♦EPA

Environmental Technology Verification Report

Soil Sampling Technology

Art's Manufacturing and Supply AMS Dual Tube Liner Sampler

SITE

Environmental Technology Verification Report

Soil Sampler

Art's Manufacturing and Supply AMS™ Dual Tube Liner Sampler

Prepared by

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Contract No. 68-C5-0037

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ETV

Notice

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, D.C. 20460

ET✓

ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM
VERIFICATION STATEMENT

TECHNOLOGY TYPE:	**SOIL SAMPLER**
APPLICATION:	**SUBSURFACE SOIL SAMPLING**
TECHNOLOGY NAME:	**AMS™ DUAL TUBE LINER SAMPLER**
COMPANY: ADDRESS:	**ART'S MANUFACTURING AND SUPPLY 105 HARRISON STREET AMERICAN FALLS, INDIANA 83211**
PHONE:	**(800) 635-7330**

ETV PROGRAM DESCRIPTION

The U.S. Environmental Protection Agency (EPA) created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. The ETV Program is intended to assist and inform those involved in the design, distribution, permitting, and purchase of environmental technologies. This document summarizes the results of a demonstration of the AMS™ Dual Tube Liner Sampler.

PROGRAM OPERATION

Under the ETV Program and with the full participation of the technology developer, the EPA evaluates the performance of innovative technologies by developing demonstration plans, conducting field tests, collecting and analyzing demonstration data, and preparing reports. The technologies are evaluated under rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the demonstration results are defensible. The EPA's National Exposure Research Laboratory, which demonstrates field characterization and monitoring technologies, selected Tetra Tech EM Inc. as the verification organization to assist in field testing various soil and soil gas sampling technologies. This demonstration was conducted under the EPA's Superfund Innovative Technology Evaluation Program.

DEMONSTRATION DESCRIPTION

In May and June 1997, the EPA conducted a field test of the AMS™ Dual Tube Liner Sampler along with three other soil and two soil gas sampling technologies. This verification statement focuses on the AMS™ Dual Tube Liner Sampler; similar statements have been prepared for each of the other technologies. The performance of the Dual Tube Liner Sampler was compared to a reference subsurface soil sampling method (hollow-stem auger drilling and split-spoon sampling) in terms of the following parameters: (1) sample recovery, (2) volatile organic compound (VOC) concentrations in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost. Data quality indicators for precision, accuracy, representativeness, completeness, and comparability were also assessed against project-specific QA objectives to ensure the usefulness of the data.

The Dual Tube Liner Sampler was demonstrated at two sites: the Small Business Administration (SBA) site in Albert City, Iowa, and the Chemical Sales Company (CSC) site in Denver, Colorado. These sites were chosen because of the wide range of VOC concentrations detected at the sites and because each has a distinct soil type. The VOCs

detected at the sites include cis-1,2-dichloroethene (cis-1,2-DCE); 1,1,1-trichloroethane (1,1,1-TCA); trichloroethene (TCE); and tetrachloroethene (PCE). Soils at the SBA site are composed primarily of clay, and soils at the CSC site are composed primarily of medium- to fine-grained sand. A complete description of the demonstration, including a data summary and discussion of results, is available in a report titled *Environmental Technology Verification Report: Soil Sampler, Art's Manufacturing and Supply, AMS*^{TM} *Dual Tube Liner Sampler*, EPA 600/R-98/093.

TECHNOLOGY DESCRIPTION

The Dual Tube Liner Sampler was designed to collect subsurface soil samples by using direct-push platform technology. The sampler assembly is constructed of two steel tubes, or "extensions," of differing diameters designed so that the smaller of the two tubes fits within the larger. The outer extension is available in two diameters, 2-1/8-inch outside diameter (o.d.) and 1-3/4-inch o.d., and is equipped with a metal drive tip at the lower end. The outer extension is threaded at the upper end to facilitate additional metal extensions with increasing depth and the addition of a drive head adaptor to the top of the tool string. The inner extension is also available in two diameters, 1-3/4-inch o.d. and 1-1/8-inch o.d., to match the selected outer extension diameter. The lower end of the inner extension is threaded with a plastic grabber to facilitate the attachment of a polybutyrate liner during sample collection or a solid point metal inner drive tip during sampler advancement. The components of the sampler are assembled such that the outer extension serves as a temporary casing so that continuous or discrete soil samples can be collected using the inner extension liner and drive tip assemblies.

VERIFICATION OF PERFORMANCE

The demonstration data indicate the following performance characteristics for the AMS^{TM} Dual Tube Liner Sampler:

Sample Recovery: For the purposes of this demonstration, sample recovery was defined as the ratio of the length of recovered sample to the length of sampler advancement. Sample recoveries from 42 samples collected at the SBA site ranged from 42 to 100 percent, with an average sample recovery of 91 percent. Sample recoveries from 42 samples collected at the CSC site ranged from 46 to 88 percent, with an average sample recovery of 70 percent. Using the reference method, sample recoveries from 41 samples collected at the SBA site ranged from 40 to 100 percent, with an average recovery of 88 percent. Sample recoveries from the 42 samples collected at the CSC site ranged from 53 to 100 percent, with an average recovery of 87 percent. A comparison of recovery data from the Dual Tube Liner Sampler and the reference sampler indicates that the Dual Tube Liner Sampler achieved higher recoveries in the clay soil at the SBA site and lower sample recoveries in the sandy soil at the CSC site relative to the sample recoveries achieved by the reference sampling method.

Volatile Organic Compound Concentrations: Soil samples collected using the Dual Tube Liner Sampler and the reference sampling method at six sampling depths in nine grids (five at the SBA site and four at the CSC site) were analyzed for VOCs. For 21 of the 25 Dual Tube Liner Sampler and reference sampling method pairs (12 at the SBA site and 13 at the CSC site), a statistical analysis using the Mann-Whitney test indicated no significant statistical difference at the 95 percent confidence level between the VOC concentrations in samples collected with the Dual Tube Liner Sampler and those collected with the reference sampling method. Of the sample pairs where a statistically significant difference was identified, one was at the SBA site and three were at the CSC site. Analysis of the CSC site data, using the sign test, indicated no statistical difference between data obtained by the Dual Tube Liner Sampler and the reference method at the CSC and SBA sites.

