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The Tri-Service Site Characterization and Analysis Penetrometer System-SCAPS:

Innovative Environmental Technology from Concept to Commercialization

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EXECUTIVE SUMMARY

Hazardous waste contamination in soil and groundwater poses significant problems for society, especially in terms of health and expense. Before a hazardous site can be cleaned up, it must first be mapped to determine the extent of subsurface contamination. Traditional site characterization is performed by collecting samples from soil boring or monitoring wells and then sending them to an off-site laboratory for analysis. This practice is extremely costly, time consuming and prone to error in determining the direction and extent of the contaminant plume. The Army recognized the need for improved, on site characterization tools more than ten years ago and began developing a direct-push chemical sensor for petroleum hydrocarbon contaminant in soil.

The Tri-Service Site Characterization and Analysis Penetrometer System, or SCAPS, program began in 1987 under sponsorship of the U.S. Army Toxic and Hazardous Materials Agency (now the U.S. Army Environmental Center) to address the need for rapid site characterization of soil contamination at U.S. Army facilities. The program evolved into a Tri-Service (Army, Air Force and Navy), multi-year research, development, and technology demonstration program with additional funding by the SERDP and ESTCP. The U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) also participated in the program. The U.S. Army Environmental Center took the lead for SCAPS sensor development efforts among DoD, DOE and EPA and coordinated with regulatory agencies, as well as potential government and commercial users. SCAPS consists of a commercial cone penetrometer unit mounted on the custom-designed bed of a 20-ton truck. The truck houses a mechanical room for the cone penetrometer and a data analysis room for operational and diagnostic computers and instrumentation. A variety of sensor probes can be attached to the cone penetrometer to investigate soil geophysical properties, or that respond to classes of contaminants such as petroleum, solvent products, metals and explosives. SCAPS operators use a 20-ton hydraulic press mounted in the truck to push the sensors up to 150 feet into the soil. The SCAPS systems relay information on subsurface contaminants to the surface for immediate analysis and interpretation. The final display products SCAPS provides can range from individual push charts to cumulative 3-D depictions of the subsurface.

The use of SCAPS typically saves approximately 50% of the costs of site characterization, and frequently more. Five different technical standards, methods or regulatory guidelines for use of SCAPS chemical sensor and sampler probes for site characterization have been approved. SCAPS probes have been used to characterize petroleum, volatile organics, explosives and metals contaminants in over 200 locations on Army, Navy, Air Force, Department of Energy (DOE) and Environmental Protection Agency (EPA) sites. The Army operates four SCAPS trucks, the Navy operates three and the DOE one truck to characterize sites. The commercial sector has acquired SCAPS technology through licensing agreements and is putting it to work in the private sector worldwide.
Highlights of the program are:

- Eleven patents and four patent applications.
- EPA Method 8265.
- SCAPS was evaluated and recommended under the EPA Superfund Innovative Technology Evaluation (SITE) program.
- Eight SCAPS trucks being operated by three federal agencies.
- The state of California has certified the LIF technology. Reciprocity with 27 other states has been achieved through the Interstate Technology Regulatory Cooperation Workgroup (ITRC).
- ASTM Standard Practice for LIF: D-6187-97.
- Documented savings of $6,031,000 at sixteen sites using SCAPS vs. conventional characterization methods.

The Tri-Service Site Characterization and Analysis Penetrometer System, or SCAPS, technology was developed to address the problems of time and expense in hazardous waste site characterization. Three Defense services and three other federal agencies coordinated their research and development efforts to make this possible. SCAPS sensor developments and demonstrations were funded by the Army Environmental Center (AEC), the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP). It has proven to be an effective tool for rapid site characterization and assessment.

SCAPS combines traditional cone penetrometer technology with contaminant sensors and samplers to provide rapid, on-site, cost effective evaluation of soil contaminants, geophysical properties and to direct traditional soil sampling and well placement. Sensors were field tested during development, and later demonstrated as part of several methodology validation programs to gain state and federal regulatory approval. Five different technical standards, methods or regulatory guidelines resulted from this effort. SCAPS probes have been used to characterize petroleum, volatile organics, explosives and metals contaminants in over 200 locations on Army, Navy, Air Force, Department of Energy (DOE) and Environmental Protection Agency (EPA) sites. The Army operates four SCAPS trucks, the Navy operates three and the DOE one truck to characterize sites. The commercial sector has acquired SCAPS technology through licensing agreements.

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I. INTRODUCTION

Hazardous waste contamination in soil and groundwater poses significant problems for society, especially in terms of health and expense. Before a hazardous site can be cleaned up, it must first be mapped to determine the extent of subsurface contamination. Traditional site characterization is performed by collecting samples from soil boring or monitoring wells and then sending them to an off-site laboratory for analysis. These practices are extremely costly, time consuming and prone to error in determining the direction and extent of the contaminant plume. The Army recognized the need for improved, on site characterization tools more than ten years ago and began developing a direct-push chemical sensor for petroleum hydrocarbons in soil. This resulted in an active multi-agency effort to develop sensors for other classes of contaminants, including solvents, metals explosives and radioactive wastes. The resulting SCAPS chemical sensor innovations to cone penetrometer technology have made reliable in-situ soil testing for environmental site characterization possible. This report summarizes the development, field demonstration and regulatory acceptance activities associated with the SCAPS technologies that are used to detect, identify and quantify subsurface contamination in soil and groundwater.

SCAPS consists of a cone penetrometer unit mounted on the custom-designed bed of a 20-ton truck. A variety of sensor probes can be attached to investigate soil geophysical properties, or that respond to classes of contaminants such as petroleum, solvent products, metals and explosives. SCAPS operators use a 20-ton hydraulic press mounted in the truck to push the sensors up to 150 feet into the soil. The SCAPS systems relay information on subsurface contaminants to the surface for immediate analysis and interpretation.

