DEVELOPMENT AND TEST OF THE HUMANITARIAN DEMINING SIFTING EXCAVATOR

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PROGRAM PURPOSE

The Humanitarian Demining Sifting Excavator has been developed to address the problem of finding and clearing deeply buried, mixed minefields. The motivation for the development came from a 2002 site assessment by the team of an existing mine problem in Honduras. Areas were identified containing both antipersonnel and antitank landmines buried up to 0.5 meters in mineralized soils. Conventional mine clearing techniques employed in the areas of interest had uncovered widespread evidence of these deeply buried mines, however, these techniques were unreliable for consistently finding mines buried at these depths. The Sifting Excavator was proposed and chosen as the best equipment and approach for addressing these mines. It is a multi-tooled, excavator-based system for safely excavating and sifting landmines from soil. A compressed, two-phase field test program was designed to run concurrently with the equipment development in order to allow the development of operational techniques and provide proof of principle testing even as the equipment was being fabricated. The equipment development and test program were conducted between June and September of 2003.

OPERATIONAL CONCEPT

The process developed for the described threat is a 2 step mechanical process which is designed to advance an excavated trench face across a mined area, leaving cleared ground in its wake. The process is based from a mine protected excavator equipped with a standard bucket and 4 special purpose tools. The standard digging bucket is used to dig the initial trench outside of the boundary of the minefield along which the access/approach lanes are provided. The excavator is positioned on the safe side of the trench facing the mined area. One of the two special purpose excavating tools is then used to “rake” the vertical wall of the trench on the “mined” side of the trench (see figures 1 and 2). The objective of this step is to expose antitank mines in the face of the wall. Excavation continues in this way until the trench is wide enough to permit the excavator to operate from inside the trench.

Large mines exposed from this initial raking are destroyed in situ (or possibly raked free and collected). The excavator works from one end of the trench to the other excavating the far side wall from 40 to 60 centimeters per pass. When the end of the trench is reached, or following multiple passes when sufficient spoils have accumulated at the base of the far side wall, preventing any further productive excavation, the residuals in the bottom of the trench are sifted with one of the two special purpose sifting tools. In order to accomplish this the excavating tool is removed from the excavator and one of the sifting tools is attached (see figures 3 and 4). All tools have quick connect couplings to facilitate the exchange process. The sifter scoops up the loosened spoils on the mined side of the trench which have already been scoured for large mines. The sifter is positioned over the edge of the trench on the safe side, and the soil is sifted to expose smaller mines and any objects the excavating tool failed to expose. The sifted soil is used to back fill along the edge of the trench on the safe side, and the remaining, unsiftable contents are emptied in an examination area. The excavator operates from on top of the bank on the safe or near side of the trench until a sufficient width has been excavated to permit the excavator to maneuver within the trench. Thereafter operations are conducted from the trench floor. Once the trench has reached a width of 13 meters the sifting is conducted so that the safe side of the trench is back filled as the process advances. A trench depth extending 0.5 meters below the mine depth is used to permit the raking action to begin from below the mines and to allow a space for the excavated soils to accumulate for collection with the sifting tools.

EQUIPMENT DESCRIPTION

The Sifting Excavator is developed around a specially converted Liebherr 904 rubber tired excavator which was originally converted for the Humanitarian Demining Heavy Vegetation Cutter program. The excavator has a 6-7 meter reach permitting a significant reach in capability from cleared area. The base machine has 99 kW of power and weighs 19,600 kg. Significant survivability and operator protection features have been incorporated into the excavator. Solid tires constructed of a composite of rubber and steel fibers are installed in order to minimize fragmentation damage or blast damage from direct contact with most AP mines. The tires are manufactured by Setco Tires of Oklahoma and have been proven blast survivable with direct contact of 200 gram TNT charges. The operator's cabin has been replaced with a custom built shell constructed of 0.5" 6066 aluminum. The cabin windows are a General Electric Lexan laminate, 1.25" thick. Previous testing with the excavator have shown the cabin protection capable of stopping fragmentation from an M16 bounding fragmentation mine initiated 1 meter from the cabin . In addition to the cabin shell, a 0.5" steel blast deflector has been developed, tested, and installed in front of the cabin as part of this development. The deflector has 38 mm transparent armor windows and is designed to deflect blast around the operator's cabin coming from the forward direction. The blast deflector was designed by Radian Inc. of Alexandria, VA and built and tested in house by Night Vision. The two-stage protection scheme (blast deflector and aluminum shell) will provide protection to the operator in the event of AT mine detonation in the working environment in front of the vehicle as well as AP mine blast and fragmentation coming from any direction.

The excavator is additionally equipped with a rear mounted hydraulic power unit (HPU) built by Shinn Systems of Charlotte, NC. The Shinn HPU is separately driven by a Cumins diesel and is capable of supplying 220 kW of hydraulic power to attachments on the excavator. All Shinn HPU controls are contained within a separate panel within the operator's cabin. The Shinn HPU is used to drive several of the special purpose attachments developed for the excavator. The Shinn HPU system is an efficient closed circuit design. It was specially modified for this development program to make it capable of driving both closed loop motors and open loop systems through the use of a shuttle valve on the low pressure side of the loop with an electrically activated venting valve. The system was also fitted with electronic controls and programmed to match the flow requirements of each separate tool for the Sifting Excavator as well as the original heavy vegetation cutter attachment.

Figure 1. Vaned Bucket

In addition to the standard quick release digging bucket, four special purpose tools have been designed and fitted for use with the Sifting Excavator. Three of these require a hydraulic power source to separately power the attachment. The one tool not requiring hydraulic power is the Vaned Bucket (see Figure 1) which is to be the main excavating tool employed. The Vaned Bucket fits on the excavator arm and curls outward, away from the vehicle in contrast to standard digging tools made for the excavator. This action is required to pick at the base of the trench wall facing the vehicle and perform all digging on the upward stroke from underneath the mine. The Vanes are spaced 4.25" to enhance the utility of the bucket for picking/sifting large items from the residuals pile such as AT mines which have dropped from the bank. The Vaned Bucket features a nearly flat bottom for straight insertion into the base of the bank with an aft to front taper of 3". The low side walls, and the open appearance of the bucket are designed to enhance the operator's vision of the workspace and identification of mines. The Vaned Bucket requires no separate power source and is manipulated solely with the existing Liebherr controls. The bucket was designed by Radian in consultation with Night Vision, and fabricated by Geith Inc. of Petersburg, Virginia.

Figure 2. Vertical Mill

The second excavation tool is the Vertical Mill shown in figure 2. Like a machinist's mill, it is designed to shave the bank with a horizontal milling action. Although the cutting speed is much higher and the digging action more abrasive to the mines than the Vaned Bucket, the mill has the advantage of approaching the mine from the side, away from fuze triggers in normally oriented mines, much as the manual deminer's digging action. The Vertical Mill is intended as an alternative to the Vaned Bucket for use in heavily rooted soils, hard soils which are resistant to the Vaned Bucket, or locations where precise control of the digging action is required. The mill rotates up to 170 rpm and features carbide tipped chisels. The chisels are "wear items" and can be replaced for $450 per set. The mill is converted from a Bobcat Asphalt Planer with 24" drum. The mechanical interface for the mill was designed by Radian and fabricated by Night Vision. The Vertical Mill is manipulated with the existing Liebherr controls. Power for the mill is supplied by the Shinn HPU, and milling speed is set from the Shinn system joystick in the operator cabin. Approximately 60 kW of power is consumed by the mill in operation.

Figure 3. Rotar Sifting Bucket

The primary sifting tool for the excavator is the Rotar sifting bucket (see figure 3). The Rotar is basically a drum shaped cage. The drum can be opened to allow the operator to scoop loosened soil into the cage, then closed and spun at speeds up to 30 RPM. Soil will crumble and pass through the cage walls, dropping to the ground. Mines and other large objects are retained and emptied for inspection at the end of the sifting cycle. The Rotar is a commercially available attachment built and sold by Rotar International b.v. of Genemuiden, Netherlands, for separating debris from soil in trash areas. It was first adapted for mine clearing by MGM of Namibia. The HEX 700 model used on the Sifting Excavator has a capacity of 650 liters and fully loaded weight of 1850 KG. The Rotar hydraulic system was custom designed for this application by Rotar Inc. according to Night Vision specifications to make the system compatible with the Shinn HPU and Liebherr controls. The Rotar is manipulated with the existing Liebherr controls; in addition, the mechanical locks which control the opening and closing of the bucket are integrated with the Liebherr control system and operated from buttons on the operator's left joystick. The power for spinning the cage is supplied by the Shinn HPU and rotational speed is controlled from the Shinn system joystick on the operator's right side. The mechanical interface with the excavator will permit the Rotar to be mounted for either forward scooping (away from the vehicle) or rearward scooping (toward the vehicle). For use consistent with the operation concept, the Rotar faces away from the cab, and the operator uses a forward stroke to pick up the residuals in the bottom of the trench against the trench wall.