Sample Integrity: A total of 12 integrity samples were collected with both sampling methods at each site to determine if potting soil in sampler interiors became contaminated after it was advanced through a zone of high VOC concentrations. For the Dual Tube Liner Sampler, VOCs were detected in only one of the 12 integrity samples. The sample was collected at the CSC site. The VOC detected in the potting soil at the CSC site was cis-1,2-DCE at a concentration of 6.07 micrograms per kilogram (μg/kg). These results indicate that the integrity of a lined chamber in the Dual Tube Liner Sampler is generally well preserved when the sampler is advanced through highly contaminated soils. Results of sample integrity tests for the reference sampling method indicate no contamination in the potting soil after advancement through a zone of high VOC concentrations. Because potting soil has an organic carbon content many times greater than typical soils, the integrity tests represent a worst-case scenario for VOC absorbance and may not be representative of cross-contamination under normal field conditions.

Reliability and Throughput: At the SBA site, the Dual Tube Liner Sampler collected a sample from the desired depth on the initial attempt 98 percent of the time. Sample collection in the initial push was also achieved 98 percent of the time at the CSC site. At the SBA site, the Dual Tube Liner Sampler did not collect a sample in the initial push in only one instance. The sample liner was lost during that attempt due to overfilling. The sample was retrieved on the second attempt, resulting in 100 percent sample completeness. At the CSC site, the Dual Tube Liner Sampler did not collect a sample in the initial push in only one instance. The sample was lost when unconsolidated sand fell from the bottom of the liner. The problem was corrected by fashioning retaining baskets out of liner caps and the sample was collected on the subsequent push, resulting in 100 percent sample completeness. One sample was collected in the saturated zone at Grid 5 at the CSC site in one attempt, resulting in an initial sampling success rate of 100 percent. The developer did not attempt to collect additional samples from the 40-foot interval due to excessive friction on the outer extension. For the reference sampling method, the initial sampling success rates at the SBA and CSC sites were 90 and 95 percent, respectively. Success rates for the reference sampling method were less than 100 percent due to (1) drilling beyond the target sampling depth, (2) insufficient sample recovery, or (3) auger refusal. The average sample retrieval time for the Dual Tube Liner Sampler to set up on a sampling point, collect the specified sample, grout the hole, decontaminate the sampler, and move to a new sampling location was 16.4 minutes per sample at the SBA site and 10.9 minutes per sample at the CSC site. For the reference sampling method, the average sample retrieval time at the SBA and CSC sites were 26 and 8.4 minutes per sample, respectively. Two people collected soil samples with the Dual Tube Soil Sampler at both the SBA and CSC sites, and a three-person sampling crew collected soil samples using the reference sampling method at both sites. Additional personnel were present at both sites to observe and assist with demonstration sampling, as necessary.

Cost: Based on the demonstration results and information provided by the vendor, the Dual Tube Liner Sampler can be purchased for $1,890 and the PowerProbe 9600 direct push rig rented for $1,800 per week. Operating costs for the Dual Tube Liner Sampler ranged from $2,280 to $4,260 at the clay soil site and $1,830 to $3,060 at the sandy soil site. For this demonstration, reference sampling was procured at a lump sum of $13,400 for the clay soil site and $7,700 for the sandy soil site. Oversight costs for the reference sampling ranged from $4,230 to $6,510 at the clay soil site and $1,230 to $2,060 at the sandy soil site. A site-specific cost analysis is recommended before selecting a subsurface soil sampling method.

A qualitative performance assessment of the AMS[TM] Dual Tube Liner Sampler indicated that (1) the sampler is easy to use and requires less than 1 hour of training to operate; (2) logistical requirements are similar to those of the reference sampling method; (3) sample handling is similar to the reference method; (4) the performance range is primarily a function of the advancement platform; and (5) no drill cuttings are generated when using the Dual Tube Liner Sampler with a push platform.

The demonstration results indicate that the Dual Tube Liner Sampler can provide useful, cost-effective samples for environmental problem-solving. However, in some cases, VOC data collected using the Dual Tube Liner Sampler may be statistically different from VOC data collected using the reference sampling method. As with any technology selection, the user must determine what is appropriate for the application and project data quality objectives.

Gary J. Foley, Ph.D.
Director
National Exposure Research Laboratory
Office of Research and Development

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's natural resources. Under the mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The National Exposure Research Laboratory (NERL) is the Agency's center for the investigation of technical and management approaches for identifying and quantifying risks to human health and the environment. Goals of the Laboratory's research program are to (1) develop and evaluate methods and technologies for characterizing and monitoring air, soil, and water; (2) support regulatory and policy decisions; and (3) provide the science support needed to ensure effective implementation of environmental regulations and strategies.

The EPA's Superfund Innovative Technology Evaluation (SITE) Program evaluates technologies for the characterization and remediation of contaminated Superfund and Resource Conservation and Recovery Act sites. The SITE Program was created to provide reliable cost and performance data to speed the acceptance and use of innovative remediation, characterization, and monitoring technologies by the regulatory and user community.

Effective measurement and monitoring technologies are needed to assess the degree of contamination at a site, to provide data that can be used to determine the risk to public health or the environment, to supply the necessary cost and performance data to select the most appropriate technology, and to monitor the success or failure of a remediation process. One component of the EPA SITE Program, the Monitoring and Measurement Technology Program, demonstrates and evaluates innovative technologies to meet these needs.

Candidate technologies can originate from within the federal government or from the private sector. Through the SITE Program, developers are given the opportunity to conduct a rigorous demonstration of their technology under actual field conditions. By completing the evaluation and distributing the results, the Agency establishes a baseline for acceptance and use of these technologies. The Monitoring and Measurement Technology Program is managed by the ORD's Environmental Sciences Division in Las Vegas, Nevada.