SCAPS can collect and analyze field data faster than traditional methods because the need for drilling to collect soil for remote laboratory analyses can be reduced, and in some cases, avoided. SCAPS costs about 50% less than conventional drilling and sampling, so researchers can collect more samples in a shorter time and quickly define a site's contamination boundaries. Because SCAPS is mobile, data can be also be gathered from areas inaccessible to drill rigs. In fact, much of the cone penetrometer data collected in real-time can be used for on-site decision making by the site investigators, as well as regulatory officials. SCAPS produces less investigation-derived waste than traditional site-characterization tools. SCAPS also can delineate the extent of subsurface contamination more accurately and for less money than widely spaced monitoring wells.

The SCAPS program began in 1987 under sponsorship of the U.S. Army Toxic and Hazardous Materials Agency (now the U.S. Army Environmental Center) to address the need for rapid site characterization of soil contamination at U.S. Army facilities. The program evolved into a Tri-Service (Army, Air Force and Navy), multi-year research, development, and technology demonstration program with additional funding by the SERDP and ESTCP. The U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) also participated in the program. The U.S. Army

Environmental Center took the lead for SCAPS sensor development efforts among DoD, DOE and EPA and coordinated with regulatory agencies, as well as potential government and commercial users. Some highlights of the program are:

- Eleven patents and four patent applications.
- EPA Method 8265.
- SCAPS was evaluated and recommended under the EPA Superfund Innovative Technology Evaluation (SITE) program.
- Eight SCAPS trucks being operated by three federal agencies.
- The state of California has certified the LIF technology. Reciprocity with 27 other states has been achieved through the Interstate Technology Regulatory Cooperation Workgroup (ITRC).
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II. OVERVIEW OF AVAILABLE SCAPS TECHNOLOGIES AND SITES

The SCAPS is a component-based system of sensors that are used interchangeably with the SCAPS truck platform. No special permits are required for the operation of a cone penetrometer. Regulatory approval is typically handled as in standard drilling, where a drilling plan is submitted to the appropriate regulatory agency for their approval prior to initiation of work. Table 1 describes the parts of the SCAPS system briefly. More details concerning specific probes follows in Section III, The SCAPS Equipment.

TABLE 1. OPERATING COMPONENTS OF THE SCAPS

SCAPS Truck	Data acquisition compartment and push room compartment (rod storage and hydraulic push ram) are isolated and have air quality monitors. Rods are steam cleaned before they enter the push compartment to keep hazardous materials from entering the vehicle.
Grouting Capability	Grout is used to seal the penetration hole when a push is completed. A cement and water mixture is pumped through a tube in the penetrometer to fill the hole as the push rods are brought to the surface. This eliminates the potential movement of contamination from one soil layer to another.
Geotechnical Probes	
Soil Sampler	Commercial probes to retrieve soil samples from discrete subsurface locations for further analysis
Geotechnical Sensor	Measures geotechnical properties to determine soil types (according to ASTM-D-3441-86), that can aid in well construction and remediation system design. NOTE: Attached to tip of other sensor probes
Moisture Probe	Quantifies soil moisture content and can aid in calculating hydraulic conductivity.
Pore Pressure Probe	Quantifies soil pore pressure for site hydraulic studies, such as direction and rate of groundwater flow and provides discrete values of relative hydraulic conductivity.
Liquid/Gas Sampler	Extracts liquid or gas samples from the subsurface for further analysis
Small Diameter Well Installation	Installs commercial, custom designed wells using direct push technology for access to groundwater.
Contaminant Probes	
Hydrocarbon Sensor System	Detects hydrocarbon contaminated soil real-time using solid state, laser induced fluorescence(LIF) technology. The LIF process has been accepted by US EPA, California EPA, and many state and local agencies.
Direct Sampling Ion Trap Mass Spectrometer (DS-ITMS)	VOCS are collected using several SCAPS sampling probes, which extract gases from the sample matrix and transport

	them through an appropriate transfer line into a direct capillary restrictor interface to the ion trap. Targeted compounds may be identified based on unique peaks in the electron impact and proton transfer chemical ionization mass spectra. Sample analysis takes 2 to 3 minutes. Using EPA method 8265 (conditional), the ITMS is capable of detecting most VOCs qualitatively and quantitatively in the low part per billion (ppb) range.
Hydrosparge/ITMS VOC Sensor	The Hydrosparge sampler removes gaseous volatiles from water in a temporary well for real-time analysis by an ion trap mass spectrometer A commercially available direct push groundwater sampler is used to make a temporary well. Groundwater enters and is allowed to come to equilibrium. Then the in situ sparge module is lowered into the well to purge VOC analytes from the groundwater using Helium gas.
Thermal Desorption Sampler	The probe collects a soil plug into a chamber where the soil is heated. A pneumatic system transports purged VOC compounds to the surface for analysis by an ITMS, or are collected onto traps for later analysis.
Vadose Sparge/ITMS Sensor	Measurements are made during probe retraction. A sacrificial sleeve is used to protect the sampling ports during the penetrometer push to the depth of interest, whereupon soil friction removes the sleeve when the probe is retracted. This creates a gap between the probe and the soil. A pneumatic system transports a carrier gas down through the probe where it is swept past the soil surface before the resultant vapors are drawn up to the ITMS in the truck.
Explosives Sensor	This probe uses electrochemical sensors that detect the presence of NO_x chemical compounds that are released by explosives. The NO_x sensors in the probe show a change in current that is proportional to the amount of explosive chemicals in the soil.
Laser Induced Breakdown Spectroscopy (LIBS)	The LIBS Sensor system focuses a high-power pulsed laser onto the surface of the soil to generate diagnostic plasma. Specific wavelengths of the light in the plasma correspond to specific metal elements present in the soil. The brightness of the light at a given wavelength indicates how much of that metal is present. LIBS can detect metals in the single ppm range.
X-ray Fluorescence (XRF)	Uses an electron tube to excite metal atoms in the soil. The XRF sensor detects the characteristic x-rays the metal atoms emit.
Spectral Gamma	The probe uses a NaI scintillation crystal to detect gamma radiation from radioactive waste directly in the ground. The spectral gamma results are analyzed to diagnose radionuclide identity and relative concentration.