The second sifting implement for the excavator is the Bertani Bucket, originally designed and sold commercially by Bertani & Donelli of Castelnovo Sotto, Italy for harvesting beets. The Bertani Bucket hangs from the end of the excavator boom and opens like a clamshell bucket for picking up loosened soil in a pile (figure 4). When the clamshell is closed, the operator activates the sifting action which consists of moving, slotted belts in the bottom of the bucket. Soil passes through the slots in the belts and mines and other large objects are retained and emptied in an inspection area (figure 5). The Bertani FBS 1500 used on the Sifting Excavator has a capacity of 1500 liters and weighs fully loaded 1770 KG. Because of the larger volume and the more aggressive sifting action, the Bertani is capable of reducing piles faster than the Rotar, however it does not pick up material as cleanly, nor does it have provision for retaining all materials inside the bucket until the sifting action has begun. This can be a problem when trying to clean the trench completely and when moving from the excavation location to the sifting location. The Bertani Bucket is manipulated with the existing Liebherr controls, and the opening and closing of the clam is integrated with the Liebherr control system and operated from buttons on the operator's left joystick. The power for running the sifting belt is supplied by the Shinn HPU, and belt speed is controlled from the Shinn system joystick on the operator's right side.

Figure 4. Bertani Sifting Bucket

Figure 5. Bertani Sifting Bucket

FIELD TEST

Three separate tests were conducted to develop and document the performance of the Sifting Excavator to perform its mission of safely excavating mixed mines from deeply buried soil. Test one involved use of a patterned mine area and could be termed a "scored practice" The purpose of test one was to develop operator skills and proficiency with the system concurrent with the collection of performance information. Test 2 was conducted for the purpose of proving the explosive integrity of the blast deflecting shield for the excavator. Test two involved subjecting the shield to appropriate blast loading and assessing the impact on the shield. Test three was designed to more accurately evaluate system performance and operational SOP's developed for the system. It involved the excavation of a random, mixed minefield replicating the field conditions expected to the maximum extent possible.

Scored Practice

Figure 6. Practice Minefield

The first test initiated with the system was in fact a "scored practice", in which operators developed their digging techniques with the equipment and records were kept of their clearance efficiency. A small part of the test was devoted to practice with the two sifting implements. A practice minefield was placed employing fuzed antitank mines in a regular known pattern. The mines used would detonate a smoke generating charge indicating when the mine had been triggered. The mine pattern was 5 marked columns spaced 5 feet apart. Within each column all mines were buried at a single depth. The spacing of the mines within each column was also 5 feet. Thus the operators would know when to expect mines as they were digging. The first column had mines buried 10 centimeters, the second had mines buried 20 centimeters, and so on with the fifth column having mines buried 50 centimeters. The AT mines were buried approximately 8 months prior to the start of testing in order to allow the soil to settle and vegetation to grow over the surface. In areas where the sifting implements were used AP mine surrogates were buried in 6 columns interlaced with the AT mine columns. The AP surrogates were designed to replicate the PPMiSrII and PMN mines in weight and physical dimensions. Since these mines do not represent as serious a threat to the equipment and personnel inside as AT mines, these surrogates were not fuzed, nor was the long lead time provided for the soil to settle around these mines.

A starter trench was dug with the standard digging bucket approximately 2.5 meters wide and 1.5-2.0 meters deep. The trench was oriented to lie adjacent to the ends of all of the mine columns. The “mined” side of the trench was excavated in passes of the excavator equipped with either the Vaned Bucket or the Vertical Mill. Quantitative records were kept of the appearance and condition of each mine encountered and qualitative records were kept of the digging techniques used in order to provide operator feedback and standardize the use of these tools.

After completion of the starter trench the excavator was positioned adjacent to the trench on the “safe” side. The operator would reach across the open trench and down into the hole to perform the excavation (figure 7). The undercarriage was positioned parallel to the long dimension of the trench so the excavator could continually drive straight along the wall of the trench as the operator progressed down the length of the hole. The digging was performed with the undercarriage positioned approximately 1.2 -1.4 meters from the edge. Multiple passes made in this manner widened the trench to 5-6 meters at which point the excavator could no longer reach across.

Figure 7. Working Across Trench

The digging bucket was again used to further excavate the safe side until the trench width was 7.5-9 meters and the excavator could drive down in the trench and have sufficient width to pivot the upper carriage 360 degrees (figure 8). As it turned out this width left insufficient room to adequately maneuver the excavator. Considerable time was wasted repositioning the excavator each time the machine needed to move, as just a little bit of drift in the positioning of the carriage as the operator moved along the trench would result in his becoming “tangled” with a wall. As the clearing operations widened the trench to 10 meters, the maneuver room was no longer an issue.

Figure 8. Working Inside Trench

Appendix 1 maps the location of each mine and records the observations made as each mine was excavated, retrieved, and examined/tested for functionality. In the operational procedure planned for the Sifting Excavator each mine encountered would have 3 separate opportunities to be visually detected and recovered. The first is when the face of the trench is excavated and the mine is left exposed in the face as in figure 9. The second is when a portion of the bank collapses and the mine is visible in the spoils at the base of the mined face. The third opportunity is when the pile is picked up by one of the sifting buckets. Best practice would demand that a given mine be recovered at the first opportunity at which the mine was visually detected. For the purposes of gathering information on the efficiency of each step in the process, AT mines which presented themselves visually in the bank were not recovered, but instead were permitted to stay in the process and be detected again in the pile. At the point at which each AT mine had fallen into the spoils, each AT mine was recovered and examined to determine whether or not the fuze had functioned in the excavation process. AT mines which appeared not to have triggered were set aside and sufficient pressure was applied to the pressure plates to cause triggering and verify that the mine was in fact able to function.

Figure 9. AT Mine Exposed In Bank

Vaned Bucket Results with AT Mines

Table 1 gives a summary of the results for AT mines from Appendix 1 for the Vaned Bucket operating in the practice area.

VANED BUCKET	Numeric Count	Efficiency
Mines Exposed in the bank	26/27	96.3%
Mines Visible in the pile	26/27	96.3%
Mines Recovered Untriggered	26/26	100%
Composite	27/27	100%

Table 1. Results of Vaned Bucket Excavation of AT Mines in Practice Area

Comments on Vaned Bucket Results with AT Mines

The overall time and scope of this project allowed the burial and recovery of nearly 250 mines. With all of the permutations of tools and test conditions, the number of test mines recorded in each situation is comparatively low for drawing statistical conclusions accurately (27 mines in the above situation for example). The bank exposure efficiency recorded in table 1 suggests that 3.7% of mines encountered with the Vaned Bucket will not be made visible in the face of the wall and will drop into the spoils pile without first being detected visually. The pile visibility efficiency recorded in table 1 suggests that 3.7% of mines falling into the spoils pile will not be visible after the excavator has moved on. The combination of these two opportunities to see and recover the AT mines will leave 00.1% of the AT mines in the spoils pile for the sifting bucket to expose or pick up. In our test case with only 27 test objects encountered in this phase of the test, all AT mines were visually detected at one of the two locations and were recovered without sifting, thus the 100% composite score reported in table 1. All mines were recovered and found to have little structural damage and no fuzes triggered, (although 1 mine was recovered in the unarmed condition) resulting in the 100% untriggered score in table 1.

Comments on Operator Techniques with Vaned Bucket

Figure 10. Fracture In Bank

The most effective and safest digging technique compatible with the Vaned Bucket was found to involve working on approximately 3-4 meters of bank at a time from a given location. The excavator would be positioned with the carriage 4-5 meters from the wall and the wheels parallel with the wall. The bucket would approach the wall from a vertical orientation with the tines penetrating the surface of the trench floor 0-7 centimeters to provide a very light raking of the materials embedded in the bottom as the bucket is moved toward the base of the wall with the stick. As the tines approached the wall the operator would curl the bucket up while dropping the boom to bring the bottom of the vanes nearly horizontal as the tines made contact with the base of the wall. As the tines continued to penetrate the wall the operator used a combination of upward curl of the bucket combined with lowering of the boom to move the bottom cord of the bucket along an upward arc through the soil, without significant lifting. The object was to create a fracture from the base of the trench up to the soil surface without lifting the face of the bank. Once the fracture was created the operator would withdraw the tines along the same path by which they were inserted. This technique was developed to avoid bringing the bucket up and catching the edge of a mine still embedded on the solid side of the fracture. The tines could penetrate 0.40 - 0.60 meters and create a correspondingly thick slice. Usually when the bucket is withdrawn the bank collapses downward under its own weight leaving the majority of AT mines exposed in the face of the bank. (See the fractured, uncollapsed bank face in the background of figure 10.) When a single pass was completed on a given section of wall the excavator would move forward 4-5 meters and begin again.

Vertical Mill Results with AT Mines

Table 2 gives a summary of the results for AT mines from Appendix 1 for the Vertical Mill operating in the practice area.