Gary Foley, Ph.D.
Director
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US EPA ARCHIVE DOCUMENT

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Acronyms and Abbreviations

bgs	below ground surface
cc	cubic centimeter
cis-1,2-DCE	cis-1,2-dichloroethene
CME	Central Mine Equipment
CSC	Chemical Sales Company
CSCT	Consortium for Site Characterization Technology
1,1-DCA	1,1-dichloroethane
E&E	Ecology & Environment
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
ETVR	Environmental Technology Verification Report
ft.-lb.	foot pound
g	gram
IDW	investigation-derived waste
LCS	laboratory control sample
mg/kg	milligrams per kilogram
mL	milliliter
MS/MSD	matrix spike/matrix spike duplicate
μg/kg	micrograms per kilogram
NERL	National Exposure Research Laboratory
o.d.	outside diameter
OU	operable unit
PCE	tetrachloroethene
QA/QC	quality assurance/quality control
RI/FS	remedial investigation/feasibility study
RPD	relative percent difference
SBA	Small Business Administration
SITE	Superfund Innovative Technology Evaluation
SMC	Superior Manufacturing Company
1,1,1-TCA	1,1,1-trichloroethane
TCE	trichloroethene
VOC	volatile organic compound

Acknowledgments

Executive Summary

In May and June 1997, the U.S. Environmental Protection Agency (EPA) sponsored a demonstration of the AMS^{TM} Dual Tube Liner Sampler, three other soil sampling technologies, and two soil gas sampling technologies. This Environmental Technology Verification Report presents the results of the Dual Tube Liner Sampler demonstration; similar reports have been published for each of the other soil and soil gas sampling technologies.

The Dual Tube Liner Sampler is a soil sampling tool capable of collecting unconsolidated subsurface material to depths that depend on the capability of the sampler advancement platform. The Dual Tube Liner Sampler is advanced into the subsurface with a direct-push platform.

The Dual Tube Liner Sampler was demonstrated at two sites: the Small Business Administration (SBA) site in Albert City, Iowa, and the Chemical Sales Company (CSC) site in Denver, Colorado. These sites were chosen because each has a wide range of volatile organic compound (VOC) concentrations and a distinct soil type. The VOCs detected at the sites include cis-1,2-dichloroethene; trichloroethene; 1,1,1-trichloroethane; and tetrachloroethene. The SBA site is composed primarily of clay soil, and the CSC site is composed primarily of medium- to fine-grained sandy soil.

The Dual Tube Liner Sampler was compared to a reference subsurface soil sampling method (hollow-stem auger drilling and split-spoon sampling) in terms of the following parameters: (1) sample recovery, (2) VOC concentrations in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost. The demonstration data indicate the following performance characteristics for the Dual Tube Liner Sampler:

- Compared to the reference method, average sample recoveries for the Dual Tube Liner Sampler were higher in clay soil and lower in sandy soil.

- A significant statistical difference between the VOC concentrations was detected for one of the 12 Dual Tube Liner Sampler and reference sample method pairs collected at the SBA site and for three of the 13 Dual Tube Liner Sampler and reference sampling method pairs collected at the CSC site.

- In one of the 12 integrity test samples, the integrity of a lined Dual Tube Liner Sampler was not preserved when the sampler was advanced through contaminated soils.

- The reliability of the Dual Tube Liner Sampler to collect a sample in the first attempt was higher than that for the reference sampling method in both clay and sandy soils. The average sample retrieval time for the Dual Tube Liner Sampler was quicker than the reference method in clay soil but slower in sandy soil.

- For both clay soil and sandy soil sites, the range of costs for collecting soil samples using the Dual Tube Liner Sampler was lower than the reference sampling method. The actual cost depends on the number of samples required, the sample retrieval time, soil type, sample depth, and the cost for disposal of drill cuttings. A site-specific cost and performance analysis is recommended before selecting a subsurface soil sampling method.

In general, results for the data quality indicators selected for this demonstration met the established quality assurance objectives and support the usefulness of the demonstration results in verifying the Dual Tube Liner Sampler's performance.

Chapter 1
Introduction

Performance verification of innovative and alternative environmental technologies is an integral part of the U.S. Environmental Protection Agency's (EPA) regulatory and research mission. Early efforts focused on evaluating technologies that supported implementation of the Clean Air and Clean Water Acts. To meet the needs of the hazardous waste program, the Superfund Innovative Technology Evaluation (SITE) Program was established by the EPA Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) as part of the Superfund Amendments and Reauthorization Act of 1986. The primary purpose of the SITE Program is to promote the acceptance and use of innovative characterization, monitoring, and treatment technologies.

The overall goal of the SITE Program is to conduct research and performance verification studies of alternative or innovative technologies that may be used to achieve long-term protection of human health and the environment. The various components of the SITE Program are designed to encourage the development, demonstration, acceptance, and use of new or innovative treatment and monitoring technologies. The program is designed to meet four primary objectives: (1) identify and remove obstacles to the development and commercial use of alternative technologies, (2) support a development program that identifies and nurtures emerging technologies, (3) demonstrate promising innovative technologies to establish reliable performance and cost information for site characterization and cleanup decision-making, and (4) develop procedures and policies that encourage the selection of alternative technologies at Superfund sites, as well as other waste sites and commercial facilities.

The intent of a SITE demonstration is to obtain representative, high quality, performance and cost data on innovative technologies so that potential users can assess a given technology's suitability for a specific application. The SITE Program includes the following elements:

- **Monitoring and Measurement Technology (MMT) Program** — Evaluates technologies that detect, monitor, sample, and measure hazardous and toxic substances. These technologies are expected to provide better, faster, and more cost-effective methods for producing real-time data during site characterization and remediation studies

- **Remediation Technologies** — Conducts demonstrations of innovative treatment technologies to provide reliable performance, cost, and applicability data for site cleanup

- **Technology Transfer Program** — Provides and disseminates technical information in the form of updates, brochures, and other publications that promote the program and the technology. Provides technical assistance, training, and workshops to support the technology

The MMT Program provides developers of innovative hazardous waste measurement, monitoring, and sampling technologies with an opportunity to demonstrate a technology's performance under actual

field conditions. These technologies may be used to detect, monitor, sample, and measure hazardous and toxic substances in soil, sediment, waste materials, and groundwater. Technologies include chemical sensors for *in situ* (in place) measurements, groundwater sampling devices, soil and core sampling devices, soil gas samplers, laboratory and field-portable analytical equipment, and other systems that support field sampling or data acquisition and analysis.

