INNOVATIVE TECHNOLOGY
Summary Report

Innovative Directional and Position Specific Sampling Technique (POLO)

OST Reference #316

Industry Programs Crosscut and
Subsurface Contaminants
Focus Area

DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

MASTER

Demonstrated at
Savannah River Site
Aiken, South Carolina

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

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

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

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

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

TABLE OF CONTENTS

APPENDICES

SECTION 1

SUMMARY

The UTD Inc. Position Location (POLO) device is used for identifying the position of characterization sensors in the subsurface. POLO fits within a cone penetrometer rod to quickly and cost-effectively identify sample location, rod tip location, and track the rod path. UTD demonstrated the POLO device at a private site in Virginia and at the DOE Savannah River Site in South Carolina. Results show POLO as accurate as any alternative approach at less than 0.50% error, and at a fraction of the cost. POLO can be used in close proximity to tanks, pipelines, and buildings with greatly reduced risk of puncture and resulting spills -- a major improvement over current approaches. POLO only adds about 4% to cost of penetrometer use.

Technology Summary

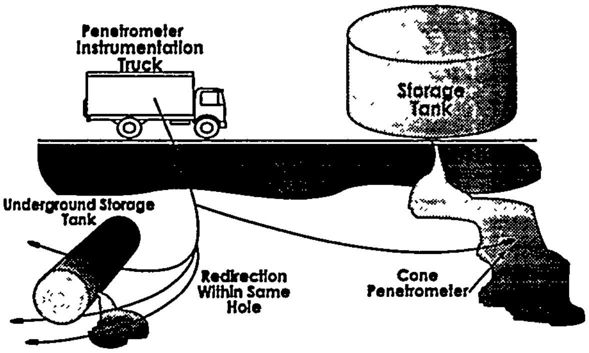

Figure 1. Example applications of POLO

POLO was developed by UTD Inc. under an Industry Program contract managed by the Federal Energy Technology Center (FETC) for the DOE EM Office of Science and Technology (OST). Figure 1 illustrates example applications of POLO.

Problem Addressed

The addition of POLO to penetrometers equipped with multiple sensors reduces time and cost for subsurface characterization by avoiding unnecessary sampling and provides the capability of sampling near or beneath structures without expensive equipment and sensors to prevent accidental damage and resulting liability.

Key Features

No other underground navigation tool can fit within a penetrometer rod and still allow room to accommodate other umbilicals. POLO provides real-time location data. POLO has been used successfully with the Site Characterization and Analysis Penetrometer System (SCAPS). The POLO sensor has exceptional accuracy and resolution which rivals the best inertial systems at a much lower cost.

Potential Markets

A major market is waste site or spill characterization.sampling. Others are utility contractor directional drilling, micro-tunneling, oil and gas slim-hole directional drilling, and mineral exploration surveys.

Advantages

Category	Comments
Cost	Adds only 4% to penetrometer application cost. Alternatives have higher cost.
Performance	Penetrometer performance unaltered. Accuracy of 0.50% of push distance.
Implementation	One part-time operator familiar with the system (typically one of the on-site crew).
Secondary Waste	Does not generate secondary waste; easily decontaminated.
ALARA/Safety	No ALARA or safety issue; can safely operate near subsurface structures.

Limitations/Skills Required

The POLO system alone is capable of providing location of the rod tip as "pushed" and is best used when combined with the ability to change course to target specific points underground or to avoid obstacles. This capability was developed through a second Industry Program contract. A part-time operator runs the POLO software, monitors its function, and relays data. Some training is needed.

Demonstration Summary

The first field demonstration was conducted at a private site in a natural deposit in normally consolidated sandy clay soil at Kingstowne, Virginia. The second field test was in a large man-made mound of non-compacted sand to cobble size particles adjacent to the railroad tie disposal site in Area F of the DOE's Savannah River Site (SRS) at Aiken, South Carolina. Four POLO pushes were made at each site. The project was completed in 1994 following these two successful demonstrations.

Key Demonstration Results

POLO location data was compared with land-surveyed locations determined using a transit, stadia rod, and tape. The difference in location of the end point of the penetrometer over the distance pushed comprised the calculated error. Error for interim points in the penetrometer path is assumed to be less than error for the end point, based on penetrometer bend characteristics. For each of the eight pushes, POLO met the success criterion of less than 0.50% error. Each POLO unit is conservatively predicted to have a useful life of over 100,000 feet of push distance. *Assuming an annual utilization of 10,000 feet for ten years; linear acquisition cost amortization; and annual software maintenance and calibration, the POLO system will add just over $0.54 to the total cost of each foot pushed.*

Attendees at the 1997 SCAPS Working Group meeting estimated their typical per foot rates for cone penetrometer work range between $13 and $15. *The added cost of the POLO system's real time navigation capability is only 4%, a considerable added advantage for a small added expense.* The cost-effectiveness of the POLO system is clearly demonstrated when costs of current state-of-the-art systems, such as gyro systems, accelerometers, and flux gates, are considered along with their accuracy. A plot of cost versus accuracy for the baseline (unguided "point and shoot") and state-of-the-art systems, including POLO, is presented in Section 5.