Video Microscope System	Provides real-time video images of the subsurface. 100X magnification provides soil type information and displays DNAPL contaminants. The GeoVIS system, developed by the Navy, uses a miniature video camera coupled with magnification and focusing lens systems integrated into a cone penetrometer probe to obtain images of soil. The signal from the camera is sent to the surface where it can be viewed in real-time on a video monitor, recorded and/or digitized for further analysis. Objects as small as about 20 microns can be resolved. The present optics system provides approximately a 100x magnification factor when viewed on the standard 13-inch monitor.

Use of SCAPS probes can potentially save from 25% to more than 50% of traditional site characterization costs. Trucks are currently being operated on a fee basis by three Army Corps of Engineer Districts: Kansas City, Savannah and Tulsa. The Navy operates three trucks through their Public Works Centers, two based on the West Coast in San Diego, CA and one on the East Coast at Norfolk, VA. In addition, the Navy and the Army Corps of Engineers each maintain fully equipped research SCAPS vehicles. The Department of Energy owns one truck that is operated for the DOE at their sites by commercial contractors.

The primary goal of SCAPS site demonstrations is to show the efficiency and accuracy of SCAPS sensors and samplers. Another very important objective has been to facilitate technology transfer by partnering with other Tri-Service users and with project managers who are interested in using innovative methods to characterize their sites. The U.S. Army Engineer SCAPS Districts, the Navy SCAPS, the DOE and various site manager personnel have participated in the demonstration and use of new probes.

Table 2 presents a list of the sites at which SCAPS probes were demonstrated during the development programs. Table 3 lists facilities that have contracted for SCAPS probes to perform site characterization work. Papers and reports that summarize several of the site investigations may be found in Section VII, Bibliography.

TABLE 2. LIST OF SITE LOCATIONS USED FOR SCAPS DEMONSTRATION OF DEVELOPMENTAL PROBES

LIF POL Sensor	DOE Pantex, Texas Sierra Army Depot, California Fort Dix, New Jersey Jacksonville Naval Air Station, Florida Philadelphia Naval Shipyard, Pennsylvania, DOE Savannah River Site, South Carolina Building 4020 Site, Aberdeen Proving Ground, Maryland Walnut Creek Watershed, Ames, Iowa Grandville, Michigan Superfund Site Rhein Main Air Base, Germany
Hydrosparge Sensor, RCI/VOC Electrochemical Sensor and Thermal Desorption Sampler	Aberdeen Proving Ground (APG), Maryland: Building 525 Bush River Area U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), New Hampshire McClellan Air Force Base, California Vance Air Force Base, Oklahoma (Hydrosparge only) Yuma Proving Ground, Arizona (Hydrosparge only) Ft. Dix, New Jersey North Island Naval Air Station, California Longhorn Army Ammunition Plant, Texas Joliet Army Ammunition Plant, Illinois (TDS only) Lake City Army Ammunition Plant, Missouri (TDS only)
Explosives Sensor	Volunteer Army Ammunition Plant, Tennessee Longhorn Army Ammunition Plant, Texas Joliet Army Ammunition Plant, Illinois DOE Pantex, Texas
Laser Induced Breakdown Spectroscopy Sensors	Keesler Air Force Base, Mississippi Joliet Army Ammunition Plant, Illinois Lake City Army Ammunition Plant, Missouri North Island Naval Air Station, California
X-ray Fluorescence Sensor	Waterways Experiment Station, Mississippi J-Field, Edgewood Area, Aberdeen Proving Ground, Maryland Joliet Army Ammunition Plant, Illinois (2x) Lake City Army Ammunition Plant, Missouri North Island Naval Air Station, California

TABLE 3. CONTRACTED SCAPS SITE CHARACTERIZATION WORK LOCATIONS

LIF POL Sensor	Camp Pendleton, CA FISC Fuel Farm, Point Loma, CA Fort Campbell Army Airfield, KY Fort Dix, NJ Long Beach Naval Complex, CA Fort Meade, MD Former Turner Air Force Base, GA Travis Air Force Base, CA Naval Exchange Service Station, San Diego, CA Norfolk Naval Shipyard, VA Naval Construction Batallion Center, Port Hueneme, CA Naval/Marine Corps Reserve Center UST, San Jose, CA Jacksonville Naval Air Station, FL Philadelphia Naval Shipyard, PA
Hydrosparge Sensor	Former Donaldson Air Force Base, SC McClellan Air Force Base, CA Massachusetts Military Reservation, MA Vance Air Force Base, OK Yuma Proving Ground, AZ Ft. Dix, NJ North Island Naval Air Station, CA Lake City Army Ammunition Plant, MO Whiting Field Naval Air Station, FL
Spectral Gamma Sensor	DOE Savannah River Site, SC
XRF Metals Sensor	Travis Air Force Base, CA

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III. THE SCAPS TRUCK

1. Truck and Push Platform

The core of SCAPS is a 20-ton truck-mounted cone penetrometer platform that is used to deploy chemical and physical sensors, and soil or water samplers (See Figure 1). SCAPS may also be used to install small, direct push monitoring wells. Hydraulic lift rams at the front and rear of the truck are used to level the truck over the push location. The truck bed supports two separate, enclosed work compartments that are monitored for air quality and temperature. The "push room" contains rods threaded with umbilical cable and a vertical hydraulic ram that forces the cone penetrometer into the ground at a controlled rate. The standard speed is 2 cms^{-1}. In nominally consolidated soil, a probe can be pushed to a depth of 50 m below the ground surface. It is standard procedure to collect and record data every 2 cm, although some probes may be operated continuously.

A pressure steam cleaner is fixed outside the truck below the push room. Rods are cleaned as they are retracted, producing a minimal amount of decontamination water at each site. This means there is significant reduction of investigation-derived wastes from SCAPS as compared to conventional drilling and sampling operations.

The SCAPS data acquisition room contains real-time data acquisition, processing and storage computers. It also provides bench space for a spectrometer or other peripheral equipment, an universal power supply (UPS), and a post-processing computer system for 3-dimensional visualization of subsurface soil stratigraphy and contaminant plumes.