The MMT Program promotes the acceptance of technologies that can be used to accurately assess the degree of contamination at a site, provide data to evaluate potential effects on human health and the environment, apply data to assist in selecting the most appropriate cleanup action, and monitor the effectiveness of a remediation process. Acceptance into the program places high priority on innovative technologies that provide more cost-effective, faster, and safer methods than conventional technologies for producing real-time or near-real-time data. These technologies are demonstrated under field conditions and results are compiled, evaluated, published, and disseminated by ORD. The primary objectives of the MMT Program are the following:

- Test field analytical technologies that enhance monitoring and site characterization capabilities

- Identify the performance attributes of new technologies to address field characterization and monitoring problems in a more cost-effective and efficient manner

- Prepare protocols, guidelines, methods, and other technical publications that enhance the acceptance of these technologies for routine use

The SITE MMT Program is administered by ORD's National Exposure Research Laboratory (NERL-LV) at the Environmental Sciences Division in Las Vegas, Nevada.

In 1994, the EPA created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative technologies in other areas of environmental concern through performance verification and information dissemination. As in the SITE Program, the goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. The ETV Program is intended to assist and inform those involved in the design, distribution, permitting, and purchase of various environmental technologies. The ETV Program capitalizes on and applies the lessons learned in implementing the SITE Program.

For each demonstration, the EPA draws on the expertise of partner "verification organizations" to design efficient procedures for conducting performance tests of environmental technologies. The EPA selects its partners from both the public and private sectors, including federal laboratories, states, universities, and private sector entities. Verification organizations oversee and report verification activities based on testing and quality assurance (QA) protocols developed with input from all major stakeholder and customer groups associated with the technology area. For this demonstration, the EPA selected Tetra Tech EM Inc. (Tetra Tech; formerly PRC Environmental Management, Inc.) as the verification organization.

In May and June 1997, the EPA conducted a demonstration, funded by the SITE Program, to verify the performance of four soil and two soil gas sampling technologies: SimulProbe® Technologies, Inc., Core Barrel Sampler; Geoprobe® Systems, Inc., Large-Bore Soil Sampler; AMS™ Dual Tube Liner Sampler; Clements Associates, Inc., Environmentalist's Subsoil Probe; Quadrel Services, Inc., EMFLUX® Soil Gas Investigation System; and W.L. Gore & Associates GORE-SORBER® Soil Gas Sampler. This environmental technology verification report (ETVR) presents the results of thedemonstration for one soil

sampling technology, the AMS™ Dual Tube Liner Sampler. Separate ETVRs have been published for the remaining soil and soil gas sampling technologies.

Technology Verification Process

The technology verification process is designed to conduct demonstrations that will generate high-quality data that the EPA and others can use to verify technology performance and cost. Four key steps are inherent in the process: (1) needs identification and technology selection, (2) demonstration planning and implementation, (3) report preparation, and (4) information distribution.

Needs Identification and Technology Selection

The first aspect of the technology verification process is to identify technology needs of the EPA and the regulated community. The EPA, the U.S. Department of Energy, the U.S. Department of Defense, industry, and state agencies are asked to identify technology needs for characterization, sampling, and monitoring. Once a technology area is chosen, a search is conducted to identify suitable technologies that will address that need. The technology search and identification process consists of reviewing responses to *Commerce Business Daily* announcements, searches of industry and trade publications, attendance at related conferences, and leads from technology developers. Selection of characterization and monitoring technologies for field testing includes an evaluation of the candidate technology against the following criteria:

- Designed for use in the field or in a mobile laboratory

- Applicable to a variety of environmentally contaminated sites

- Has potential for resolving problems for which current methods are unsatisfactory

- Has costs that are competitive with current methods

- Performs better than current methods in areas such as data quality, sample preparation, or analytical turnaround time

- Uses techniques that are easier and safer than current methods

- Is commercially available

Demonstration Planning and Implementation

After a technology has been selected, the EPA, the verification organization, and the developer agree to a strategy for conducting the demonstration and evaluating the technology. The following issues are addressed at this time:

- Identifying and defining the roles of demonstration participants, observers, and reviewers

- Identifying demonstration sites that provide the appropriate physical or chemical attributes in the desired environmental media

- Determining logistical and support requirements (for example, field equipment, power and water sources, mobile laboratory, or communications network)

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- Arranging analytical and sampling support

- Preparing and implementing a demonstration plan that addresses the experimental design, the sampling design, quality assurance/quality control (QA/QC), health and safety, field and laboratory operations scheduling, data analysis procedures, and reporting requirements

Report Preparation

Each of the innovative technologies is evaluated independently and, when possible, against a reference technology. The technologies are usually operated in the field by the developers in the presence of independent observers. These individuals are selected by the EPA or the verification organization and work to ensure that the technology is operated in accordance with the demonstration plan. Demonstration data are used to evaluate the capabilities, performance, limitations, and field applications of each technology. After the demonstration, all raw and reduced data used to evaluate each technology are compiled into a technology evaluation report as a record of the demonstration. A verification statement and detailed evaluation narrative of each technology are published in an ETVR. This document receives a thorough technical and editorial review prior to publication.

Information Distribution

The goal of the information distribution strategy is to ensure that ETVRs are readily available to interested parties through traditional data distribution pathways, such as printed documents. Related documents and technology updates are also available on the World Wide Web through the ETV Web site (*http://www.epa.gov/etv*) and through the Hazardous Waste Clean-Up Information Web site supported by the EPA OSWER Technology Innovation Office (*http://clu-in.org*). Additional information on the SITE Program can be found on ORD's web site (*http://www.epa.gov/ORD/SITE*).

Demonstration Purpose

The primary purpose of a soil sampling technology is to collect a sample from a specified depth and return it to the surface with minimal changes to the chemical concentration or physical properties of the sample. This report documents the performance of the AMS™ Dual Tube Liner Sampler relative to the hollow-stem auger drilling and split-spoon sampling reference method.

This document summarizes the results of an evaluation of the AMS™ Dual Tube Liner Sampler in comparison to the reference sampling method in terms of the following parameters: (1) sample recovery, (2) volatile organic compound (VOC) concentrations in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost. Data quality measures of precision, accuracy, representativeness, completeness, and comparability were also assessed against established QA objectives to ensure the usefulness of the data for the purpose of this verification.