Regulator Issues

The use of the POLO system will not change the number or type of permits required. POLO does not generate secondary waste.

Technology Availability

A commercial POLO system (instrumented of penetrometer rod section, downhole electronics, initializer, and computer) was officially transferred to SRS for their use in 1997. UTD is developing a POLO-based tracking system for use inside of drill strings. This activity is being co-funded by UTD and a commercial drilling company. In addition, UTD has been marketing the POLO system to penetrometer contractors as a bend indicator warning system as well as a path tracking device. The technology developer expects to manufacture, sell, and service POLO units.

Technology Limitations/Needs for Future Development

POLO's benefit increases with greater length of penetrometer push. The benefit of using the POLO system is only fully realized when used in conjunction with UTD's steerable penetrometer system developed under a subsequent FETC Industry Program contract, completed in 1997, and commercially available through UTD, Inc.

■ Contacts

Technical

UTD Contact:
Barney Harris, (703) 339-0800
E-mail: barnstorm@compuserve.com

Management

DOE Project Manager:
John R. Duda, DOE FETC, (304) 285-4217
E-mail: jduda@fetc.doe.gov

Other

All published Innovative Technology Summary Reports are available at http://em-50.em.doe.gov. The Technology Management System, also available through the EM50 (Office of Science and Technology; OST) web site, provides information about OST programs, technologies, and problems. The OST reference number for the Innovative Directional and Position Specific Sampling Technique (POLO) is 316.

SECTION 2

TECHNOLOGY DESCRIPTION

POLO is a sensor designed to provide accurate position location of the tip of a penetrometer rod as it is being advanced into the subsurface. Position location information is displayed on a field computer as the penetrometer advances into the soil. POLO is a sophisticated bend sensor based on the use of strain gages to detect bending of the POLO module. Each bend encountered by the POLO module is integrated by the computer software to geometrically calculate penetrometer tip location.

Overall Process Definition

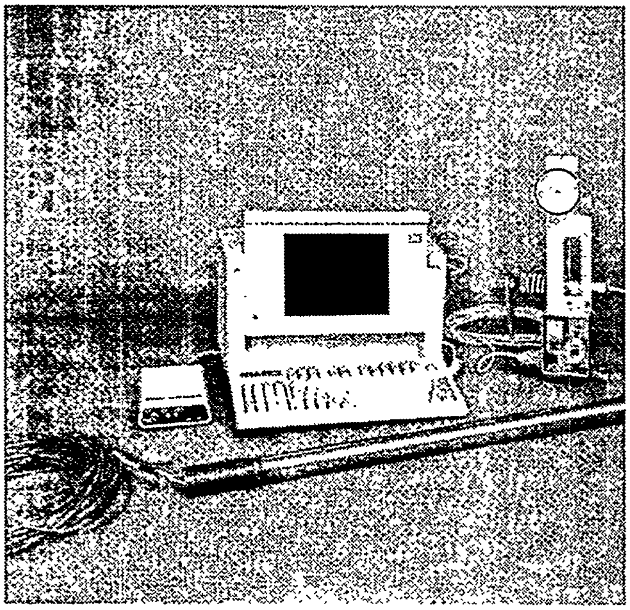

Figure 2. POLO Components

POLO is comprised of four basic components as shown in Figure 2:

- A downhole POLO module (physical appearance is equivalent to an approximate 5 foot length of penetrometer rod, inclusive of a miniature downhole data acquisition board).
- Umbilical hardwire connection from the POLO module to the above-ground data analysis and display functions (see coiled wire connected to POLO module in Figure 2).
- A field computer and software for real-time interface and display of POLO data.
- A POLO initializer used once at the beginning of POLO use at each penetration location.

Specific DOE applications for this technology include:

- Penetrometer pushes in rocky soil where risk of penetrometer deflection is high.
- Penetrometer pushes in layered dipping soil strata where risk of penetrometer deflection is high.
- Penetrometer pushes adjacent to buried storage tanks or other underground structures.

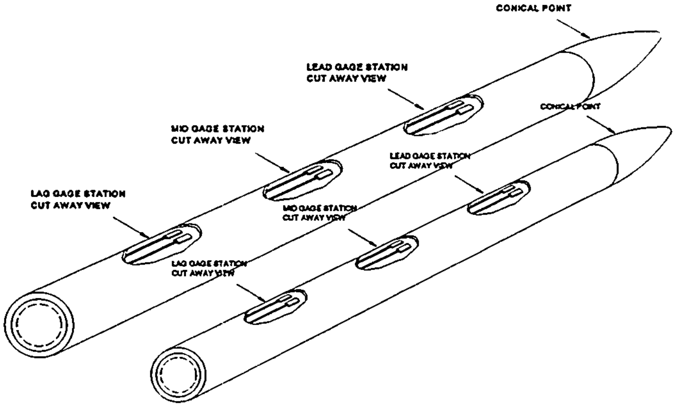

Figure 3. POLO Module Basic Design for Penetrometer Applications

The fundamental theory of POLO is based on the relationship of strain to bend radius. The strain difference is related to the diameter of the pipe and the radius of curvature and is measured by POLO using strain gages wired in a Wheatstone bridge. The general configuration of a POLO module is shown schematically in Figure 3. This particular module has 3 gage stations, each with 6 strain gages equally spaced at 60 degrees around its circumference. Together, these define the shape of the module axis as the module is moved along the profile to be measured. Data are carried from the POLO module to the aboveground data analysis software by an umbilical cord. Note that a shield covers the strain gages, protecting them from the environment, which can include water, dirt, and other contaminants. Decontamination, if contaminated soil came in contact with POLO, would consist of decontaminating the shield.

