22 Void Detection Sensors & Vibrators

The continuous grout mixer automatically proportioned and mixed the grout materials providing a steady flow of material to the concrete pump. The positive displacement concrete pump discharged the grout into the distribution hose to the injector and into the slipform.

Two methods of grout distribution were tested:

Side Injection:

This injector consisted of a 3-inch-diameter port located on the side of the slipform.

Traveling Nozzle Injection:

The traveling injector consisted of a guide tube, traveling nozzle for multipoint injection, seals, and drive unit. The guide tube provided support for the seals and maintained alignment of the nozzle. The nozzle was positioned in the guide tube by the drive unit and injected grout into the placement chamber at specified locations. The seals kept the grout from entering into the guide tube.

The void detection system consisting of pressure transducers monitoring the placement activities for void formation.

Cleanout was accomplished by manually removing the distribution system and cleaning the hose and nozzle using conventional methods.

A latex-modified grout mix using Rapid Set® cement was selected as the barrier material. This mix was selected to provide quick-setting material with low permeability, high adhesion, and resistance to chemical attack as well as resilience and resistance to crack formation. Latex-modified grout is preferred because of its workability properties similar to conventional concrete; it is hazard free and environmentally safe; it is easily cleaned up with water; and it is expected to have satisfactory, long-term durability properties.

Three test barriers were constructed as shown in Figure 23. The first barrier was constructed using the side injection system; the second used the traveling nozzle injector. After evaluating the performance of these alternate methods during visual testing, the traveling nozzle injection system was selected for construction of the buried test barrier. The visual test allowed the observation of the barrier placement through a plexiglass window. The buried test was performed under a 4-inch-thick layer of soil.

Figure 23 Test Sequences

Table 4 describes the test characteristics for the construction of each of the three test barriers.

TABLE 4—BARRIER TEST CHARACTERISTICS								
	Test Barrier 1			Test Barrier 2		Test Barrier 3		
Hardware Configuration	<ul style="list-style-type: none"> • Continuous Mixer • Concrete Pump • Side Injector 			<ul style="list-style-type: none"> • Continuous Mixer • Concrete Pump • Traveling Nozzle 		<ul style="list-style-type: none"> • Continuous Mixer • Concrete Pump • Traveling Nozzle 		
Barrier Material	Latex Modified Grout 11.5-Sack Mix 30% Water			Latex-Modified Grout 11.5-Sack Mix 35% Water		Latex-Modified Grout 9-Sack Mix 35% water		
Test Mode	Visual			Visual		Buried		
Rate of Advance	~2 ipm			~2 ipm		~2 ipm		
Number of Start/Stop Joints	2			1		2		
Injection Rate	~1.7 cfm			~1.7 cfm		~1.7 cfm		
Test Runs	3			2		3		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 1	Run 2	Run 3
Operating Pressure	10	10	10	10	10	10	10	5
Nozzle Positions	1	1	1	2	2	1	2	3
Side	✓	✓	✓					
30-in. from West Side				✓	✓		✓	✓
30-in. from East Side				✓	✓		✓	✓
Middle						✓		✓
Barrier Length (in.)	19	20	24	27	36	26	32	15

Test Results:

1. The test facility performed exceptionally well with some minor mechanical problems.
2. The continuous mixer and concrete pump performed successfully with the exception that the cement content of the grout mix was not consistent.
3. The fixed injector operated successfully and demonstrated that a properly designed, fixed injector system can effectively place the barrier material.
4. The traveling injector was very effective at placing the barrier material, but some seal leakage and other minor mechanical problems were experienced.
5. The slipform assembly experienced both structural problems and seal leakage that can easily be remedied by further design efforts.

6. Cleanout was easily performed and very effective for both placement methods.
7. The void detection system performed as desired.

Conclusions:

This test established that the Barrier Placement System, using either a fixed or traveling injector, is fully capable of successfully installing a barrier material in a subsurface slot. Figure 24 shows the top surface of the test slab using the side injection method. Figure 25 shows a saw cut surface of a cross section through the test slab done with the traveling, multipoint injection method. The selected barrier material shows great promise in that it was easy to handle, is compatible with the equipment, and appears to provide the desired short- and long-term characteristics. Permeability testing of the slabs was not part of this RAHCO contract, but testing was completed under separate contract by Lockheed Martin Idaho Technologies Company (LMITCO) indicated very favorable results. Further design efforts will focus on the following:

- Improve the controls and feed design for the continuous mixer to ensure mix consistency.
- Improve pump control to provide consistent flow volumes.
- Design a multiple-location, fixed injection system with an improved slipform design that reduces drag loads on the slipform and minimizes seal leakage.
- Modify the design of the cleanout system to be compatible with the multiple, fixed injector system.

These design modifications will enhance the overall system performance and will result in a highly reliable and effective subsurface barrier placement system.

Figure 24 Test Barrier #1

Figure 25 Test Barrier #2

SECTION 4.0

SUMMARY

The Proof-of Principle Tests established that the Slot Cutter System is fully capable of successfully cutting a slot in materials expected at DOE sites. Further design efforts will focus on the following:

1. Repositioning the minidisc cutters to avoid material plugging and improve muck handling. Repositioning should reduce individual cutting tool impact and improve cutting speed in hard materials.
2. Improving the minidisc seal design and adding a method of single point or automated bearing relubrication to compensate for grease loss that occurs during the cutting of hard materials.
3. Adding the ability to adjust the cutterhead to allow correction in the slot path.
4. Improving or replacing the method of using cam follower rollers to transfer load from the cutterhead to the cutterhead beam.
5. Improving the manufacturing tolerance of the cutterhead-to-cutterhead beam fitup.
6. Changing the external muck handling system to a mechanical conveying method, but retaining negative pressure ventilation for dust control.
7. Improving the cutterhead position sensor system to provide a more reliable and robust method of monitoring cutterhead location.
8. Modifying the winch drive hydraulic system to provide better tension control of the cutterhead drive rope.
9. Modifying the hydraulic thrust system to improve thrusting position control.

In addition, these tests showed that a Barrier Placement System, using either a fixed or traveling injector, is fully capable of successfully installing a barrier material in a subsurface, horizontal slot. The selected barrier material shows great promise in that it was easy to handle, is compatible with the equipment, and appears to provide the desired short- and long-term characteristics. Further design efforts will focus on the following:

1. Improving the controls and feed design for the continuous mixer to ensure mix consistency.
2. Improving pump control to provide consistent flow volumes and size pump to match delivery requirements.

3. Developing the injection system as a multiple, fixed-port injection system.
4. Improving the slipform design to minimize deflection and prevent grout migration under the slot cutter structure.
5. Modifying the design of the cleanout system to be compatible with the multiple, fixed-port injector system.

These design modifications will enhance the overall system performance and will result in a highly reliable and effective subsurface barrier placement system.