Chapter 2
Technology Description

This chapter describes the AMS^{TM} Dual Tube Liner Sampler, including its background, components and accessories, sampling platform, and general operating procedures. The text in this chapter was provided by the developer and was edited for format and relevance.

Background

The Dual Tube Liner Sampler (patent pending) was developed by AMS^{TM} solely for collection of subsurface soil samples. The physical limitations on the operation of the Dual Tube Liner Sampler depend on the method of sampler advancement and the nature of the subsurface matrix. The technology is primarily restricted to unconsolidated soil free of large cobbles or boulders. Sediments containing pebbles supported by a finer-grained matrix can also be sampled. The developer claims that the Dual Tube Liner Sampler can be used to sample soil for volatile organic compounds (VOCs), semivolatile organic compounds, metals, general minerals, and pesticides. Additional developer claims for the performance of the Dual Tube Liner Sampler are that it:

- Prevents cross-contamination and preserves sample integrity

- Collects samples that are chemically representative of the target interval

- Collects either discrete or continuous soil samples

- Works in unconsolidated materials

During the demonstration, the developer's claims regarding the ability of the Dual Tube Liner Sampler to be used to sample for VOCs, preserve sample integrity, and collect representative discrete soil samples in consolidated and unconsolidated materials were evaluated.

Components and Accessories

The Dual Tube Liner Sampler (Figure 2-1) was designed to collect subsurface soil samples using direct-push platform technology. The sampling system consists of tools to be used with direct push sampling equipment in the collection of continuous or discrete soil samples. The sampler assembly is constructed of two steel tubes, or "extensions," of differing diameters designed so that the smaller of the two tubes fits within the larger. The outer extension is available in two diameters, 2-1/8-inch outside diameter (o.d.) with a 3/8-inch wall thickness and 1-3/4-inch o.d. with a 1/4-inch wall thickness, and is equipped with a metal drive tip at the lower end. The thick-walled extensions are typically used when pushing the sampler through gravelly or dense material. The outer extension is threaded at the upper end to facilitate additional metal extensions with increasing depth and the addition of a drive head adaptor
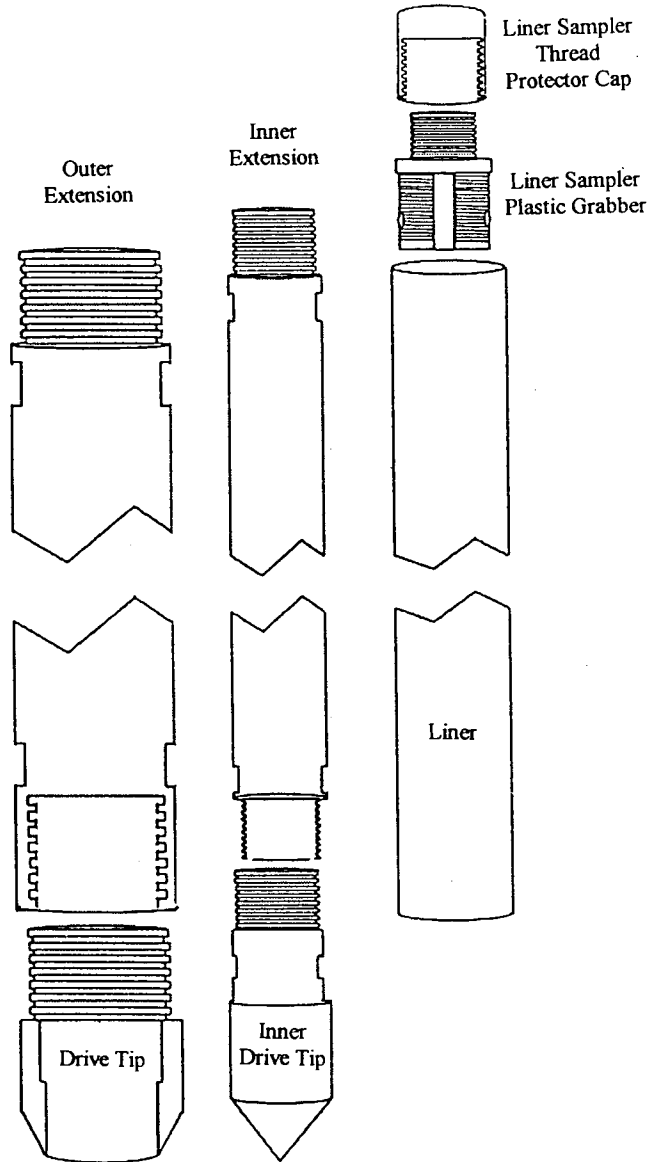
Figure 2-1. Dual Tube Liner Sampler Components (modified from AMS™, 1997)

to the top of the tool string. The inner extensions are also available in two diameters, 1-3/4-inch o.d. and 1-1/8-inch o.d., to match the selected outer extension diameter. The lower end of the inner extension is threaded with a plastic grabber to facilitate the attachment of a polybutyrate liner during sample collection or a solid point metal inner drive tip during sampler advancement (Figure 2-2). The inner drive tip fits tightly into the outer extension drive tip; the drive tip and inner extensions are held firmly in place by the drive head.

Dual tube sampler extensions are available in lengths of 1, 2, 3, and 4 feet and wall thickness of 1/4-inch and 3/8-inch. The components of the sampler are assembled with the outer extension serving as a temporary casing, so that continuous or discrete soil samples can be collected using the inner extension liner and drive tip assemblies. The Dual Tube Liner Sampler is designed to allow collection of the soil sample while preventing cross contamination that may result through contact with contaminated soils. In addition, the 3/8-inch walled inner extensions are designed for single tube sampling as well as dual tube sampling with the 2-1/8-inch outer extensions.

Additional tools offered by AMS™ include an optional sample preparation station designed to provide a means of opening the clear polybutyrate liners. The free-standing or truck-bed-mounted sample preparation station provides a "V"-shaped tray to hold the liner in position as a track-mounted razor knife is used to open the liner. Four additional "V" trays are provided to hold opened samples for examination.