The initializer is designed to provide basic information about the initial location and orientation of the POLO module as it enters the ground. The needed information is shown in Figure 4. It includes the elevation angle, the azimuth angle of the direction of advance, and the POLO module rotation angle (azimuth about the pipe centerline). In addition, the geodetic coordinates of the point of penetration into the ground must be established.

System Operation

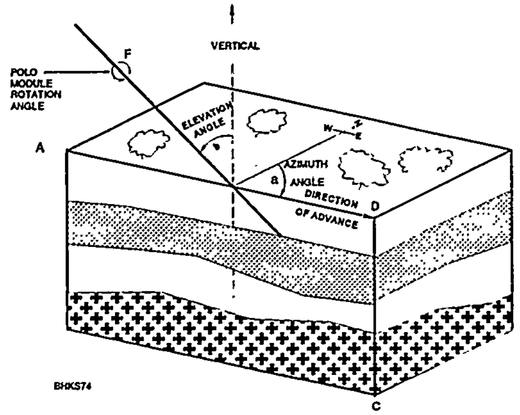

Figure 4. Basic Information Provided by the Initializer

POLO is used in the field by installing the module directly behind the penetrometer cone tip as one would install a normal penetrometer rod. The POLO umbilical is threaded through the entire remaining set of penetrometer rods in the same manner as that done for other hardwired sensor packages. The umbilicals of other sensors being used can be threaded through the POLO module and to the surface since the POLO module allows for more than two thirds of normal penetrometer rod internal area to be available for this purpose. The POLO umbilical is connected to the field computer and power supply and the cone penetrometer is lowered to the ground. A POLO initializer is temporarily attached to the penetrometer rod just below the truck to provide initial orientation information. The initializer is removed and the penetrometer is thrust into the ground per standard practice. At selected intervals (typically 1 meter), POLO provides position location of the penetrometer tip (in the form of coordinates and graphics on the field computer) relative to the point where it entered the ground.

General specifications for the POLO sensor are:

- Conditioning electronics are located in the downhole POLO module.
- Power requirements are +/-12 volts to 15 volts at 100ma (max).
- POLO accuracy is 0.50% of distance traveled, consistent with proper use.
- The POLO module is calibrated for temperature and natural bend compensation.
- POLO module dimensions are 62 inches in length, including end adapters; outer diameter of 1.75 inches; inner diameter of 1.00 inches; onboard data acquisition system occupies minimal internal space in the POLO module.

Under the initial FETC contract, one prototype POLO system (instrumented section of penetrometer rod, downhole electronics, initializer, and computer) plus a spare POLO downhole rod were manufactured. Based on lessons learned in this initial effort, a new UTD contract (DE-AR21-94MC31178) was awarded by FETC to complete development of a steering and vibratory thrusting capability for penetrometer delivery systems. Steering allows for the controlled directional use of the penetrometer, and vibratory thrusting provides greater depth penetration and improves the ability to penetrate harder materials. Another objective was to integrate a commercial position location device for penetrometers (POLO) into a Site Characterization and Analysis Penetrometer System (SCAPS) truck. This second contract was successfully completed in 1997.

The strain-gaged rod and the tracking algorithm, which are the heart of the POLO system have been patented. A complete POLO system was officially transferred to SRS for their use in 1997.

Demonstration Plan

UTD has conducted two field tests of the POLO system, and has successfully validated the hardware and software under field conditions, thus meeting field test objectives. UTD's success criterion was to determine the penetrometer tip position with an accuracy of 0.50% of the distance pushed.

The first field test was conducted in a vacant field near a ridge in a natural deposit in normally consolidated sandy clay soil at Kingstowne, Virginia; the second in a non-compacted man-made mound of sand to cobble size particles adjacent to the railroad tie disposal site in Area F of the DOE's Savannah River Site at Aiken, South Carolina (See Figure 5). Four POLO pushes were made at each site.

To determine accuracy, POLO position data had to be compared with a measurement of greater accuracy. One method to accomplish this would have been to use a second (more accurate) navigation system in parallel with POLO. Another method is to deploy the penetrometer to "hole out" (emerge from the subsurface) and to directly measure its location. Since there are no other underground navigation systems available which had both greater accuracy than POLO and the small size to fit within a penetrometer rod, UTD selected the second approach. All field validations of POLO were based on comparison of POLO position data to precisely surveyed locations of the holed-out penetrometer tip and entry point. (See page 7 for discussion of a recent demonstration that was not a part of this project in which POLO was compared with use of a compass and tilt sensor for surveying an existing borehole).