Figure 1. The SCAPS truck and grout trailer. The push room is adjacent to the cab and the data room is at the rear. This shows the truck leveled by the hydraulic rams at the front and rear of the truck.

2. Grouting Capabilities

The SCAPS penetrometer leaves a very narrow hole in the ground after the sensors/samplers are removed from the push location. Although it is small (diameter < 2 in.), it is an avenue for cross contamination of subsurface layers and groundwater aquifers. It is a standard to seal penetrometer holes at the end of a push to minimize the potential for migration of contaminants. Grout is injected into the hole through the probe tip as the probe is pulled from the ground. As the penetrometer rods are brought up to the surface, a mixture of Portland cement, bentonite clay, and water is pumped through an internal tube down to the bottom rod. The pressure of the liquid blows an expendable tip off the tip of the probe, and the grout flows into the cavity, sealing the hole. Open holes may also be filled with grout poured from the surface.

IV. SITE CHARACTERIZATION AND ANALYSIS PROBES

SCAPS probes usually incorporate geophysical sensors (tip resistance and sleeve friction sensors) for determining soil classifications/layering. The probe collects soil classification versus depth and contaminant concentration versus depth information while the sensor gathers contaminant data. Soil classification is displayed continuously during a push.

1. Petroleum, Oils and Lubricants: The Laser Induced Fluorescence (LIF) Sensor

The Tri-Service SCAPS LIF Sensor can delineate the extent of subsurface petroleum, oils, and lubricants (POL) contamination, as well as map subsurface stratigraphy, more accurately and less expensively than widely spaced monitoring wells and soil borings. The LIF Sensor uses an ultra-violet laser to induce fluorescence in subsurface POL contamination (See Figure 2). Using a fiber optic cable, the UV-laser energy is transmitted from the surface down an umbilical, through a sapphire window located on the side of the probe, and is emitted into the surrounding soil. The POL contaminants become excited and emit fluorescent energy that is carried by another fiber optic cable back up to the truck where it is analyzed in real time. This process is continuous, gathering data as the probe is steadily pushed through the subsurface media.

The SCAPS LIF has obtained numerous evaluations and certifications through state and federal regulatory agencies, including the U.S. Environmental Protection Agency (USEPA) Superfund Innovative Technology Evaluation (SITE) Program, the EPA Consortium for Site Characterization Technology (CSCT), the California EPA Innovative Environmental Technology Certification Program, and the Interstate Technology Regulatory Cooperation (ITRC) Workgroup. A cost/benefit analysis conducted by DOE (DOE report no. LA-UR-91-4016) indicates that at least 25 to 35 percent cost avoidance can be realized with the SCAPS LIF technology, although recent practices have generated savings in excess of 50%. The patented Tri-Service SCAPS LIF Sensor is licensed, commercially available, and is used worldwide.

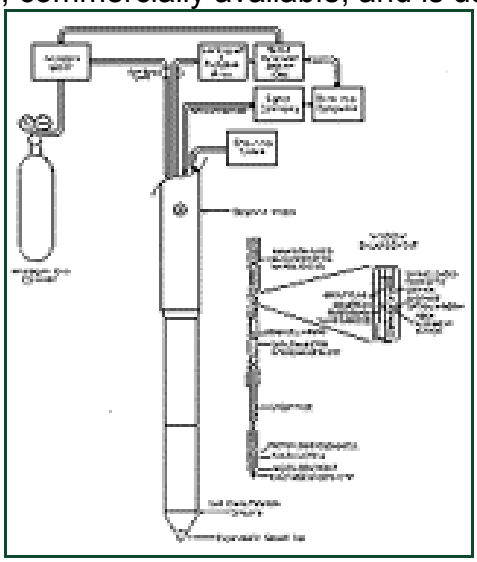

Figure 2. Schematic of the LIF sampler.

2. Volatile Organic Compounds Sensing Tools

The basis for the very successful application of SCAPS probes for sensing Volatile Organic Compounds (VOCs) in soils is due to the use of Direct Sampling Ion Trap Mass Spectrometry (DSITMS). These probes work by bringing a sample of gas from soil or groundwater through a transport line to the DSITMS for analysis in the truck. Sample analysis takes 2 to 3 minutes and detection limits are typically in the range of 1 ppb or less. The ITMS field methodolgy (Method 8265) has been conditionally approved by the EPA.

A. Thermal Desorption Sampler (TDS)

The operation of the Thermal Desorp-tion VOC Sampler is based on the capture of a known volume of soil (See Figure 3). The TDS is pushed to the desired ground depth and an interior rod retracts the penetrometer tip. The probe is then pushed further into the soil, collecting a 5 gm soil plug in the sample chamber. The soil plug is heated, releasing the VOC gases from the soil. The vapors are drawn to the surface by an inert carrier gas, where they are trapped on an adsorbent media. The trap is then thermally desorbed into an onboard, field portable ITMS where the contaminants are analyzed in near-real time.

The soil plug is then expelled from the sample chamber. The sample chamber is heated and purged to remove any residual contamination before the process is repeated at multiple depths during a single push. Upon completion of the push, grout is used to seal the penetrometer hole upon retraction.

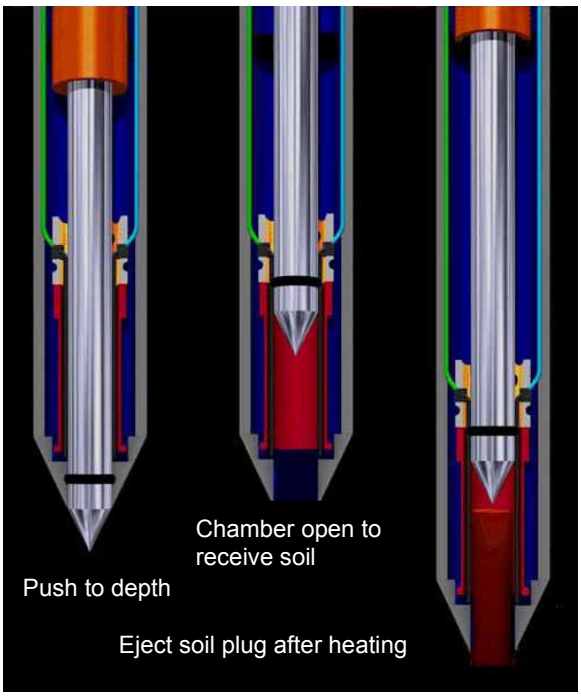

Figure 3. Schematic of the TDS sampler.