Description of Platforms

A PowerProbe 9600 direct push rig was used to advance the sampler during the demonstration. The PowerProbe 9600 is an engine-driven combination hammer and auger drilling unit equipped with electronically activated hydraulic valves. The rig is equipped with a 50-foot-pound variable speed hydraulic hammer equipped with a separate auger unit on the drive head. The drive mechanism can apply 30,000 pounds of down force using a 5-foot stroke. The unit can expend 40,000 pounds of up force in retrieving tool strings from the subsurface. The unit is powered by a belt-driven hydraulic pump installed on the vehicle engine.

The platform must be mounted on a three-quarter ton or heavier pickup truck that is supplied by the buyer or custom truck assembled by AMS™. The probe platform is adjustable and offers 20 inches of extension and 52 inches of left-right swing. The angle of the probe rig mast is adjustable at 15-degree increments between 45 and 105 degrees to allow diagonal sampling.

General Operating Procedures

Before use and between each sample collected during the demonstration, the Dual Tube Liner Sampler probe and any supporting equipment that may come in contact with the sample were decontaminated. The sampler equipment was then assembled according to the following protocol: (1) the Dual Tube Liner is threaded onto the lower end of the metal liner grab unit, (2) the 1-1/8-inch extension is threaded to the upper end of the sampler, (3) the assembly is lowered into the outer extension, using additional 1-1/8-inch inner extensions as needed, (4) a thread protector cap is added to the inner extension, and (5) the drive head adaptor is added to the outer extension.

For use in the continuous sampling mode, the assembled tool string is advanced either 2 or 4 feet (depending on the length of the unit in use) into the subsurface to collect the sample. Discrete samples are collected by outfitting the inner extension with a solid drive tip prior to assembly; this drive tip fits

DUAL TUBE
LINER SAMPLING

(A) Driving Dual Tubes to the sampling point
(B) The outer tube in place with the AMS Liner sampler
(C) Collecting the sample directly in the liner
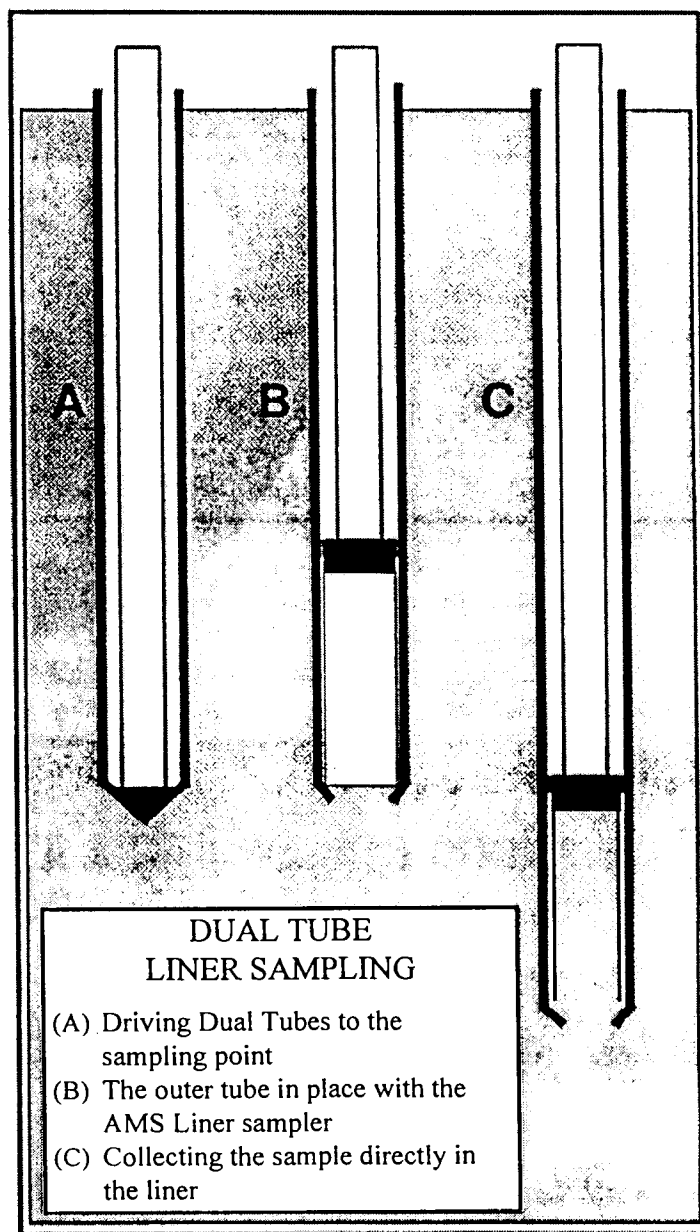
Figure 2-2. Dual Tube Liner Sampling (modified from AMS™, 1997)

snugly into the outer extension drive tip, as shown on Figure 2-2, Part A. The inner extensions remain unsecured within the outer extension and are held in place by the drive head during advancement. Upon reaching the desired sampling depth, the inner extensions are retrieved either by hand or using the drive head and a liner is installed as described above and shown on Figure 2-2, Part B. The tool string is then advanced, filling the sample liner as shown on Figure 2-2, Part C.

The following procedure was followed when disassembling the sampler: (1) the drive head adaptor is removed from the outer extension, (2) the thread protector is removed from the inner extension and the unit is retrieved from the outer extension string, (3) the liner is unscrewed from the inner extension assembly and the plastic grabber, (4) the Dual Tube Liner is removed from the assembly and positioned for sample removal, and (5) a razor knife is used to open the polybutyrate sampler liner, exposing the sample.

The Dual Tube Liner Sampler equipment was decontaminated according to the procedures specified in the demonstration plan (PRC Environmental Management, Inc. [PRC], 1997). The disposable polybutyrate liners do not require decontamination prior to use. At a minimum, the plastic grabber, inner and outer extensions, thread protector, and drive tip were decontaminated with an Alconox® wash and potable water rinse. Decontamination was completed while the tools were being removed from the ground using an AMS^{TM} on-board wash station with two spray wands supplying fresh wash solutions. One person was able to decontaminate all components of one sampler in 3 to 5 minutes.