The verification survey was conducted with the penetrometer rods still in the ground. The "X" coordinate was measured by tape laterally from the tip to the azimuth line. The "Y" coordinate was measured by tape and is the horizontal distance along the azimuth line from the starting point to the tip. The "Z" coordinate was measured using a stadia rod and a tripod-mounted transit and is the difference in vertical height from the start point to the finish point. The error is the difference between the position predicted by POLO and the actual position as determined by the survey.

UTD used a mechanical rod pushing mechanism to push the penetrometer rod at shallow angles to the horizontal so that the tip would hole out and its position could be directly measured. UTD employed screw-in soil anchors to fix the pusher in place and resist high thrust loads. The rod pusher apparatus operated as planned. While this type of penetrometer deployment at shallow angles is not typical, identical results would be expected from vertical deployment of POLO.

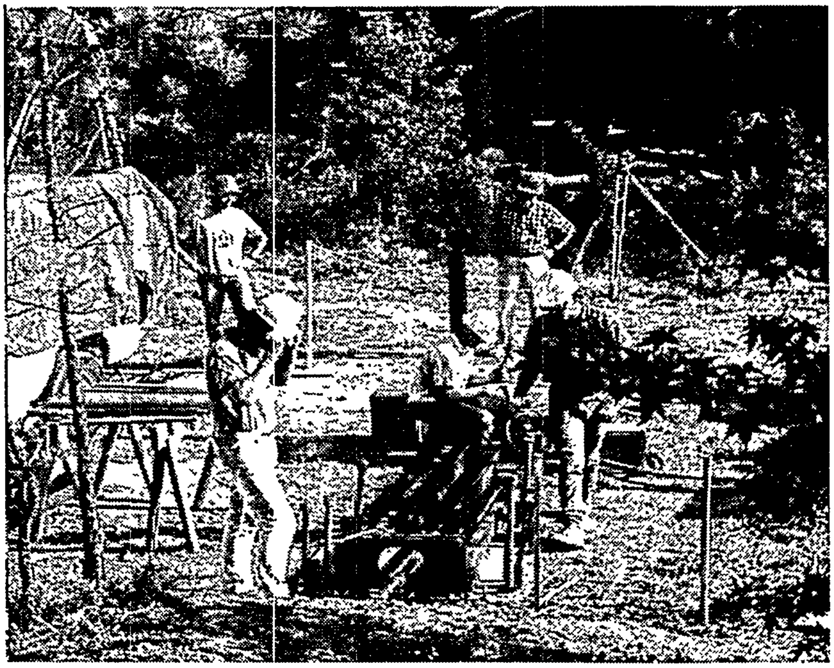

Figure 5. POLO Push Underway at DOE Savannah River Site (Transit for Actual Position Data in Background).

Results

While the rod pusher was set up and anchored to the ground surface, the POLO electronics were set up. The POLO bend sensor strain gage data was telemetered to the surface via an electrical umbilical. This umbilical was pre-lead through the penetrometer rods and connected to the instrumented section of penetrometer rod.

At the start of each push, the instrumented rod section was placed into the cradle of the rod pusher and thrust into the ground. The initializer was then placed directly on the instrumented rod section and used to determine its initial heading by measurement of the azimuth, elevation, and rotation angles.

The azimuth heading of the penetrometer was marked with survey stakes using a transit mounted on the initializer. With this approach, the azimuth for the survey was coincident with the initial heading of the penetrometer rod and instrumented rod section.

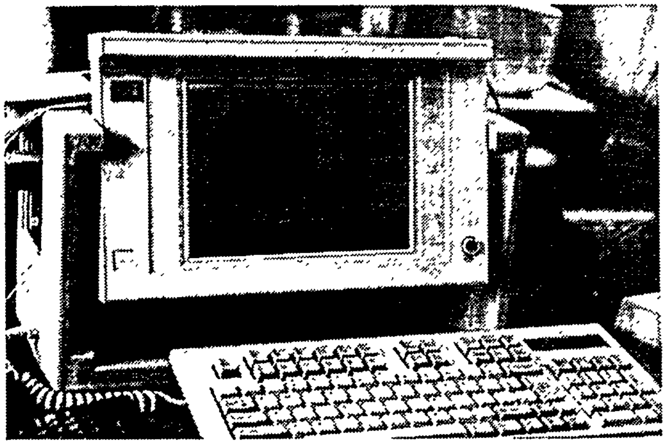

Figure 6. Computer Readout of POLO Data in SCAPS Truck

After this survey work was completed, the initializer was removed and the first set of POLO tracking measurements were made. Six full bridge strain circuit readings on the instrumented rod section were acquired in less than 10 seconds. This information was processed by the computer to update the location of the tip (see Figure 6). The string of penetrometer rods was then advanced one meter into the ground. The process of signal measurement and rod advancement was repeated until the tip "holed out" on the slope of the hillside.

Table 1 summarizes the results for all eight POLO pushes. The first column identifies the test; the second column identifies the total length of rod in the ground; the next column is the linear distance between the penetrometer tip's actual location and the location predicted by the POLO system; the last column is the total error, expressed as a percentage of the distance pushed. It can be seen that the POLO System met the success criterion of tracking with less than 0.50% error in two significantly different types of soil. To illustrate the accuracy of 0.50% error, POLO-generated data should routinely be within an actual range of a 6 inch diameter circle at push distances of 50 feet.