B. Hydrosparge Sensor

The Hydrosparge VOC Sensor uses a commercially available Hydropunch™ or Powerpunch™ direct push groundwater sampling tool to access the groundwater. The Hydropunch™ sampler is pushed to the desired depth and the push pipes are retracted, exposing the screen to the groundwater. The water level is then allowed to come to equilibrium, which generally takes less than 15 to 20 minutes.

The in situ sparge module (See Figure 4), developed by Oak Ridge National Laboratory, is then lowered into the well to operates about 18 inches below the surface. The sparge module purges the VOC analytes in situ from the groundwater using Helium gas. The volatiles sparged out of the water are transported to an ITMS in the truck, where the contaminants are analyzed in real-time. When the in situ sparge module is interfaced with a mass flow meter, data may be acquired at various depths, ultimately producing a depth profile of the contaminant(s).

The reliability of in situ, direct sparging of VOC analytes from groundwater in concert with the ITMS has been successfully demonstrated at numerous sites where it has provided cost savings of at least 40% over conventional methods. The technology is currently being evaluated by the California Environmental Protection Agency Innovative Environmental Technology Certification Program and the U.S. EPA Office of Hazardous Waste.

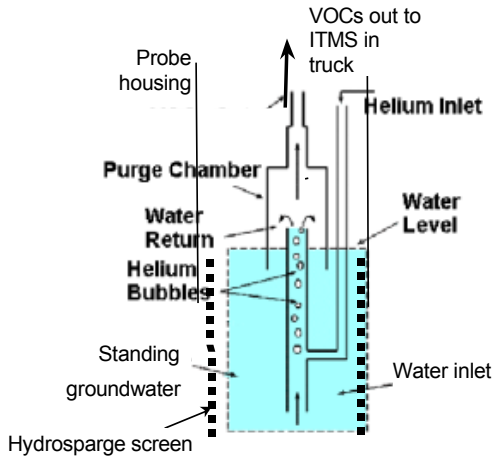

Figure 4. Schematic of the in situ sparge module.

C. Vadose Sparge Sensor

The SCAPS vadose sparge sensor is a soil vapor probe that is deployed in conjunction with a DSITMS in the truck. This probe evolved from a probe that was designed for detecting chlorinated solvents by an electrochemical cell after the manufacturer of the cell discontinued its production.

The Vadose Sparge Sensor consists of a standard geophysical cone module and a sacrificial sleeve that protects vapor delivery and sampling port openings in the probe during a downward push. Data are taken during probe retraction. The sleeve falls off when the probe is pulled from the ground. A pumping system pushes air from the surface to ports at the bottom of the sampling module, and then outward from the probe. The air sweeps over a cylindrical soil surface area around the probe that corresponds to an area ~4 in. long by 1.75 in diameter. Soil vapors are transferred to the purge gas and then captured by four intake valves. Vapors are delivered through the purge-gas tubing to an in situ sparge inlet for input to a DS-ITMS. In situ soil vapor measurements made with this sensor correlate well with contaminant concentrations of conventional soil samples measured by gas chromatography/mass spectrometry.

3. Explosives Sensing

Site characterization of explosives-contaminated sites is frequently difficult, with physical sampling very costly since the distribution of these contaminants can be extremely heterogeneous. Cone penetrometry offers cost relief and time savings. The SCAPS Explosives Sensor was designed to contain electrochemical sensors for nitroaromatic breakdown products and geophysical sensors for determining soil layering. The increase in current output of the sensor electrode is directly related to the concentration of the explosive in the soil. The design uses an imbedded heating element that is isolated from direct contact with the soil. When the soil is warmed briefly, explosive compounds vaporize and decompose into nitrogen-containing gaseous products. Then the evolved gases are drawn by a pneumatic system through an internal vapor sweep gas stream into the probe, and detected using an NO sensor in concert with a CO sensor. This duo permits discrimination of explosive organic nitrogen compounds from inorganic nitrogen compounds such as fertilizers.

The safety of this probe was evaluated by an independent contractor. GES Allegany Ballistics Laboratory SCAPS Explosives Hazard Analysis report concludes that "SCAPS Explosives probe operation offers occasional marginal or remote marginal probability of risk associated with the evaluation of explosives-contaminated soils."

4. Metals Sensing

A. Laser Induced Breakdown Spectroscopy (LIBS) Sensors

These sensors are used to detect and identify heavy metal contaminants in the unsaturated and capillary zones. LIBS uses a high-power pulsed laser to generate a diagnostic plasma from soil. Two LIBS sensor probes have been developed, one by the Navy that is configured with the laser in the SCAPS truck (See Figure 6) and one by the Army Engineers (See Figure 5) that uses a miniaturized laser in the probe. The output of the laser beam is focused on the surface of the soil. This causes a breakdown of the soil and contaminants that results in the formation of a high temperature plasma spark that emits light for a brief time. A spectrometer breaks this light into its constituent colors, much like the action of a prism. The wavelengths of light in the plasma correspond to specific metal elements and the brightness of the light at a given wavelength indicates how much of that metal is present. LIBS can detect metals in the single ppm range.