VERTICAL MILL	Numeric Count	Efficiency
Mines Exposed in the Bank	16/18	88.9%
Mines Visible in the Pile	18/18	100%
Mine Recovered Untriggered	17/18	94.4%
Composite	18/18	100%

Table 2. Results of Vertical Mill Excavation of AT Mines in Practice Area

Comments on Vertical Mill Results with AT Mines

Figure 11. Mine Exposed in Bank with Vertical Mill

The Vertical Mill was perhaps the most operator skill intensive tool developed on this project. With additional practice time it is believed that the 88.9% bank exposure efficiency in table 2 could be made to approach 100% in homogeneous soils without large rocks or tree roots. As it was, 2 of the 18 mines encountered were excavated from the bank without first becoming visible. Structural damage to mines still embedded in the bank but visible on a side was light to moderate, and in normally oriented mines safely isolated from the fuzing portions of the mine. One such mine is pictured in the center of figure 11. All mines were excavated from the wall face with the mill and appeared visible in the spoils pile at the base of the trench. The structural damage to the mines after extraction from the bank was in most cases moderate to substantial. Again, most of the damage was on the sides and bottom of the mine, away from the fuze. 1 of the 18 mines did trigger upon extraction from the bank with the Vertical Mill. Acknowledging the statistical problem of reporting efficiencies to two or three significant digits on the basis of 18 test objects, we expect the Vertical Mill to eject 11.1% of the mines from the trench wall without first exposing them. 5.6% of those mines which are ejected may be expected to function, giving a theoretical ability to safely detect 99.4% of the all AT mines and trigger the remaining 00.6%. Again with the low number of test objects in this test, the composite score for all of the AT mines being safely recovered was 100% (because the 1 mine that was triggered was visible and recoverable when it first appeared in the bank before being triggered).

Comments on Operator Techniques with the Vertical Mill

Several variables are available for controlling the digging performance with the Vertical Mill. Among the most important: the direction (forwards/backwards) of the stroke along the wall in reference to the fixed clockwise direction of spin when viewed from above, the depth (into the wall) of the cut, the height on the wall to begin a given cut (the mill is 0.70 m high, and the wall is 1-1.2 meters high).

A rearward stroke, that is moving the mill against the direction of spin produces a very aggressive cutting action. It is believed to be gentler on the mine cases because the maximum angle the mine must be transported through the soil is 1/4 of a rotation before reaching a free surface. Unfortunately this direction also produces a wide dispersion of materials coming off of the wall (see figure 12). The excavated soil layer although thin (<0.1 m beyond 1 m from wall), extends to 4.5 m from the wall and overlaps with the path of the excavator. A forward stroke, on the other hand, produces a very well behaved pile which lays in tight against the wall. The disadvantage to moving in this direction is a slower cut and a perceived rougher treatment of the mines since they must be pushed deeper into the bank for 1/4 of a revolution before movement toward the free surface for another 1/4 of a revolution. Mainly owing to the better dispersion of excavated soils, the forward stroke was chosen as the preferred direction for the majority of the testing. It is possible to envision a usage SOP with very tight monitoring of the

Figure 12. Vertical Mill Completing a Rearward Pass

vehicle path which would make the rearward stroke more attractive, however, the secondary problem of picking up the thinly dispersed soils spread far from the wall for sifting represents another inefficiency which would need to be overcome.

The mill is capable of hogging a groove, or skimming the wall face with the drum engaged to the full diameter, however, these techniques were felt to leave the mines no free surface to escape the milling action and subject to more complete structural damage. The preferred depth of cut targeted for this test was 1/4 to 1/3 of a drum diameter per pass of the mill (about 0.10 - 0.20 m depth of cut). Operators could exercise greatest control of the depth of cut by operating from a stationary point, swinging the cab rotation through the digging pass, and then moving the excavator forward 5 - 10 meters and beginning again. However, the constant repositioning of the excavator is inefficient and the wavy pattern of arcs produced in the face of the bank must be matched on subsequent passes or compensated for by the operator at the cost of considerable time. Instead we chose to develop the operator skill at moving the carriage parallel with the wall continuously while the operator focused on producing a uniform depth of cut at a uniform depth below grade. The operator in this approach must contend with steering to keep the excavator 5 meters (plus or minus 1 meter) from the wall simultaneously with fine adjustments to the depth of cut (0.15 meter plus or minus 0.10 meter) with the motion of the stick, simultaneously with keeping the proper depth below grade with the boom. This left the operator with one leg free to perform the remaining task of adjusting the angle of the mill axis relative to the wall. Although this multitasking required good skills and concentration, our operators became adept at juggling these tasks and producing a uniform cut.

The target depth of 1.0 meters was achieved by performing a low pass with the mill down the length of the trench. This would produce a machined surface from the trench bottom up 0.60 meters. Sometimes the upper ridge left above the machined surface would collapse down into the trench and sometimes a second high pass would be required along the length of the trench. Upward strokes with the drum were avoided to preclude the possibility of bringing upward pressure from below on a mine from the top edge of the drum. The drum axis was kept vertical in order to keep the digging action on the mine bodies perpendicular to the direction of pressure actuation of the fuzes in normally oriented mines.

Result of Excavating Tools and Sifting Buckets with AP Mines In Practice Area

Far less practice time was allocated to familiarizing the test operators with the operations and techniques of using either of the two sifting buckets available. Further, complete functionality of the Rotar Bucket was not realized during the field test portions of this project owing to a parts supply problem with the Liebherr excavator. Piping required to bring auxiliary hydraulics forward to the implement was delayed several months requiring the team to sacrifice use of the wrist curling function in order to power the drum locking cylinders on the Rotar. This meant that the Rotar Bucket was frozen in a single orientation during use and this required the operators to fill the bucket solely from use of the motion of the stick. Table 3 gives a summary of the AP mines encountered in the practice area with each of the buckets.

Excavating Tool	PPMiSRI Mines Exposed	PMN Mines Exposed	Mines Sifted with Bertani	Mines Sifted with Rotar	Mines Picked Up Manually
Vaned Bucket	3/11	5/10	8/8	12/12	1/1
Vertical Mill	1/1	1/1	0/0	0/0	2/2

Table 3. Excavation and Sifting Results of AP Mines in Practice Area

Comments on Results Against AP Mines in Practice Area

Obviously a much lower percentage of the smaller AP mines will be seen during the excavation process than was experienced excavating AT mines as indicated in the first two columns of table 3. This is acceptable as long as a reliable means of sifting out the AP mines from the spoils is provided. The AP targets sifted in the practice area, although low in number, give confidence that both the Bertani Bucket and the Rotar Bucket are capable of providing this capability. Each mine in the respective areas where the sifting buckets were used was successfully sifted, and deposited in plain view of operational observers. Three AP mines were displaced from the spoils pile during the excavation process and plainly visible on the ground surface. These mines were picked up manually as indicated in table 3. The important conclusion was that no AP mine was left unaccounted for at the end of the excavation/sifting in the practice area.

Comparison of the Rotar and Bertani Sifters

The Bertani Bucket is a lighter and simpler design than the Rotar Bucket. It has a larger volume and very aggressive sifting action. For these reasons it is capable of sifting through a pile more quickly. The scooping action is not as clean as the Rotar, nor is the construction as robust. The Bertani tends to leave a 0.1 meter high trail of soil where the jaws come together and for this reason, the operators tend to dig a little deeper with the Bertani in order to ensure that all mines have been picked up. In the dry, powdery conditions prevalent during the practice operations, there was no method of retaining all the soil in the bucket until the sifting action was started. Although no mines would be lost, the spilled residuals can create uncertainty for the operator and observers as to where the sifter has been when a small pile is left at the pickup location. The Bertani Bucket was originally designed for harvesting beets from cultivated soil. Thus the construction is somewhat fragile and the drive motors lightly powered. One or two back and forth movements of the sifting belt are sometimes needed before continuous sifting action is sustained in heavy, wet, or heavily rooted soils. The sifting bars on the belt are constructed of 22 mm nylon bars. The bars are somewhat pliant and can be sprung from their mounting pins on the drive chains. On average 1 bar dropped out for every 8 hours of operation. Although losing 1 bar is not a crisis, each lost bar must be replaced eventually. A tool will have to be designed to assist with this, as few people possess the strength needed to deform the bars enough to spring them back into place.

The various tools of the Sifting Excavator proved to be quite robust in their ability to find and isolate mines of a range of sizes and burial depths. 68 mines were recovered in the practice area without loss of any. 44 of the mines were fuzed and armed of which 43 were safely extracted by beginner operators. The operators not only possessed no prior experience with digging excavators but additionally were required to develop the excavation techniques as the testing progressed. In fact the practice results reported above were not originally intended to be part of this report but instead to serve as feedback for the operators preparing to conduct the blind test reported in the next section.

Blast Shield Test

As described in the introduction to the equipment, the vehicle cab was developed previously to provide protection for the operator from AP mine blast and bounding mine fragments. It is constructed of 0.5 inch 6066 hardened aluminum. It has been successfully demonstrated stopping fragments from the M16 bounding fragment mine detonated 1 meter from the cab. In order to enhance the blast survivability of the operator an additional layer of protection was designed and added to the front of the cab. The blast shield is intended to deflect heavy blast loading from reaching the aluminum cab coming from the forward direction . If the excavator is always kept on cleared ground, reaching into the hazardous areas to work, the shield will always be between the operator and the most likely sources of heavy mine blasts encountered during the initial excavation of the mines. The technical goal of the shield, then, is to ensure the aluminum cab remains fully intact when subjected to the blast of a large antitank mine detonated in the working zone around the end of the bucket positioned at minimal working distance. The minimum working distance was chosen at 4.0 meters, which is the location of the tine tips on the Vaned Bucket when the bucket is lying flat on the ground and the stick is vertical.