Health and safety considerations for operating the sampler and the sampling platforms included complying with all applicable Occupational Safety and Health Administration hazardous waste operation training as well as eye, ear, head, hand, and foot protection.

Developer Contact

For more developer information on the Dual Tube Liner Sampler, please refer to Chapters 8 and 9 of this ETVR or contact the developer at:

> Brian Anderson
> Art's Manufacturing and Supply
> 105 Harrison Street
> American Falls, Indiana 83211
> Telephone: (800) 635-7330
> Facsimile: (208) 226-7280
> E-mail: brian@bankipds.com

Chapter 3
Site Descriptions and Demonstration Design

This chapter describes the demonstration sites, predemonstration sampling and analysis, and the demonstration design. The demonstration was conducted in accordance with the "Final Demonstration Plan for the Evaluation of Soil Sampling and Soil Gas Sampling Technologies" (PRC, 1997).

Site Selection and Description

The following criteria were used to select the demonstration sites:

- Unimpeded access for the demonstration

- A range (micrograms per kilogram [μg/kg] to milligrams per kilogram [mg/kg]) of chlorinated or aromatic VOC contamination in soil

- Well-characterized contamination

- Different soil textures

- Minimal underground utilities

- Situated in different climates

Based on a review of 48 candidate sites, the Small Business Administration (SBA) site in Albert City, Iowa, and the CSC site in Denver, Colorado, were selected for the demonstration.

SBA Site Description

The SBA site is located on Orchard Street between 1st and 2nd Avenues in east-central Albert City, Iowa (Figure 3-1). The site is the location of the former Superior Manufacturing Company (SMC) facility and is now owned by SBA and B&B Chlorination, Inc. SMC manufactured grease guns at the site from 1935 until 1967. Metal working, assembling, polishing, degreasing, painting, and other operations were carried out at the site during this period. The EPA files indicate that various solvents were used in manufacturing grease guns and that waste metal shavings coated with oil and solvents were placed in a former waste storage area. The oil and solvents were allowed to drain onto the ground, and the metal waste was hauled off site by truck (Ecology & Environment [E&E], 1996).

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N

2nd Avenue

Former SMC
Waste Storage
Area

Main Street

Former
Jim's
Tire and
Service

Alley

4

2

Former SMC
Plant Building

3

Pole
Barn

Orchard Street

1

Garage

Albert City
Fire Station

Museum
Annex

Historic
School House

Former
Pump House

Shop

Shop

5

Abandoned Alley

Historic
Train
Station

Museum
Building

School
Bus
Storage
Building

Grape Street

Buena Vista
County
Maintenance
Facility

Railroad Street (1st Avenue)

11

SCALE

LEGEND

100   0   100

1   DEMONSTRATION GRID LOCATIONS
     AND GRID NUMBER

- - - - -   APPROXIMATE SITE BOUNDARY

FEET

Figure 3-1. Small Business Administration Site

The site consists of the former SMC plant property and a waste storage yard. The SMC plant property is currently a grass-covered, relatively flat, unfenced open lot. The plant buildings have been razed. A pole barn is the only building currently on the SMC plant property. Several buildings are present in the waste storage yard, including three historic buildings: a garage, a museum, and a school house.

Poorly drained, loamy soils of the Nicollet series are present throughout the site area. The upper layer of these soils is a black loam grading to a dark gray loam. Below this layer, the soils grade to a friable, light clay loam extending to a depth of 60 inches. Underlying these soils is a thick sequence (400 feet or more) of glacial drift. The lithology of this glacial drift is generally a light yellowish-gray, sandy clay with some gravel, pebbles, or boulders. The sand-to-clay ratio is probably variable throughout the drift. Groundwater is encountered at about 6 to 7 feet below ground surface (bgs) at the SBA site (E&E, 1996).

Tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride are the primary contaminants detected in soil at the site. These chlorinated VOCs have been detected in both surface (0 to 2 feet deep) and subsurface (3 to 5 feet deep) soil samples. TCE and cis-1,2-DCE are the VOCs usually detected at the highest concentrations in both soil and groundwater. In past site investigations, TCE and cis-1,2-DCE have been detected in soils at 17 and 40 mg/kg, respectively, with vinyl chloride present at 1.4 mg/kg. The areas of highest contamination have been found near the center of the former SMC plant property and near the south end of the former SMC waste storage area (E&E, 1996).

CSC Site Description

The CSC site is located in Denver, Colorado, approximately 5 miles northeast of downtown Denver. From 1962 to 1976, a warehouse at the site was used to store chemicals. The CSC purchased and first occupied the facility in 1976. The CSC installed aboveground and underground storage tanks and pipelines at the site between October 1976 and February 1977. From 1976 to 1992, the facility received, blended, stored, and distributed various chemicals and acids. Chemicals were transported in bulk to the CSC facility by train, and were unloaded along railroad spurs located north and south of the CSC facility. These operations ceased at the CSC site in 1992.

The EPA conducted several investigations of the site from 1981 through 1991. Results of these investigations indicated a release of organic chemicals into the soil and groundwater at the site. As a result of this finding, the CSC site was placed on the National Priorities List in 1990. The site is divided into three operable units (OU). This demonstration was conducted at OU1, located at 4661 Monaco Parkway in Denver (Figure 3-2). In September 1989, EPA and CSC entered into an Administrative Order on Consent requiring CSC to conduct a remedial investigation/feasibility study (RI/FS) for CSC OU1. The RI/FS was completed at OU1 in 1991 (Engineering-Science, Inc., 1991).