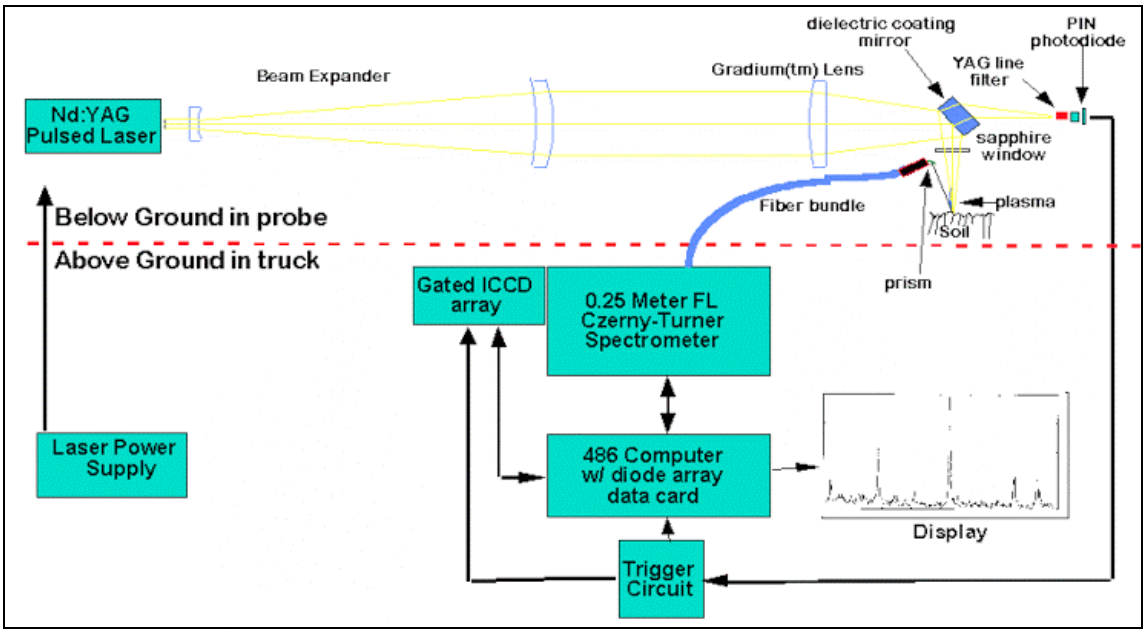

Figure 5. The SCAPS DL-LIBS (Downhole Laser) system.

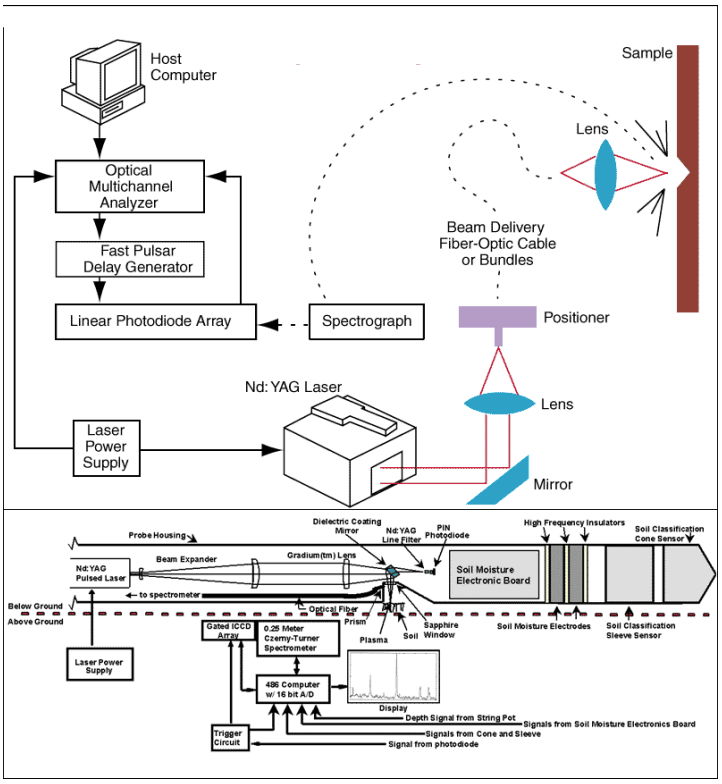

Figure 6. SCAPS FO-LIBS (Fiber Optic) probe schematic that shows that the laser operates from the SCAPS truck through a fiber optic cable

B. X-Ray Fluorescence (XRF) Sensor

The SCAPS XRF Metals Sensor can detect metal elements at levels below 100 ppm in both the saturated and unsaturated zones. This probe can detect elements higher than atomic number 20, calcium, including radioactive elements. XRF technology is a well-established, non-destructive laboratory and hand-held field screening method for determining elemental concentrations at ppm levels in complex samples

The SCAPS XRF Metals Sensor operates by detecting the characteristic x-ray emitted by metal atoms in the soil (See Figure 7). The sensor is advanced to a selected sampling depth at which point an x-ray source in the probe tip bombards the surrounding soil with incident x-rays. Metal atoms present in the soil are excited and emit fluorescent x-rays with energy that is characteristic for specific elements. The emitted x-rays are detected at the probe tip and provide an individual peak for each type of metal present in the soil. These signatures are identified and quantified in real time on board the SCAPS truck.

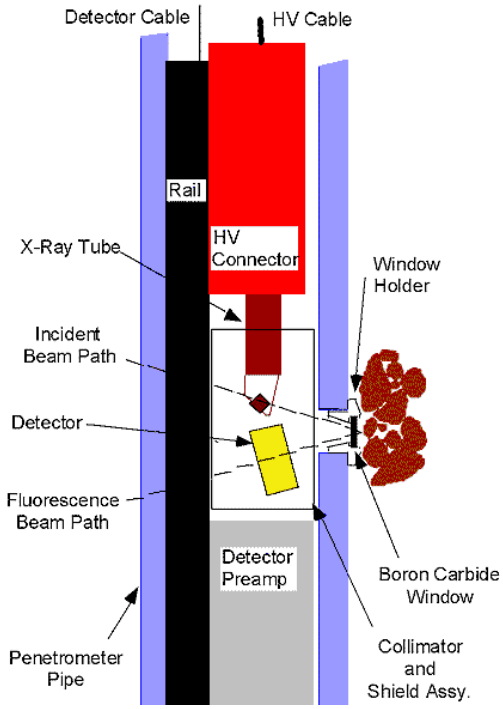

Figure 7. Schematic of the XRF probe optics.