For the purposes of conducting the tests a simplified replica of the blast shield was constructed. The test shield had the same geometry and materials as the actual shield; however, only one of the three windows in the shield was installed (see figure 13). The actual shield has three windows stacked in a column on the shield face. Only the lowest window (which is closest to the blast site) was in place on the replica. Placed on vertical columns approximately 0.25 meters behind the shield were 4 aluminum witness plates of varying strength. The plates were bolted at each end to the columns and spanned a distance approximately 1 meter. The lowest plate on the columns was 0.5 inches thick (12.7 mm), the second plate was 0.25 inches thick (6.4 mm), the third plate was 0.125 inches thick (3.2 mm), and the top plate was 0.0625 inches thick (1.6 mm). The purpose of the plates was to provide evidence of the destructive strength of the blast behind the shield as well as any fragmentation penetrating or spalling on the interior of the shield.

Figure 13. Blast Shield

Figure 14. Shield Before Blast

The shield was mounted on cantilevered beams welded to a heavy metal structure to hold it in place for the test. The shield was mounted so that the height above ground matched the height of the actual shield installed on the tractor. The shield was placed 4.0 meters from the base of the 3 meter high embankment shown in figure 14. A 14.0 kg explosive charge TNT equivalent was placed at the base of the embankment to replicate the blast of a very large antitank mine detonating in the trench wall facing the excavator.

Figures 15 and 16 show the effects of the blast on the shield. The outer surface of the shield was pitted with impact marks from flying debris but none of the fragments penetrated the thickness of the metal more than 0.5 mm. There was no perceptible deformation to the shield structure or cracks visible in the surfaces. The glass cracked extensively and two rock fragments embedded in the outer surface. No evidence could be found of any materials penetrating through the glass. An icecube sized chunk of glass did spall on the inner surface; however the evidence suggests that it came off at low velocity. There were no scratch marks on the soft aluminum witness plate directly behind the glass surface, less than 0.2 meters away. The glass chunk itself was lying intact about 0.1 meter from the spot where it originated.

Figure 15. Shield After Blast

Figure 16. Window Interior After Blast

Figures 17 and 18 provide a overhead view of the witness plates standing behind the shield before and after the blast. As commented above, no scratches or impact marks of any kind were found on any of the witness plates. The 1.6 mm plate did deform significantly as did the 3.2 mm plate below it. No perceptible deformation occurred to either the 6.4 mm or 12.7 mm plates.

Figure 17. Witness Plates Before Blast

Figure 18. Witness Plates After Blast

The shield was blasted a second time with conditions identical to the first. As can be seen from figures 19 and 20 no further damage was done to the shield beyond additional cracking of the glass and further bending of the 1.6mm and 3.2 mm witness plates.

Figure 19. Interior of Glass After Second Blast

Figure 20. Witness Plates After Second Blast

Conclusions from Blast Testing

The shield performed well and is believed to be capable of adequately protecting the structures behind it from blasts originating in front of the cab, provided the minimum 4.0 meter standoff from potential mine hazards is maintained. The cab construction of 12.7 mm 6061 aluminum plate has over ten times the strength of the thinnest witness plate (6.4 mm) which did not deform in the blast test. The blast protecting glass also performed well and did not permit any through penetrations when twice blasted.

Blind Test

Figure 21. Blind Test Minefield

The proof of concept test was performed in a randomly laid, mixed minefield. Procedures similar to those which might be used in an actual mine clearance operation were employed and the operators had no knowledge of the mine locations. The same mine simulants as were used in the practice area were employed in the blind test: smoke fuzed antitank mines, PMN size/weight replicas, and PPMiSrII size/weight replicas. The size of the mined area measured a little over 12 by 28 meters. The mine locations within the field were randomly assigned and 50 of each type were emplaced. The antitank mines were buried 10 months in advance of the test to allow the soil to settle and vegetation to grow. 20% of the AT mines were buried 50 centimeters, 20% at 40 centimeters, 20% at 30 centimeters, 20% at 20 centimeters, and 20% at 10 centimeters. The AP simulants were buried one month in advance, approximately 10 to 20 centimeters. The minefield layout and mine locations are shown in appendix 2.

Blind Test – Operating Procedure

The tools chosen to use to perform the test were the Vaned Bucket and the Bertani sifter. The Vaned Bucket was chosen as the faster more robust approach for safely excavating AT mines. The per pass cut from the Vaned Bucket is about twice the recommended cutting penetration with the Vertical Mill. In addition, the mill was judged to require additional practice time in order to develop sufficient confidence that operators could bring the detonation risk down to an acceptable level. In contrast, the Bertani Bucket was chosen mainly on the basis of speed. It is believe that either the Rotar or Bertani could sift the AP mines from the soils with equal performance reliability. With modifications to the excavator to make the Rotar fully functional not complete, the Bertani showed a small edge in terms of speed for sifting through piles of loose dirt and sod.

Figure 22. Blind Test - Excavation

The starting trench was dug with the excavator immediately adjacent to the minefield boundary. The trench was dug 9 - 10 meters wide and 32 meters long. A drainage ditch was cut at one end 1 meter wide which ran down a slope. The other end had the entrance ramp. Excavating passes were made starting at the "far" end and working toward the ramp. Although test personnel were close by, they were not permitted to influence the operator and only observations made by the operator were recorded during the time the system was in operation. In between passes inspections of the area were made and additional observations recorded. AT mines were recorded as "exposed in the bank" if they were visible in the bank to the inspection team after the excavator had finished making a pass or if the operator saw them fall from the bank during operation. Mines that were exposed in the bank were left in place until subsequent excavation passes had brought them down. Once the mine had fallen from the bank it was recorded as being visible in the pile if they could be seen by the inspection team in the pile after the excavator had finished making a pass. If a mine was not visible in the pile to the inspection team it would be noted as such when it was ultimately accounted for (presumably during sifting). AT mines which were visible in the pile were recovered by the inspections team and checked to see if the fuze had triggered. AT mines would then have sufficient pressure applied to the fuze to cause detonation of the smoke charge to verify that the mine was functional. Exposure of the AP mine simulants was recorded in the same way; however, mines visible in the pile were not recovered by the inspection team. They were left in place for subsequent sifting operations.

When the digging pass was completed, the Vaned Bucket would be removed from the excavator and the Bertani Bucket would be installed. Soil which had accumulated at the base of the wall would be picked up with the Bertani. Use of the Bertani was determined to require the operator to run with the boom nearly perpendicular to the wall. Thus he could pick up soil from a zone approximately three buckets wide before having to move the excavator. After a load was picked up, the cab would rotate 180 degrees with the Bertani over the edge of the pile on the "safe" side. The rotation would always be done to the rear so that the Bertani Bucket never traveled over the path of escape for the excavator. The sifting action would be started and would continue until only large solid materials (heavy soil clods, roots, mines etc) remained in the bucket. The sifting action required approximately 15-30 seconds. When the sifting was completed, the bucket was again swung in the rearward direction and the contents emptied in the trail behind the excavator. Initially we had hoped to confine the residuals to a narrow band following the excavator tracks; however, experience dictated a wider spread to the residuals to keep the layer thin. In the end the area from the wheel track on the mined side of the trench over to the base of the clean soil pile was used for inspection of residuals. When the sifting pass was completed, the inspection team would again enter the trench and inspect the residuals with metal detectors. In addition to inspecting the residuals pile, a 2 meter zone beginning 1 meter from the wall out to the 3 meter point would be given a final check with the metal detector to ensure no mines had slipped by the process. The overall layout of the working process is diagrammed in figure 23.

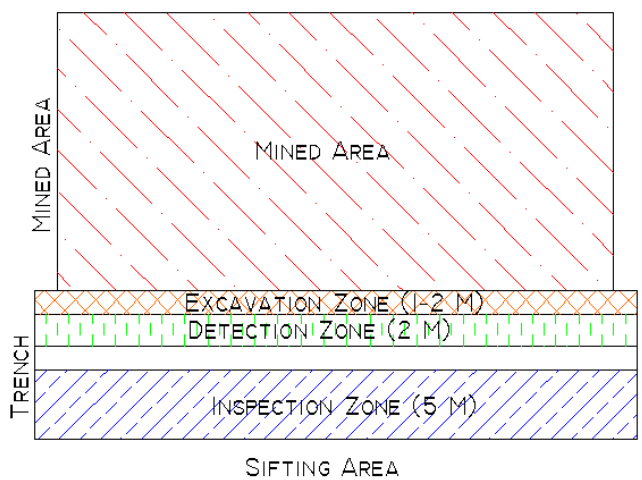


Figure23. Layout of Working Trench

Following the inspection the residuals were cleared from the bottom of the trench. In this test a vibratory roller was used to flatten the clods and provide a smooth surface for the next iteration of the process. Other alternatives to the roller could be used; such as a dozer, loader, or grader to push the inspected materials into the sifted soils on the "safe" side of the trench. The roller, however, proved a valuable addition to the process as the base of the trench was kept rolled and well drained. Heavy rains delayed testing of other systems on adjacent fields for nearly six weeks due to the soggy conditions. During this same time, the Sifting Excavator was only out of operation during and immediately after the rains.