Table 1. POLO System Field Test Results

Test	Distance Pushed, Inches	Distance Between Predicted and Actual Tip Location, Inches	System Error, %
Kingstowne #1	276	0.6	0.22
Kingstowne #2	552	1.4	0.25
Kingstowne #3	413	0.5	0.13
Kingstowne #4	394	1.9	0.48
Savannah River #1	589	2.7	0.45
Savannah River #2	616	2.8	0.46
Savannah River #3	558	2.7	0.48
Savannah River #4	414	1.5	0.36

Additional performance data were developed from a January 1998 field test of a POLO system modified for use in the survey of drill strings. This demonstration was conducted under an agreement between UTD and Ontario Hydro Technologies. For an 1,800 foot long core boring, primary means of survey consisted of sending a compass with a tilt sensor downhole and photographing their readings. The negatives were processed at the site and the compass and tilt angle readings were used to calculate coordinates on a point and slope basis. This method represents a standard of high accuracy against which other methods, such as POLO, can be compared.

At 1,710 feet (last point surveyed by POLO), the lateral deviation between POLO position data and the primary survey data was 8.3 feet. This is equal to 0.48% error as a function of the traveled distance of 1,710 feet. The survey time using POLO took 20 minutes to push the device down the hole and 10 minutes to pull it back to the surface. Data transfer and path calculations took an additional 10 minutes to complete.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

UTD's POLO system is unique in that no other underground navigation tool can fit within the confines of a penetrometer rod with room left over to pass other umbilicals. The POLO sensor does not rely on flux gate compasses, and therefore is immune to magnetic anomalies. Finally, the POLO sensor has exceptional accuracy and resolution which rivals the best inertial systems at a much lower cost. Example scenarios in which POLO can provide critically valuable information are given in Figures 7-9.

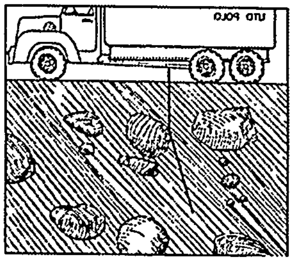

Figure 7. Penetrometer Pushes in Rocky Soil Where Risk of Deflection is High

■ Technology Applicability

Cone penetrometers have been used for subsurface characterization for many years; however, it has not been possible to determine accurately the position of the probe when a sample is collected. Traditionally, the results of the sample are plotted on a grid that represents the location of the probe at the surface; frequently, the path of the probe is deflected by subsurface obstacles or other geophysical phenomena.

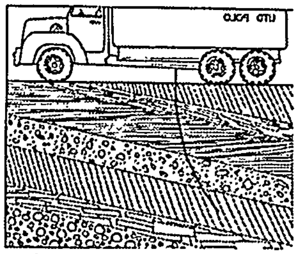

Figure 8. Penetrometer Pushes in Layered Dipping Soil Strata Where Risk of Deflection is High

The annual market for site assessment and remediation in the United States is estimated to be $6.5 billion and is expected to increase. This demand has driven the adaptation of directional drilling and unguided direct push technology, developed for underground utility installation and soil geotechnical analysis, to underground well drilling, sampling, and sensor delivery.

Cone penetrometers are used increasingly to detect gases in the soil, take soil samples, detect alpha, beta, and gamma radiation, and other materials using various detection equipment and sample collection techniques. Penetrometers advance a wide range of sensors and sampling devices through soil, using small-diameter push rods, and have been widely accepted for environmental work because they are faster and less expensive to use than traditional drilling rigs. In addition, penetrometers minimize environmental impacts because they avoid the rotary motion of a drill that can bring contaminated material to the surface. Despite their advantages, locating the final position of a sensor at the head of a penetrometer that has been pushed a specified distance has previously been difficult and of questionable accuracy.

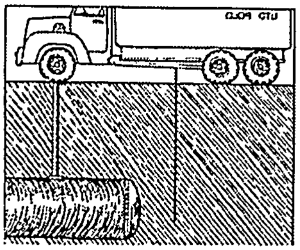

Figure 9. Penetrometer Pushes Adjacent to Buried Storage Tanks or Other Underground Structures

The POLO device is used as the position feedback sensor in the Steerable Vibratory Penetrometer System developed by UTD. The POLO system will enable penetrometers to be viable alternatives to directional drilling for many applications. *The POLO system's immunity to magnetic anomalies will permit work near and beneath underground storage tanks.*

Other applications include adapting POLO for ultra-precision drilling to produce highly accurate surveys of drill strings in a fraction of the time required using current technology. This adaptation is in progress, as demonstrated by the January 1998 field demonstration discussed beginning on page 7. A similar adaptation for utilities would allow profiling of existing conduits, pipelines, and ducts. Gas, electrical, and water utilities can employ POLO technology to survey areas for which incomplete documentation exists.

Competing Technologies

Several manufacturers supply underground navigation systems for drilling, tunneling, and surveying. Navigation systems can be broken down into two categories: those which do and do not require access to the ground surface immediately above the drill tip.