5. Radionuclides

A. Spectral Gamma Probe

The SCAPS spectral gamma probe was developed for rapid, cost-effective site characterization of radionuclide contaminated soils with funding from SERDP and the Department of Energy.

The spectral gamma probe consists of a temperature-monitored sodium iodide (NaI) detector and a custom designed preamplifier installed downhole in the penetrometer tip. Power supplies and state-of-the-art support electronics located in the truck are connected through an umbilical cable to the downhole sensors. This sensor was designed with a view toward sensitivity, ruggedness and low cost in light of the possibility that the probe could become contaminated by radiation and need to be properly disposed. The use of this probe at highly contaminated sites may necessitate the use of specialized radiological-control area equipment in addition to the usual protection provided by SCAPS truck operations. This can be accomplished by using a "tent" inside the push room in the truck and placing a self-contained decontamination unit under the truck for the probe to push through in order to isolate personnel from possible radioactive contamination.

Figure 8. The spectral gamma probe in use at the DOE Savannah River Site.

The probe was first used at the Savannah River Site R-reactor basin area during the summer of 1997 (See Figure 8). The SRS site consists of a filled basin area that was covered with asphalt paving in order to isolate the ~2700 Ci of mixed radioactive waste that was discharged into Basin 1 in the late 1950s. An independent assessment of cost savings realized by using the SCAPS spectral gamma probe at the Savannah River Site was estimated to have saved in excess of $800,000 (equal to 56% of the cost) in these operations.

B. Multisensor Probe

The development of the sensors that allowed this probe to be made was supported by the SERDP, although the construction of this multisensor device was funded by the DOE. The Multisensor probe combines the XRF metals sensor and the spectral gamma sensor in a single probe housing.

V. TECHNOLOGY TRANSFER

The Army Environmental Center uses multiple approaches to present and promote the use of SCAPS by public and private sector users. These include oral and poster presentations at national environmental meetings, brochures, and maintenance of a web site and articles in environmental newsletters. In addition to the formalized tech transfer routes of certification, patent application, electronic and print publications, networking among SCAPS development scientists, engineers and users also proved to be especially effective and beneficial to the overall program. Networking was fostered in several ways, such as biannual SCAPS users' meetings and use of the Navy and Army SCAPS crews and trucks for probe development fieldwork whenever possible. These interactions continue today.

As mentioned previously, one very important objective of the SCAPS programs has been to facilitate technology transfer by partnering with other Tri-Service users and with project managers who are interested in using innovative methods to characterize their sites. Ten different U.S. Government agencies have participated in the growth of SCAPS technology. Furthermore, engineers and scientists from many other organizations such as universities and private contractors participated in the development, test and evaluation of SCAPS probes.

The Army has transitioned three SCAPS trucks to the U.S. Army Corps of Engineers to characterize Army and Air Force sites. In addition, one truck is maintained by the U.S. Army Engineering Research and Development Center Environmental Laboratory (formerly Waterways Experiment Station) for research work. The Navy operates three trucks to characterize its sites. The Department of Energy commissioned one truck from the Army that is operated for the DOE by commercial contractors.

1. Points of Contact

U.S. Army

Army Environmental Center http://aec.army.mil
Army Environmental Hotline 1-800-USA-3845

Army Corps of Engineers
Waterways Experiment Station (WES) http://www.wes.army.mil/el/
Mr. John Ballard
BALLARJ1@wes.army.mil

Army Corps of Engineers Kansas City District http://www.nwk.usace.army.mil/
Ms. Kathy Older
816/426-3554
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Army Corps of Engineers Savannah District http://www.sas.usace.army.mil/
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Army Corps of Engineers Tulsa District http://www.swt.usace.army.mil/
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U.S. Navy

Naval Facilities Engineering Service Center (NFESC) http://www.nfesc.navy.mil/
Mr. Dennis How, P.E.
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2. Patents

Eleven patents have been awarded and four patent applications are still active. All are listed in Section VII, Bibliography.

3. Licenses

SCAPS probe technology has been offered for license to the private sector. The Laser Induced Fluorescence (LIF) probe was licensed to both Hogentogler and Applied Research Associates (ARA). Hogentogler subsequently sold their license to Fugro. The LIF technology is currently recognized as the most reliable in the industry. Licensing of other SCAPS probe technologies is currently being pursued.

4. Publications, Presentations and Electronic Information

Approximately 100 technical papers were published during the course of this program, including an overview of all successful systems in Field Analytical Chemistry and Technology, Volume 2(2), 1998. Publications are listed in Section VII, Bibliography.

The AEC established a SCAPS web site early in the program. They also maintain the U.S. Army Environmental Hotline which can be accessed by telephone or e-mail. Numerous other Internet sites are maintained by SCAPS developers and operators and are listed in the Bibliography in section VII. The main sites are:

- U.S. Army Environmental Center - http://aec.army.mil
  Email: t2hotline@aec.apgea.army.mil
  Hotline: 1-800-USA-3845

U.S. Army Waterways Experiment Station - http://www.wes.army.mil

U.S. Navy - http://www.nfesc.navy.mil/enviro/ps/scaps/scaps.htm

Strategic Environmental Research and Development Program (SERDP) - http://www.serdp.com

Environmental Security Technology Certification Program (ESTCP), "Tri-Service SCAPS Demonstration/Validation Programs," - http://www.estcp.com

5. Certification and Regulatory Acceptance

The pursuit of regulatory acceptance was an initial program goal despite the fact that no previous model for the process was available on which to build. The SCAPS program has had phenomenal success in gaining regulatory approval and now serves as a model for other Department of Defense new technology programs. The effort began with the Laser Induced Fluorescence (LIF) sensor in the Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program. From there, the LIF entered the EPA Consortium for Site Characterization Technology (CSCT) and Interstate Technology Regulatory Cooperation Workgroup (ITRC), formerly the WGA-ITRC. A standard practice for the American Society of Testing and Materials (ASTM) for the LIF has been accepted and given the designation D-6187-97.