Seven hours was required to dig the starter trench at 32 meters by 9 meters using the standard digging bucket on the excavator. The total time required to complete the mine clearance process over the 32 meter by 13 meter rectangular area was 62.5 hours (about 9 minutes per square meter). During this time the excavator completed 21.5 passes with the Vaned Bucket and 21.5 passes with the Bertani Bucket. On average a digging pass required 50 minutes plus 10 for the installation of the Vaned Bucket and a sifting pass required 100 minutes plus 15 for the installation of the Bertani Bucket. Fuel consumption to dig the starter hole and excavate the minefield was 255 gallons, of which 145 was in the excavator and 110 was in the hydraulic power unit.

Blind Results with AT Mines

Appendix 2 lists the accounting for each mine buried for this test. Table 4 summarizes the results for the AT mines.

AT Mines Visible in the Bank	AT Mines Visible in the Pile	AT Mines Found by Sifter	AT Mines Triggered in the Recovery	AT Mines Verified as Functional
41/50	48/50	1/1	0/50	50/50
82%	96%	100%	0%	100%

Table 4. Results of Blind Testing with AT Mines

82% of the AT mines were either visible in the bank or became visible to the operator as they dropped from the bank. Because the mines were not recovered at this point during the test, a second opportunity to detect them visually in the pile independently produced 96% success against the entire AT mine population. Consistent with the results obtained in the practice area, the combination of these two opportunities would be expected to leave 00.7% of the AT mines in the soil pile for the sifting bucket to encounter if each mine was recovered after first being detected. In our case 1 AT mine did make it to the sifter and was detected and recovered there. In the end all AT mines were recovered and accounted for using the prescribed process, and no mines were triggered in the process.

Blind Results with AP Mine Simulants

Table 5 gives the summary results for the AP mines listed in Appendix 2.

Mine Type	Mines Visible in Bank	Mines Visible in Pile	Mines Picked up by Sifter	Mines Visible in Residuals Pile	Recovered from Residuals Pile
PMN (Raw Count)	21/50	19/50	49/50	47/49	49/49
PMN (Percent)	42%	38%	98%	96%	100%
PPMiSrII (Raw Count)	35/50	28/50	50/50	49/50	49/50
PPMiSrII (Percent)	70%	56%	100%	98%	98%
PMN and PPMiSrII Combined	56%	47%	99%	97%	99%

Table 5. Blind Test Results with AP Mines

Clearly the AP mines are much less visible in this process than the AT mines. Even within the size differential between the PMN and PPMiSrII significant separation in the results emerges, with 70% of the larger PPMiSrII mines showing in the bank versus 42% of the PMN's. With such separation in the results, analyzing the combined results of course is only accurately predictive of operations in mined areas having an equal mix of each of these mine types as were encountered in the test minefield. Nevertheless this is a useful indication of the magnitude of process efficiency.

If the clearance process is set up to remove or neutralize each mine in or from the location where it first becomes visible, then 56.0% of the AP mines are handled manually in the bank and 20.7% of the mines are handled manually on the spoils pile by the wall. 23.1% of the mines are picked up by the sifting bucket, and 00.2% of the mines escape visual detection in the excavation zone. (We relied on the detection sweep made of this area to find any mines in this condition.) The fraction of mines picked up by the sifter is further dissected into 22.4% which end up visible on top of the residuals pile in the inspection zone, and 00.7% which end up concealed in the sifted residuals pile and would require additional detection to expose. Process-wise this extensive procedure has the advantage that the sifting equipment is exposed to the smallest risk and overall the process has the highest reliability. However, the added time of having manual collections or neutralizations at three different locations (in the bank, on the spoils pile, and on the residuals pile) may require too much additional time to justify the incremental benefit as compared with not collecting or neutralizing mines until they have been sifted and deposited on the residuals pile. Table 6 shows the results discussed above versus this second, more streamlined, clearance approach.

Mine Collection Locations	CLEARANCE METHODS	
	Collection/Neutralization at Three Points	Collection/Neutralization only from Sifted Residuals Pile
Mines Collected from Bank	56.0%	NA
Mines Collected from Spoils Pile	20.7%	NA
Mines Collected from Residuals Pile	22.4%	96.0%
Mines Requiring Secondary Detection Near Excavation Zone	00.2%	1.0%
Mine Requiring Secondary Detection In Residuals Pile	00.7%	3.0%
	100.0%	100.0%

Table 6. Theoretical Comparison of Process Efficiency with AP Mines Collected When First Visible, Versus Inspection and Collection Only at the Residuals Pile

Additional Observations Concerning the Blind Test.

The AT and AP mines each had a point in the process at which they were intended to be recovered. For the AT mines this was just after the excavator pass was completed with the Vaned Bucket and the overwhelming majority had been visually spotted and recovered. For the AP mines, this was just after the sifting pass was completed and the AP mines had been visually spotted in the inspection area. The extremely low numbers of mines which passed these points in the process deserve additional examination to try and describe contributing factors and ways to improve upon and compensate for these percentages.

The one AT mine which was not seen either in the bank or in the spoils pile became visible as the Bertani Bucket began removing soil from the spoils pile. This particular mine was recovered before entering the sifting process. The possibility that a mine in this situation could be squeezed and triggered in the scooping or closing of the bucket remains. This eventuality could be further quantified experimentally; however, the cost and effort associated with testing this is high as fairly large numbers of AT mines would need to be buried in piles and sifted with this sole objective. The possibility that a mine could be detonated while tumbling in the sifter would be a little easier to explore experimentally. These tests are recommended for future work.

The three AP mines which were not made visible on top of the residuals pile in the inspection area were easily found during the inspection process with metal detectors and physical probing. The residuals pile generally contained a small amount of almost sifted granular soil spread in a layer 0-2 cm thick, large solid rocks and clods 0.2 - 0.5 meters in diameter, tree roots, and small amounts of surface vegetation. The residuals were generally spread thin enough that the granular materials in most places was negligible and layered up to 2 cm thick in a few places. The large clods accounted for the majority of unsifted residuals. They were dumped and ended up creating a layer no more than 1 clod deep. 1 AP mine was underneath one of these clods, 1 AP mine was underneath a small clump of grass, and 1 AP mine was underneath a 0.15 meter diameter tree root further covered in a light layer of granular soil. Each of these mines was quickly detected when the residuals pile was examined with the metal detector. Two of these mines were very lightly covered and would have been detected without the use of the metal detector as the inspection process continued through the area. Thorough processing with the sifter and close observation of the dumping in the inspection area are recommended to help insure that all mines are recovered and to reduce the reliance of the process on the use of detectors.

The one AP mine which the system failed to pick up for sifting had been seen and recorded when it was visible on the spoils pile. In the envisioned operational case this mine would have been recovered at this point, in the test case it was not. It is believed to have rolled down the front of the pile and been re-covered with a thin layer of soil during the process of picking up soils from the pile with the Bertani Bucket. It was rediscovered, under 1 centimeter of soil, during the detector sweep of the outer edges of the excavation zone following the end of the pass with the Bertani Bucket. This may be the biggest vulnerability of the process. It is difficult when picking up the soil for sifting to determine exactly where the bottom of the spoils pile is relative to the floor of the trench. There is always some small quantity of loose soils left behind when scooping out the bottom, and with it, the possibility that a mine could be in that location. Of course the operator can always scoop out whatever loose soils or small piles are in the bottom of the trench, but this generally creates a new small pile and a new bottom of the trench somewhere else. Getting that last bit of loose materials also competes with the need to keep the depth of the trench under control, as there is a tendency to continually work the trench to greater depths as the process works its way across the minefield. The solution was to add the detector sweep of the area between the path of the excavator and the wall for any shallow buried mines after each sifting pass was completed. The sweep was 2 meters in width and began 1 meter away from the wall. This sweep was performed quickly, as most of the surface scrap was gone, and relatively few detections had to be investigated.

SUMMARY AND CONCLUSIONS

The tight development schedule compressed a great deal of work and testing into a rather short timetable and precluded the extensive test each of the individual tools developed for this system deserves. Overall, the process which was developed produced an extraordinarily reliable means of dealing with the mine threat. Of nearly 250 test mines buried, only one mine remained unaccounted for at the conclusion of the test, and this situation is believed to have resulted from poor inspection of the residuals pile rather than true failure of the process to separate mines from a hazardous area. In the final analysis the process reliability estimates resulting from the blind test in theory leave no mines unfound, although reliance on good manual detection for 00.9% of the AP mines is implied and acknowledgment is made of the untested threat to equipment from the 00.7% of AT mines which the sifting tool must encounter. All test results were obtained with operators having no previous experience using a digging excavator; this speaks well for the prospects of training indigenous equipment operators in the techniques developed.