Systems requiring access to the ground above the drill tip include walkover systems consisting of a transponder in the drill string and a hand held device which senses the transponder underground. A readout provides depth and pitch of the drill bit. Walkover systems are inexpensive, easy to use, and are ideal when drilling horizontally, however, they are unsuitable for most environmental work due to limitations in depth and the required access to the ground above the rod string. A variant of this system uses sensors in the drill string to detect a magnetic field created by electric current in cables laid on the ground surface. These systems are used to provide final course correction during hole out or for relatively shallow (less than 5-10 foot depth) horizontal drilling operations.

Three types of systems that do not require access to the ground above the drill tip are in common use:

- The least expensive is the incline/azimuth type which rely on flux gate compass(s) and accelerometers to measure azimuth and inclination respectively. These devices lose accuracy near magnetic anomalies as from steel reinforcing rods (rebar), steel tanks, or large electrical currents. Nonmagnetic sections must be inserted into the drill string to house these sensors.
- One of the most accurate downhole systems rely on rate gyros and inertial measurements and are typically used in oil field applications.
- Optical systems rely on lasers to maintain a straight trajectory in micro-tunneling applications. Other systems rely on a series of optical measurements made within the pipe to sense deviation. These systems are expensive and are typically used by service contractors called in to perform detailed surveys of an existing bore hole.

Patents/Commercialization/Sponsors

UTD filed with the United States Patent and Trademark Office on June 3, 1991 and was granted Patent number 5,193,628 for the POLO navigation tool on March 16, 1993.

Work to date has been funded from UTD's IR&D, an Industry Program contract managed by the FETC for the DOE EM OST, and a separate agreement with Ontario Hydro Technologies. UTD has had considerable liaison with personnel at the FETC at both Morgantown and Pittsburgh, DOE's Savannah River Site, Argonne National Laboratory, and the Dover Air Force Base.

POLO is applicable in all underground probe systems. UTD has concentrated its efforts on the following major areas for commercialization:

- environmental characterization,
- utility contractor directional drilling,
- micro tunneling,
- oil and gas slim-hole directional drilling, and
- mineral exploration borehole surveys

UTD is actively marketing the POLO sensor, including the steerable vibratory penetrometer system, through direct contact with companies that conduct the above activities. UTD also plans to pursue a strategic alliance with a larger company, with an existing distribution network, to enable more effective commercialization and implementation of the technology.

SECTION 5

COST

Methodology

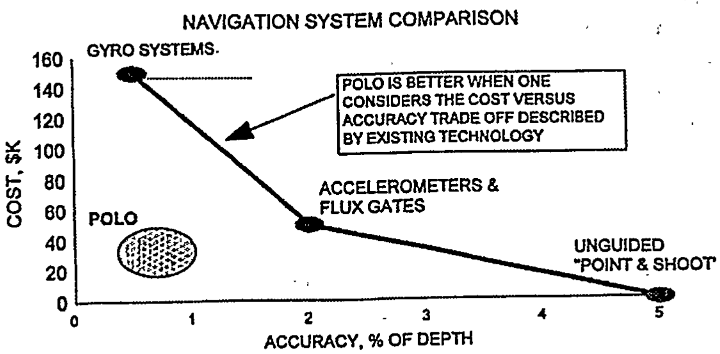

Figure 10. Cost Comparison Between POLO and Other Navigation Systems

The POLO system is used as the position feedback sensor for the steerable penetrometer system developed by UTD. At the present time, no small diameter navigation systems exist which can match the accuracy, small size, immunity from magnetic anomalies, and low cost of the POLO system. While not directly comparable due to POLO's small size, Figure 10 presents a comparison of navigation devices, along with representative capital costs and accuracy acquired from several manufacturers. POLO system cost estimates are based on UTD's experience in fabricating six units for research and cost projections of hardware designed for commercial manufacture. The relative uncertainty of this data is represented by the size and shape of the cost and accuracy data ranges.

Cost Analysis

A commercial POLO system will be sold for approximately $33K. This unit will be suitable for immediate use in a penetrometer string and will include PC based software, user manual, initializer, and all cabling. In addition, two days of training at the customer site will be required at a cost of approximately $1000 per day plus travel expenses. A laptop computer is required, along with power source, and a relatively clean, dry place in which to work. The total implementation costs are presented in Table 2.

Table 2. Implementation Cost Summary

Component or Service	Cost	Remarks
POLO System	$33,000	Including downhole sensor, PC based software, user manual, initializer, and all cabling and interfaces, one year technical support
Training	$ 2,000	Conducted at user site
Travel Expenses	$ 1,000	Conservatively estimated
Laptop Computer	$ 3,000	Procured by end user
Battery Power Supply	$ 200	Procured by end user
TOTAL CAPITAL COST	$39,200	

The POLO system will enable a cone penetrometer rig to effectively compete with a small directional drill. An illustrative example could involve sensors which must be precisely located at a typical depth of 60 feet with a required precision exceeding that available with unguided cone penetrometer rigs. Directional drills create a hole in the ground at a cost from thirty to one-hundred dollars per foot. A guided cone penetrometer rig, equipped with the POLO system, could perform the same function in subsurface conditions such as those illustrated in Figures 7-9. Based on the above, the cost of using a directional drill to create this hole is between $1,800 and $6,000, as compared with $812 to $932 for a POLO-equipped penetrometer system, a savings of at least 52%.