A. Certifications and Evaluations for the Laser-Induced Fluorescence (LIF) Sensor:

U.S. EPA Superfund Innovative Technology Evaluation (SITE) Program:

The EPA's Monitoring and Measurement Technologies Program (MMTP) selected cone penetrometer sensors as a technology class to be evaluated under the SITE Program. Based on the evaluation, the SCAPS LIF Sensor was described as being capable of being able to provide rapid and reliable maps of the relative magnitude of the vertical and horizontal extent of subsurface petroleum contamination.

U.S. EPA Consortium for Site Characterization Technology (CSCT):

The CSCT has established a formal program to accelerate acceptance and application of innovative monitoring and site characterization technologies that improve the way the nation manages its environmental problems. The SCAPS LIF Sensor was evaluated under this program and was found to provide real-time field screening of subsurface physical characteristics and petroleum contamination.

California EPA Innovative Environmental Technology Certification Program (Cal/Cert):

The California Hazardous Waste Environmental Technology Certification Program (Cal/Cert program) is an innovative environmental technology certification program through the California EPA. The Cal/Cert program is intended to evaluate the effectiveness and reliability of environmental technologies through an extensive technical/data review. This certification can be used to support marketing of the environmental technology throughout the United States and abroad. The Cal/Cert program issued certification for the use of the SCAPS LIF Sensor in the state of California.

Interstate Technology and Regulatory Cooperation (ITRC) Working Group:

The Interstate Technology and Regulatory Cooperation (ITRC) Working Group is a federal and state advisory committee primarily funded by DOE/EPA. Its purpose is to facilitate state reciprocity of innovative environmental technologies by building on Cal/Cert results. The ITRC enables the formation of national/regional partnerships and interstate verification standards that use innovative technologies to stimulate competitive, cost-effective solutions to environmental protection, restoration, and conservation problems.

The Cone Penetrometer Site Characterization Technology Task Group was established under ITRC to facilitate interstate acceptance of the SCAPS Laser Induced-Fluorescence (LIF) Sensor. The Task Group's participation in the review of SCAPS protocol, demonstration evaluations, and the California verification process resulted in formal endorsement of the technology by 7 states: California, New Jersey, Idaho, Utah, Louisiana, Nebraska, and New Mexico.

American Society for Testing and Materials (ASTM)

ASTM is an internationally recognized organization that develops and provides standards, related technical information, quality-assurance programs and training. Standards are developed that contribute to the reliability of materials, products, systems and services; that promote public health and safety, and the overall quality of life; and facilitate national, regional, and international commerce. A standard is a document that has been developed and established with the cooperation, input and consensus from all technically competent, concerned individuals from industry, government and academia. ASTM standards are expected to have the highest credibility when examined and used as the basis for commercial, legal, or regulatory actions.

The SCAPS LIF procedure was drafted in 1996 and was balloted as approved in April 1997 by subcommittee D.18.21. The draft standard practice was forwarded to D.18, the main Committee on Soil and Rock, and was approved by ~700 reviewers. The ASTM accepted the practice as a standard in October 1997, and designated it number D6187-97.

B. Certifications and Evaluations for the VOC Sensors:

Regulatory acceptance for the Hydrosparge Sensor and Thermal Desorption Sampler is being sought on state and federal levels, as well as in the private sector. The technologies have been submitted for certification with Cal/Cert and ITRC on state and federal levels and are expected to be endorsed soon. ASTM methods for these technologies have been initiated and a strong interest in licensing has been expressed by the leading commercial cone penetrometer service organizations.

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VI. ECONOMIC BENEFITS OF SCAPS

Use of SCAPS sensors and samplers to first screen a site can result in cost savings of 30 to more than 60%. Savings are due to a reduction of monitoring wells required because well locations can be optimized, saving on equipment, labor and industrial-derived wastes. Further savings will be realized because laboratory analyses are only performed on useful samples. CPT characterization of site geology is an ASTM accepted method. CPT-based site characterization can examine from 5 to15+ times more locations than can standard cable tool core holes. Further savings are gained due to the lack of waste from soil cuttings.

An effort at the Naval Air Station North Island, Coronado, California (NASNI) installed 70 conventional wells as part of an aggressive characterization and contaminant removal project from 1990 to 1997. The presence of chlorinated hydrocarbons was detected in 1997 and it was determined the site required additional characterization. The Navy project managers wished to use more innovative characterization methods after noting the excessive time required to characterize the site using conventional groundwater monitoring wells, so they asked to have the Hydrosparge VOC sensor demonstrated at NASNI. It took 22 days using the Hydrosparge VOC sensor to determine the extent of the shallow chlorinated hydrocarbon plume. Eight groundwater monitoring wells were installed after the investigation was completed to confirm the findings. When the well results were compared with the Hydrosparge results, the site mangers concluded A...downgradient confirmation wells confirmed that the horizontal extent of the TCE plume above 40 feet bgs (below ground surface) had been fully characterized.@ Table 4 presents a comparison of the advantages of using SCAPS over conventional monitoring wells.

TABLE 4. COMPARISON OF SITE CHARACTERIZATION OF NAVAL AIR STATION NORTH ISLAND BY CONVENTIONAL GROUNDWATER MONITORING WELLS VS. HYDROSPARGE VOC SENSOR.

Category	Monitoring Wells	Hydrosparge VOC Sensor
Duration of Effort	8 years	22 days
Number of Locations	70	50
Number of Sample Collection Locations	70	130
Volumetric Sample Density	$6x10^{-6}$ per cubic feet	$1.7x10^{-6}$ per cubic feet
Vertical Sample Density	0.1 sample/sample interval	0.2 sample/sample interval
Cost of Installation	$138,721*	Included in Total
Cost of Analysis	$67,200*	Included in Total
Volume of IDW	140 drums*	10 drums
Total	$205,921	$129,000

* estimated amounts

The DOE promotes use of CPT in radiological areas because of the fact that it will reduce worker exposure, time, and cost. Use of the spectral gamma probe resulted in savings of nearly 60% at the DOE Savannah River Site in 1997. This market niche is in its infancy but has great potential. (http://www.em.doe.gov/cgi-bin/parse/plumesfa/intech/conepen/cost.html)

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