Figure 24. Mines Recovered In Blind Test

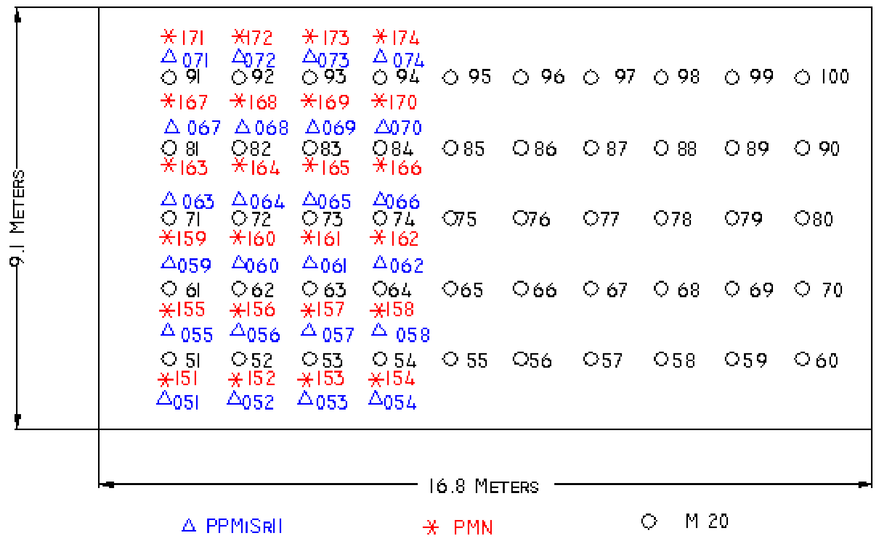
Also unexplored in the completed testing is the threat to the equipment from AP mines. The most worrisome threat is from detonation of AP mines in one of the sifting buckets. The characterization of detonation rates is possible to conservatively estimate from testing with new mines as was done with the AT mines; however, insufficient time was available to include this work. Previous testing with the Rotar Buckets for survivability analysis has been performed with TNT charges from 225 grams to 450 grams with good results.

The process is greatly enhanced by the availability of additional support equipment. Either a dozer, grader, or vibratory roller is a valuable aid in digging the initial trench, keeping the excavated trench bottom well formed and drained, and recovering the land at the conclusion. Also on hand but not used in the course of conducting the blind test were pumps to keep the trench dry and defoliants to reduce vegetation if necessary. In addition to support equipment, compatible personnel and manual operations are required. A supervisory observer in close proximity to the digging is recommended for alerting the operator to hazardous situations he may be unable to see from inside the cab. A portable protection shield has been constructed to permit supervision of the operation from 25 meters.

The two most undesirable aspects of the mine clearance process with the Sifting Excavator are the pace of operations and the complete rearrangement of the landscape resulting from the excavation. The pile of sifted soil seen in the background of figure 24 is a substantial testament to the operations completed.   As slow as the excavation process is, there is no known alternative for finding mines so deeply buried in mineralized soil. There is also every reason to believe that as experience with the system continues to grow, there will be better control of digging unnecessarily deep in places to ensure complete coverage, better control of the equipment motion, and streamlining of the process to speed up the advance rate from the 9 minutes per square meter of surface realized during this program.

The blast deflector developed for this program combined with the other existing blast and fragment survivability features of the excavator provide a high degree of protection for the operator from mines encountered in the working environment. Test evidence indicates the cab will remain intact and unpierced by anticipated threats when used within the confines of the procedures approved. Operator vision from inside the cab could be improved, however, the successful results obtained with all of the protections in place during the blind testing show adequate operator vision.

Appendix One
Practice Minefield Map
And Mine Recovery Log



Layout and Mine Locations within Practice Area

AT Mines In Practice Minefield							
AT Mine Number	**Burial Depth (cm)**	**Tool Used**	**Visible in Bank**	**Visible on Pile**	**Triggered in Recovery**	**Function Verified**	**Comments**
51	10						Area Not excavated
52	10	Vaned	Yes	Yes	No	Yes	
53	10	Vaned	Yes	Yes	No	Yes	
54	10	Vaned	Yes	Yes	No	Yes	
55	10	Mill	Yes	Yes	No	Yes	
56	10	Mill	Yes	Yes	No	Yes	
57	10	Vaned	Yes	Yes	No	No	Mine was buried unarmed
58	10	Vaned	Yes	Yes	No	Yes	
59	10	Vaned	Yes	No	No	Yes	
60	10	Vaned	Yes	Yes	No	Yes	
61	20						Area Not excavated
62	20	Vaned	Yes	Yes	No	Yes	
63	20	Vaned	Yes	Yes	No	Yes	
64	20	Mill	Yes	Yes	No	Yes	
65	20	Mill	Yes	Yes	Yes	Yes	
66	20	Mill	No	Yes	No	Yes	
67	20	Mill	Yes	Yes	No	Yes	

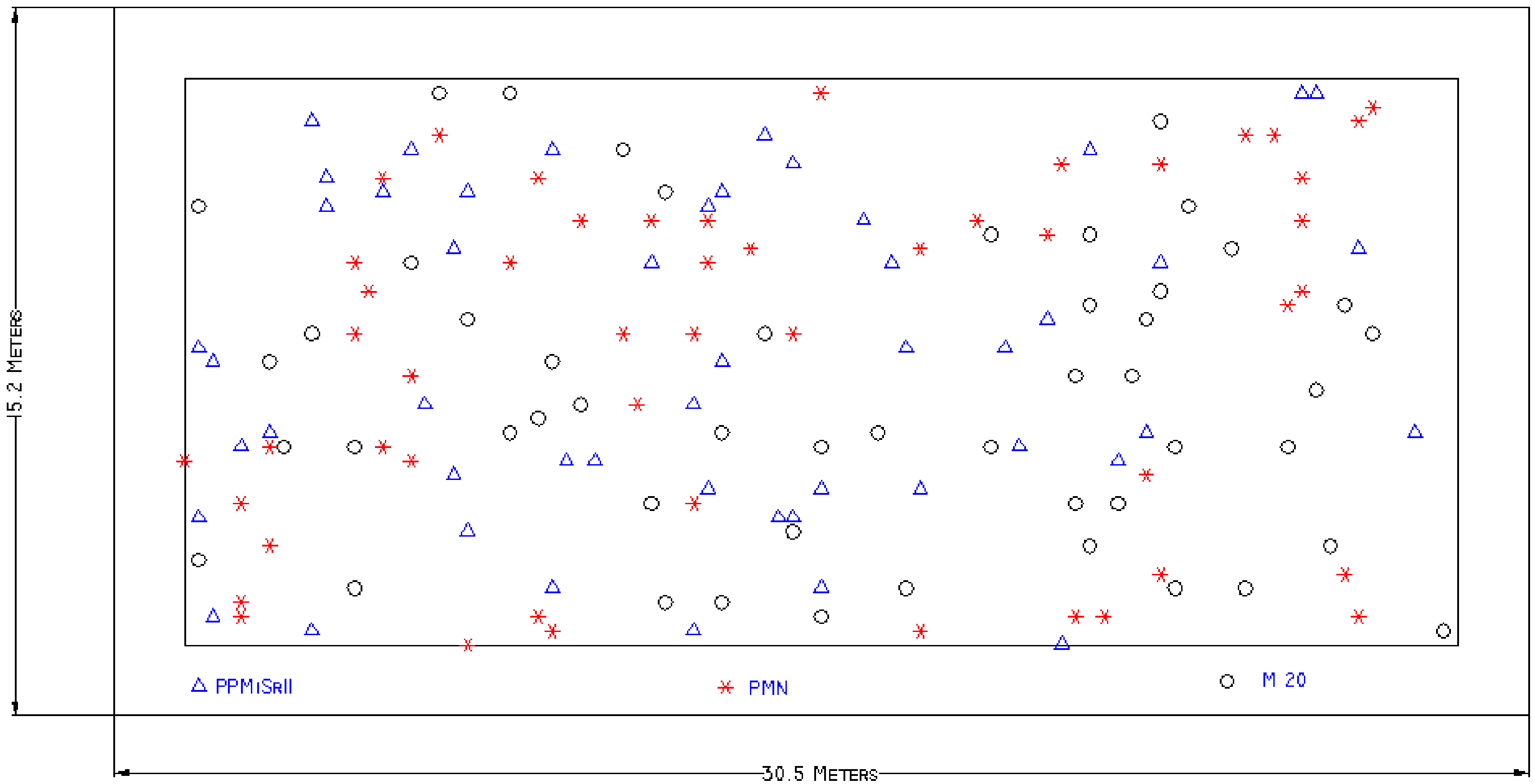
AT Mines In Practice Minefield							
AT Mine Number	**Burial Depth (cm)**	**Tool Used**	**Visible in Bank**	**Visible on Pile**	**Triggered in Recovery**	**Function Verified**	**Comments**
68	20	Vaned	No	Yes	No	Yes	
69	20	Vaned	Yes	Yes	No	Yes	
70	20	Vaned	Yes	Yes	No	Yes	
71	30						Area Not excavated
72	30	Vaned	Yes	Yes	No	Yes	
73	30	Vaned	Yes	Yes	No	Yes	
74	30	Mill	Yes	Yes	No	Yes	
75	30	Mill	Yes	Yes	No	Yes	
76	30	Mill	No	Yes	No	Yes	
77	30	Mill	Yes	Yes	No	Yes	
78	30	Vaned	Yes	Yes	No	Yes	
79	30	Vaned	No	Yes	No	Yes	
80	30	Vaned	Yes	Yes	No	Yes	
81	40						Area Not excavated
82	40	Vaned	Yes	Yes	No	Yes	
83	40	Vaned	Yes	Yes	No	Yes	
84	40	Mill	Yes	Yes	No	Yes	