Currently, because of the lack of precise location data and directional control, sampling near tanks, buildings, and underground pipelines does not take full advantage of penetrometer technology. Through the use of POLO and the recently developed steering and vibratory thrusting capability, these activities can benefit from the use of penetrometer technology without risking damage and resulting spills caused by lack of location information and control. Both POLO and the Steerable Vibratory Penetrometer System are commercially available through UTD.

POLO operating costs are minimal. One part-time operator is required to run the POLO software, monitor its function, and relay data. It is envisioned that the operator (navigator) will simply be one of the on-site crew. The POLO downhole sensor will require periodic calibration and an annual fee for software maintenance and upgrades after the first year. Other costs may include additional training or modifications.

Life cycle costs beyond acquisition are minimal. Once the hardware and software are procured, the only ongoing expense will be a periodic recalibration of the POLO sensor and initializer, software maintenance, online technical support, and new operator training. These expenses are outlined in Table 3.

Table 3. Annual Cost Summary

Component or Service	Cost	Remarks
POLO System	$1,000	Calibration
Software Maintenance	$ 500	Free for one year following purchase
TOTAL ANNUAL COST	$1,500	

■ Cost Conclusions

Based on experience to date and underlying principle of the technology, the POLO underground sensor is conservatively predicted to have a useful life of over 100,000 feet of pushing. Assuming an annual utilization of 10,000 feet for ten years; linear acquisition cost amortization ($39,200 over ten years, or $3,920 annually); and $1,500 annual software maintenance and calibration, the POLO system will add just over [($3,920+$1,500)/10,000 feet] = $0.54 to the total cost of each foot pushed.

Attendees at the 1997 SCAPS Working Group meeting estimated their typical per foot rates for cone penetrometer work range between $13 and $15. The added cost of the POLO system's real time navigation capability adds only 4% to this, a small added expense for a considerable added advantage.

The POLO system has been designed to be a drop-in enhancement to existing penetrometer systems. The benefit of using the POLO system is only fully realized when used in conjunction with UTD's steerable penetrometer system.

POLO's cost relative to other underground navigation technologies was presented graphically in Figure 10 The cost effectiveness of the POLO system is clearly demonstrated when costs of current state-of-the-art systems are plotted as a function of accuracy.

SECTION 6

REGULATORY/POLICY ISSUES

■ Regulatory Considerations

Cone penetrometers equipped with sensors that can detect and help quantify contamination are increasingly used at all waste sites, including CERCLA sites, because of data collection speed and low cost compared to drilling. POLO has the potential for further reducing time and cost by precisely locating characterization data, thus reducing the need for collecting extra unneeded data to ensure adequate delineation and to avoid redeployment to fill data gaps. Regulatory agencies should [are expected to] view the use of POLO as a positive development that increases the certainty that field data is truly representative of actual field conditions. The use of the POLO system with cone penetrometers will not change the number or type of permits required for penetrometer operations. POLO does not generate secondary waste and will not change the total amount of secondary waste (if any) created by direct-push penetrometers.

POLO is a drop-in enhancement to existing penetrometer capabilities, therefore, CERCLA evaluation criteria are not applicable to the use of POLO.

■ Safety, Risk, Benefits, and Community Reaction

POLO is a safety enhancement due to its accurate navigation: the POLO system will permit safer operation probing in close proximity to storage tanks and/or pipes which contain hazardous materials. POLO reduces the risk of puncturing such structures and causing further release of contaminants to the soil.

Advantages penetrometers have over drilling include:

- No contaminated cuttings: the hole is created by compaction - no cuttings are removed from the ground or transported to other subsurface layers.
- No drill fluids: no drilling fluids are used, reducing the spread of contamination.
- Continuous data collection: nonrotating direct push technology enables on board sensors to function while the penetrometer is advanced.
- Smaller hole diameter: penetrometers are typically smaller in diameter than even the smallest drills, resulting in less subsurface disturbance.

■ Socioeconomic Impacts and Community Perception

POLO will have minimal impact on the labor force and economy of a given region where it is applied. The general public has minimal familiarity with the concept of underground navigation and the devices used.

SECTION 7

LESSONS LEARNED

POLO provides location information to 0.50% accuracy, while the baseline technology, unguided "point and shoot", is accurate to approximately 5%. Problems that may be encountered vary depending on field conditions and specific applications. For example, unguided pushes of 20 feet would routinely hit a target 2 feet in diameter which may provide acceptable accuracy, unless the push is near an underground storage tank or other structure. Other less sensitive applications may not derive substantial benefit unless pushes are greater than 50 feet. However, the POLO system's real time navigation capability adds only 4% to the cost of penetrometer use, a considerable advantage for small added expense.

■ Implementation Considerations

The POLO system alone is only capable of providing location - and is best when combined with the recently developed ability to change course to target specific points underground or to avoid obstacles. POLO has accuracy similar to the state-of-the-art in underground navigation and has several advantages not available with any other system. POLO is less costly to implement than other baseline navigation systems.