AT Mines In Practice Minefield							
AT Mine Number	**Burial Depth (cm)**	**Tool Used**	**Visible in Bank**	**Visible on Pile**	**Triggered in Recovery**	**Function Verified**	**Comments**
85	40	Mill	Yes	Yes	No	Yes	
86	40	Mill	Yes	Yes	No	Yes	
87	40	Mill	Yes	Yes	No	Yes	
88	40	Vaned	Yes	Yes	No	Yes	
89	40	Vaned	Yes	Yes	No	Yes	
90	40	Vaned	Yes	Yes	No	Yes	
91	50						Area Not excavated
92	50	Vaned	Yes	Yes	No	Yes	
93	50	Vaned	Yes	Yes	No	Yes	
94	50	Mill	Yes	Yes	No	Yes	
95	50	Mill	Yes	Yes	No	Yes	
96	50	Mill	Yes	Yes	No	Yes	
97	50	Mill	Yes	Yes	No	Yes	
98	50	Vaned	Yes	No	No	Yes	
99	50	Vaned	Yes	Yes	No	Yes	
100	50	Vaned	Yes	Yes	No	Yes	

AP Mines In Practice Minefield						
Minetype	**Number**	**Excavation Tool**	**Mine Exposed**	**Sifting Tool**	**Mine Visible in Residuals Pile**	**Comments**
PPMiSrII	054	Mill	Yes	None	NA	Mine displaced and picked up manually
PPMiSrII	057	Vaned	Yes	Rotar	Yes	
PPMiSrII	058	Vaned	Yes	Rotar	Yes	
PPMiSrII	061	Vaned	Yes	None	NA	Mine displaced and picked up manually
PPMiSrII	062	Vaned	Yes	Rotar	Yes	
PPMiSrII	065	Vaned	No	Bertani	Yes	
PPMiSrII	066	Vaned	No	Rotar	Yes	
PPMiSrII	069	Vaned	No	Bertani	Yes	
PPMiSrII	070	Vaned	No	Rotar	Yes	
PPMiSrII	073	Vaned	No	Bertani	Yes	
PPMiSrII	074	Vaned	Yes	Rotar	Yes	
PMN	153	Vaned	No	Rotar	Yes	
PMN	154	Mill	Yes	None	NA	Mine displaced and picked up manually
PMN	157	Vaned	No	Bertani	Yes	
PMN	158	Vaned	Yes	Rotar	Yes	

AP Mines In Practice Minefield						
Minetype	**Number**	**Excavation Tool**	**Mine Exposed**	**Sifting Tool**	**Mine Visible in Residuals Pile**	**Comments**
PMN	161	Vaned	No	Bertani	Yes	
PMN	162	Vaned	Yes	Rotar	Yes	
PMN	165	Vaned	No	Bertani	Yes	
PMN	166	Vaned	No	Rotar	Yes	
PMN	169	Vaned	No	Bertani	Yes	
PMN	170	Vaned	No	Rotar	Yes	
PMN	173	Vaned	No	Bertani	Yes	
PMN	174	Vaned	Yes	Rotar	Yes	

Appendix 2
Blind Minefield – Mine Locations
And Mine Recovery Log for Blind Test



Mine Locations In Blind Minefield

AT Mines Blind Minefield					
Mine Number	**Visible In Bank**	**Visible in Pile**	**Fuze Triggered**	**Function Verified**	**Comments**
1	Yes 2:25 10/2/03	Yes 2:25 10/2/03	No	Yes 2:25 10/2/03	
2	Yes 2:00 10/2/03	Yes 2:00 10/2/03	No	Yes 2:05 10/2/03	
3	Yes 2:00 10/2/03	Yes 2:00 10/2/03	No	Yes 2:05 10/2/03	
4	Yes 2:00 10/2/03	Yes 2:00 10/2/03	No	Yes 2:05 10/2/03	
5	Yes 11:15 10/2/03	Yes 11:15 10/2/03	No	Yes 11:15 10/2/03	
6	Yes 2:00 10/2/03	Yes 2:00 10/2/03	No	Yes 2:00 10/2/03	
7	Yes 11:40 10/2/03	Yes 2:20 10/2/03	No	Yes 2:20 10/2/03	

AT Mines Blind Minefield					
Mine Number	**Visible In Bank**	**Visible in Pile**	**Fuze Triggered**	**Function Verified**	**Comments**
8	Yes 2:15 10/2/03	Yes 2:15 10/2/03	No	Yes 2:20 10/2/03	
9	Yes 8:45 10/2/03	Yes 8:45 10/2/03	No	Yes 8:50 10/2/03	
10	Yes 9:10 10/2/03	Yes 9:11 10/2/03	No	Yes 9:12 10/2/03	
11	Yes 9:15 10/2/03	Yes 9:15 10/2/03	No	Yes 9:15 10/2/03	
12	Yes 9:00 10/2/03	Yes 9:00 10/2/03	No	Yes 9:00 10/2/03	
13	No	Yes 2:40 10/1/03	No	Yes 2:45 10/1/03	
14	Yes 2:50 10/1/03	Yes 2:50 10/1/03	No	Yes 2:50 10/1/03	

AT Mines Blind Minefield					
Mine Number	**Visible In Bank**	**Visible in Pile**	**Fuze Triggered**	**Function Verified**	**Comments**
15	Yes 1:00 10/1/03	Yes 2:55 10/1/03	No	Yes 2:55 10/1/03	
16	Yes 7:45 10/1/03	Yes 7:45 10/1/03	No	Yes 8:10 10/1/03	
17	Yes 12:50 9/30/03	Yes 7:50 10/1/03	No	Yes 8:10 10/1/03	
18	Yes 7:50 10/1 /03	Yes 8:00 10/1/03	No	Yes 8:10 10/1/03	
19	No	Yes 8:15 10/1	No	Yes 8:15 10/1/03	
20	Yes 1:35 9/30/03	Yes 8:22 10/1	No	Yes 8:22 10/1/03	
21	Yes 1:45 9/30	Yes 8:25 10/1/03	No	Yes 8:26 10/1/03	

AT Mines Blind Minefield					
Mine Number	**Visible In Bank**	**Visible in Pile**	**Fuze Triggered**	**Function Verified**	**Comments**
22	Yes 7:30 10/1/03	Yes 7:30 10/1/03	No	Yes 8:10 10/1/03	
23	Yes 1:30 9/30	Yes 7:30 10/1/03	No	Yes 8:10 10/1/03	
24	Yes 1:30 9/30/03	Yes 8:05 10/1/03	No	Yes 8:10 10/1/03	
25	Yes 1:00 9/30/03	Yes 7:30 10/1/03	No	Yes 8:10 10/1/03	
26	Yes 1:00 9/30/03	Yes 1:01 9/30/03	No	Yes 1:02 9/30/03	
27	Yes 10:00 9/30/03	Yes 10:00 9/30/03	No	Yes 10:02 9/30/03	
28	Yes 9/29/03	Yes 9/29/03	No	Yes 9:55 9/30/03	

AT Mines Blind Minefield					
Mine Number	**Visible In Bank**	**Visible in Pile**	**Fuze Triggered**	**Function Verified**	**Comments**
29	Yes 9:50 9/30/03	Yes 9:55 9/30/03	No	Yes 9:56 9/30/03	
30	Yes 2:45 9/29/03	Yes 2:48 9/29/03	No	Yes 2:48 9/29/03	
31	Yes 2:50 9/29/03	Yes 2:51 9/29/03	No	Yes 2:52 9/29/03	
32	No	Yes 12:10 9/29/03	No	Yes 12:10 9/29/03	
33	Yes 12:23 9/29/03	Yes 9/29/03	No	Yes 9/29/03	
34	Yes 12:35 9/29/03	Yes 3:15 9/29/03	No	Yes 3:20 9/29/03	
35	Yes 8:12 9/29/03	Yes 8:13 9/29/03	No	Yes 8:15 9/29/03	

AT Mines Blind Minefield					
Mine Number	**Visible In Bank**	**Visible in Pile**	**Fuze Triggered**	**Function Verified**	**Comments**
36	Yes 9:22 9/29/03	Yes 12:30 9/29/03	No	Yes 12:30 9/29/03	
37	Yes 9:05 9/29/03	Yes 9:08 9/29/03	No	Yes 9:08 9/29/03	
38	Yes 9:20 9/29/03	Yes 9:20 9/29/03	No	Yes 9:21 9/29/03	
39	Yes 9/26/03	Yes 9:10 9/29/03	No	Yes 9:11 9/29/03	
40	No	No	No	Yes 10:42 9/26/03	This mine was uncovered by the Bertani Bucket during a sifting pass
41	No	Yes 9:46 9/26/03	No	Yes	
42	No	Yes 9:37 9/26/03	No	Yes	