POLO was successfully tested with SCAPS and the technology developer maintains contact with SCAPS personnel. However, in spite of this, significant implementation of the technology across the DOE complex has not yet been effected. The developer continues to assess DOE opportunities/needs, and is modifying its marketing strategies in order to better deploy the technology.

■ Technology Limitations/Needs for Future Development

Marketing of POLO capabilities for uses outside DOE, particularly for accurately surveying existing boreholes, appears to have gained interest. The January 1998 demonstration cited in Section 3, page 7, directly compared POLO with a baseline technology with favorable results that further verified the 0.50% accuracy that was a major success criterion of FETC's Industry Programs technology development project. Presently, it is thought that additional demonstrations of the integrated system (POLO and the steerable vibratory penetrometer system) are needed to more effectively penetrate the private sector market, and subsequently expand market share.

APPENDIX A

REFERENCES

Most references listed below are documents or contract deliverables associated with Contract DE-AC21-92MC29119 for design, development and demonstration of the POLO system.

1. Monthly Status Reports
2. METC EWM Division Weekly Bullets
3. Volume II, Technical Proposal, undated
4. Management Plan, August 1992
5. Phase II Management Plan, June 1993
6. Phase II Draft Final Report and Phase III Technical Proposal, November 1993
7. Phase III Proposal Review, December 9, 1993
8. Phase III Management Plan, February 1994
9. Memorandum, S. Brett Humble and Chris Wyatt, Energetics, Inc., to Wilkins Smith, Energetics, Inc., September 30, 1994, re: Meeting Minutes for the Phase III Review Meeting at METC, September 30, 1994
10. Task Description, December 1, 1994
11. Status Reports, from July 28 - August 31, 1992 through September 1994
12. ***Innovative Directional and Position Specific Sampling Technique.*** Foster, E.L. . UTD, Inc., Newington, VA (United States). [1994]. 10p. DOE Contract AC2192MC29119. Sup. Doc. Num. E 1.99:DE95008362. NTIS Order Number DE95008362. Primary Report Number: DOE/MC/29119--95/C0429. Source: OSTI (DOE and DOE contractors only); NTIS (Public Sales); GPO Dep. (Depository Libraries)
13. ***Innovative Directional and Position Specific Sampling Technique: Phase I; Final Report, July 28, 1992--April 28, 1993.*** Hutzel, W. J.; Foster, E. L. UTD, Inc., Newington, VA (United States). Apr 1993. 34p. DOE Contract AC2192MC29119. Sup. Doc. Num. E 1.99:DE94000049. NTIS Order Number DE94000049. Primary Report Number: DOE/MC/29119--3524. Source: OSTI (DOE and DOE contractors only); NTIS (Public Sales); GPO Dep. (Depository Libraries)
14. ***Innovative Directional and Position Specific Sampling Technique. Phase 3: Final Report, July 1992--September 1994.*** Hutzel, W. J.; Hill, J. L. III; Foster, E. L. UTD, Inc., Newington, VA (United States). Sep 1994. 98p. DOE Contract AC2192MC29119. Sup. Doc. Num. E 1.99:DE95000006. NTIS Order Number DE95000006. Primary Report Number: DOE/MC/29119--3881. Source: OSTI (DOE and DOE contractors only); NTIS (Public Sales); GPO Dep. (Depository Libraries)
15. ***Innovative Directional and Position Specific Sampling Technique; Phase 2, Final report, [July 28, 1992--February 15, 1994].*** Hutzel, W. J.; Hill, J. L. III; Foster, E. L. UTD, Inc., Newington, VA (United States). Jan 1994. 38p. DOE Contract AC2192MC29119. Sup. Doc. Num. E 1.99:DE94004083. NTIS Order Number DE94004083. Primary Report Number: DOE/MC/29119--3667. Source: OSTI (DOE and DOE contractors only); NTIS (Public Sales); GPO Dep. (Depository Libraries)

16. "Cone Penetrometer," Innovative Technology Summary Report, U.S. Department of Energy, April 1996.

17. "HDD Locator Review," article in Directional Drilling supplement to Trenchless Technology, Volume 1, Number 2, September 1996.

18. "An Introduction to Trenchless Technology," Steven R. Kramer, William J. McDonald, James C. Thomson, Van Nostrand Reinhold, New York, NY, 1992.

19. "Cleaning up the Nation's Waste Sites: Markets and Technology Trends, 1996 Edition," Environmental Protection Agency, EPA Report Number EPA-542-R-96-005.

20. Product Brochures, various.

APPENDIX B

ACRONYMS AND ABBREVIATION

ALARA	As low as reasonably achievable, a measure of potential worker exposure to radiation.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CPT	Cone Penetrometer
DOE	Department of Energy
FETC	Federal Energy Technology Center
ma	milliamps
NTIS	National Technical Information Service
POLO	Position Location
OST	DOE Office of Science and Technology
rebar	steel reinforcing bars embedded in concrete used to increase tensile strength
SCAPS	Site Characterization and Analysis Penetrometer System, a platform with state-of-the-art sensor technology and a suite of cone penetrometer (CPT) tools.