AT Mines Blind Minefield					
Mine Number	**Visible In Bank**	**Visible in Pile**	**Fuze Triggered**	**Function Verified**	**Comments**
43	No	Yes 9:40 9/26/03	No	Yes	
44	Yes 12:00 9/24/03	Yes 12:00 9/24/03	No	Yes	
45	Yes 9:45 9/25/03	Yes 9:50 9/25/03	No	Yes	
46	Yes 12:00 9/24/03	Yes 12:00 9/24	No	Yes	
47	No	Yes 10:45 9/22/03	No	Yes	
48	Yes 8:30 9/22/03	Yes 11:00 9/22/03	No	Yes	
49	No	Yes 11:00 9/16/03	No	Yes	

AT Mines Blind Minefield					
Mine Number	**Visible In Bank**	**Visible in Pile**	**Fuze Triggered**	**Function Verified**	**Comments**
50	Yes 1:00 9/16/03	No	No	Yes	

PMN Mines In Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
101	No	No	Yes 3:04 10/2	
102	No	No	Yes	
103	Yes 2:00 10/2	Yes 2:00 10/2	Yes 3:30 10/2	
104	Yes 11:15 10/2	Yes 11:15 10/2	Yes 12:45 10/2	
105	Yes 2:00 10/2	Yes 2:00 10/2	Yes 3:00 10/2	
106	Yes 2:05 10/2	Yes 2:30 10/2	Yes 7:50 10/3	
107	No	No	Yes 7:50 10/3	

PMN Mines In Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
108	No	Yes 2:30 10/2	Yes 7:55 10/3	
109	No	No	Yes 12:36 10/2	
110	Yes 11:35 10/2	No	Yes 1:15 10/2	
111	Yes 11:42 10/2	No	Yes 1:30 10/2	
112	Yes 2:35 10/1	Yes 2:36 10/1	Yes 3:45 10/1	
113	Yes 11:00 10/1	No	Yes 12:00 10/1	
114	Yes 11:30 10/1	No	Yes 10:15 10/2	This mine initially stuck in gap between tines on the Vaned Bucket

PMN Mines In Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
115	Yes 8:21 10/1	No	Yes 1:40 10/1	
116	No	No	Yes 9:45 10/1	
117	No	No	Yes 9:45 10/1	
118	Yes 7:35 10/1	No	Yes 9:45 10/1	
119	Yes 7:35 10/1	Yes 7:35 10/1	Yes 9:45 10/1	
120	Yes 1:00 9/30	No	Yes 2:43 9/30	
121	Yes 2:48 9/29	No	Yes 11:10 9/30	

PMN Mines In Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
122	Yes 1:14 9/29	No	Yes 1:30 9/29	
123	Yes 12:20 9/29	No	Yes 8:10 9/30	
124	Yes 12:20 9/29	No	Yes 1:40 9/29	
125	Yes 12:23 9/29	Yes 1:55 9/29	Yes 8:19 9/30	
126	No	No	Yes 11:30 9/29	
127	No	Yes 7:50 9/29	Yes 10:00 9/29	
128	No	Yes 9:18 9/29	Yes 11:00 9/29	

PMN Mines In Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
129	No	No	Yes 1:00 9/26	
130	No	No	Yes 1:22 9/26	
131	No	Yes 12:08 9/26	Yes 1:40 9/26	
132	No	No	Yes 10:55 9/26	
133	No	No	Yes 11:02 9/26	
134	No	No	Yes	
135	Yes	No	Yes 2:00 9/25	

PMN Mines In Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
136	No	No	Yes 2:00 9/25	
137	Yes 9:30 9/25	Yes 10:30 9/25	Yes 2:00 9/25	
138	No	Yes 7:55 9/26	Yes 7:59 9/26	
139	No	Yes 9:50 9/26	No	This mine was found after detector sweep along the edge of the current excavation zone 12:20 9/26/03
140	No	Yes 7:50 9/24	Yes 11:15 9/24	
141	No	Yes 7:50 9/24	Yes 11:15 9/24	
142	No	Yes 1:26 9/24	Yes 8:10 9/26	

PMN Mines In Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
143	No	No	Yes 8:10 9/25	
144	No	No	Yes 12:15 9/24	
145	No	No	Yes 9:00 9/22	
146	No	No	Yes 8:10 9/25	
147	No	No	Yes 12:15 9/24	
148	No	Yes 8:30 9/22	Yes 9:45 9/22	
149	No	No	Yes 9:45 9/22	

PMN Mines In Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
150	Yes 9:00 9/17	Yes 10:00 9/17	Yes 2:00 9/17	

PPMiSrII Mines in Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
001	Yes 2:00 10/2	Yes 2:00 10/2	Yes 3:40 10/2	
002	Yes 11:14 10/2	No	Yes 2:58 10/2	
003	No	No	Yes 3:30 10/2	
004	Yes 11:15 10/2	Yes 11:15 10/2	Yes 12:35 10/2	
005	Yes 11:20 10/2	Yes 11:21 10/2	Yes 12:45 10/2	
006	Yes 2:00 10/2	Yes 2:00 10/2	Yes 3:15 10/2	
007	Yes 2:40 10/1	Yes 8:55 10/2	Yes 10:00 10/2	

PPMiSrII Mines in Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
008	Yes 2:26 10/1	No	Yes 3:35 10/1	
009	Yes 2:45 10/1	Yes 2:45 10/1	Yes 7:45 10/2	
010	Yes 2:45 10/1	No	Yes 10:05 10/2	
011	Yes 11:15 10/1	Yes 11:15 10/1	Yes 1:30 10/1	
012	Yes 2:45 10/1	No	Yes 7:45 10/2	
013	Yes 2:45 10/1	Yes 2:45 10/1	Yes 7:45 10/2	
014	Yes 11:05 10/1	No	Yes 1:00 10/1	

PPMiSrII Mines in Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
015	Yes 7:50 10/1	Yes 8:15 10/1	Yes 9:45 10/1	
016	Yes 7:50 10/1	Yes 8:15 10/1	Yes 9:45 10/1	
017	No	No	Yes 10:30 10/1	
018	Yes 12:45 9/30	Yes 1:05 9/30	Yes 2:00 9/30	
019	No	No	Yes 10:00 10/1	
020	Yes 12:48 9/30	Yes 12:48 9/30	Yes 2:00 9/30	
021	Yes 8:19 10/1	Yes 8:20 10/1	Yes 10:25 10/1	

PPMiSrII Mines in Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
022	Yes 8:29 10/1	No	Yes 10:45 10/1	
023	No	No	Yes 11:05 9/30	
024	Yes 1:05 9/30	Yes 1:05 9/30	Yes 2:40 9/30	
025	Yes 8:00 9/30	No	Yes 8:17 9/30	
026	Yes 2:50 9/29	No	Yes 8:16 9/30	
027	Yes 1:10 9/29	Yes 1:12 9/29	Yes 1:14 9/29	
028	Yes 3:04 9/29	No	Yes 11:30 9/30	

PPMiSrII Mines in Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
029	Yes 3:08 9/29	No	Yes 8:35 9/30	
030	Yes 12:30 9/29	No	Yes 2:15 9/29	
031	No	Yes	Yes 1:30 9/26	
032	Yes 12:20 9/26	No	Yes 2:05 9/26	
033	No	No	Yes 7:50 9/29	
034	No	Yes 10:30 9/26	Yes 1:20 9/26	
035	No	Yes 9:50 9/26	Yes 8:15 9/29	

PPMiSrII Mines in Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
036	No	No	Yes 7:45 9/26	
037	No	Yes 1:58 9/24	Yes 2:10 9/24	
038	No	No	Yes 2:15 9/24	
039	Yes 9:10 9/25	Yes 10:45 9/25	Yes 1:30 9/25	
040	No	Yes 7:50 9/24	No	This mine is believed to have been sifted and dumped but missed in the inspection
041	No	No	Yes	
042	No	No	Yes 11:15 9/24	

PPMiSrII Mines in Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
043	Yes 1:20 9/23	No	Yes 11:40 9/24	
044	Yes 10:50 9/22	Yes 11:20 9/22	Yes 9:00 9/24	
045	Yes 10:50 9/22	Yes 11:20 9/22	Yes 11:20 9/24	
046	No	No	Yes 8:11 9/25	
047	Yes 8:25 9/22	Yes 9:15 9/22	Yes 9:25 9/22	
048	Yes 8:05 9/22	Yes 8:15 9/22	Yes 9:00 9/22	
049	Yes 8:00 9/22	Yes 8:30 9/22	Yes 9:45 9/22	

PPMiSrII Mines in Blind Minefield				
Mine Number	**Mine Visible in Bank**	**Mine Visible on Spoils Pile**	**Mine Sifted and Visible on Residuals Pile**	**Comments**
050	Yes 8:00 9/22	Yes 8:30 9/22	Yes 9:45 9/22	