The current site features of OU1 consist of the warehouse, a concrete containment pad with a few remaining tanks from the aboveground tank farm, another smaller containment pad with aboveground tanks north of a railroad spur, and multiple areas in which drums are stored on the west side of the warehouse and in the northwest corner of the property. The warehouse is currently in use and is occupied by Steel Works Corporation.
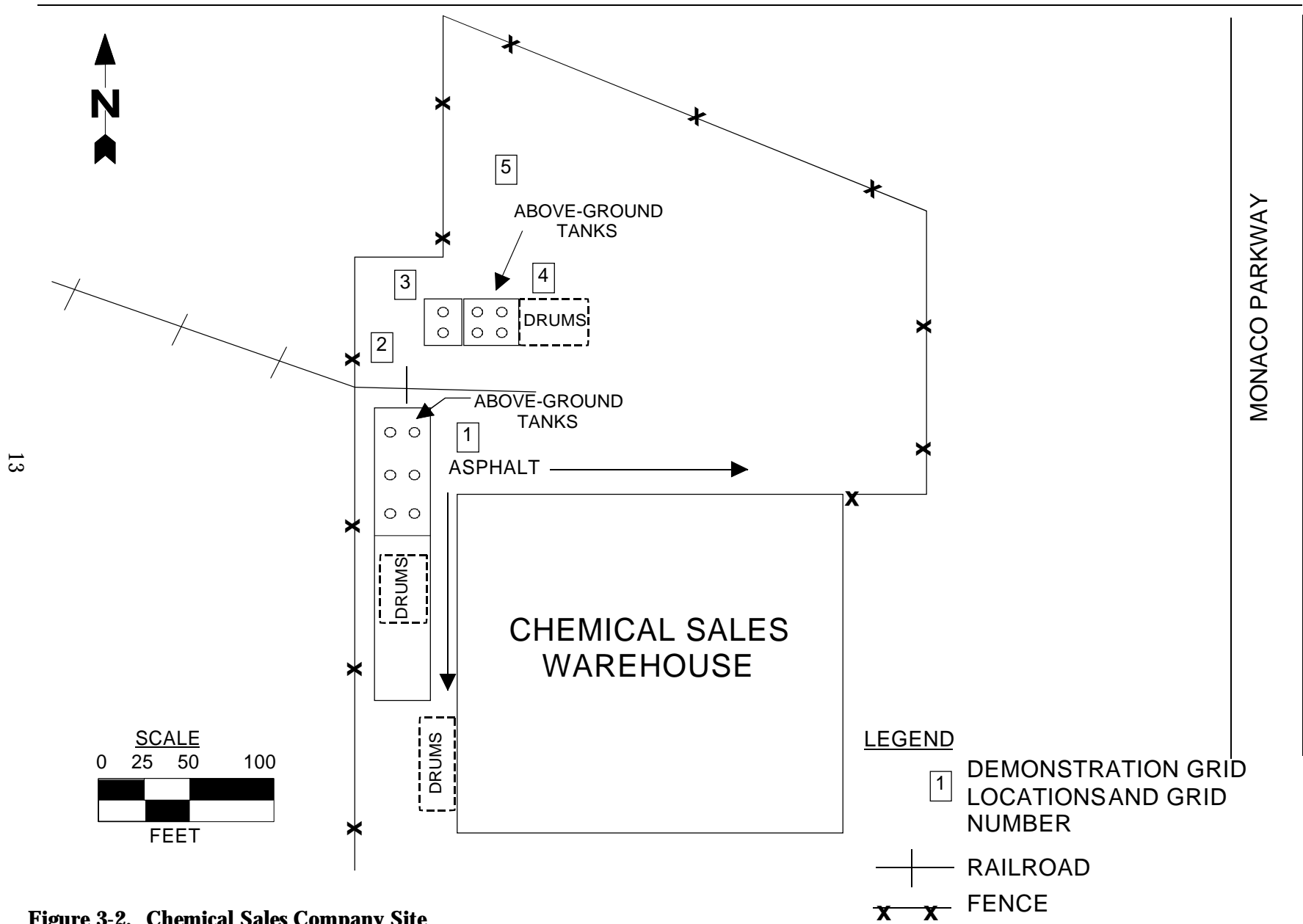
Figure 3-2. Chemical Sales Company Site

The topography, distribution of surficial deposits, and materials encountered during predemonstration sampling suggest that the portion of OU1 near the CSC warehouse is a terrace deposit composed of Slocum Alluvium beneath aeolian sand, silt, and clay. The terrace was likely formed by renewed downcutting of a tributary to Sand Creek. Borings at the CSC property indicate that soils in the vadose zone and saturated zone are primarily fine- to coarse-grained, poorly sorted sands with some silts and clays. The alluvial aquifer also contains some poorly sorted gravel zones. The depth to water is about 30 to 40 feet bgs near the CSC warehouse.

During previous soil investigations at the CSC property, chlorinated VOC contamination was detected extending from near the surface (less than 5 feet bgs) to the water table depth. The predominant chlorinated VOCs detected in site soils are PCE, TCE, 1,1,1-trichloroethane (1,1,1-TCA), and 1,1-dichloroethane (1,1-DCA). The area of highest VOC contamination is north of the CSC tank farm, near the northern railroad spur. The PCE concentrations detected in this area measure as high as 80 mg/kg, with TCE and 1,1,1-TCA concentrations measuring as high as 1 mg/kg.

Predemonstration Sampling and Analysis

Predemonstration sampling and analysis were conducted to establish the geographic location of sampling grids, identify target sampling depths, and estimate the variability of contaminant concentrations exhibited at each grid location and target sampling depth. Predemonstration sampling was conducted at the SBA site between April 1 and 11, 1997, and at the CSC site between April 20 and 25, 1997. Ten sampling grids, five at the SBA site and five at the CSC site, were investigated to identify sampling depths within each grid that exhibited chemical concentration and soil texture characteristics that met the criteria set forth in the predemonstration sampling plan (PRC, 1997) and would, therefore, be acceptable for the Dual Tube Liner Sampler demonstration.

At each of the grids sampled during the predemonstration, a single continuous core was collected at the center of the 10.5-by 10.5-foot sampling area. This continuous core was collected to a maximum depth of 20 feet bgs at the SBA site and 28 feet bgs at the CSC site. Analytical results for this core sample were used to identify target sampling depths and confirm that the target depths exhibited the desired contaminant concentrations and soil type. After the center of each grid was sampled, four additional boreholes were advanced and sampled in each of the outer four corners of the 10.5- by 10.5-foot grid area. These corner locations were sampled at depth intervals determined from the initial coring location in the center of the grid, and were analyzed for VOCs and soil texture.

During predemonstration sampling, ten distinct target depths were sampled at five grids at the SBA site: three depths at Grid 1, two depths at Grid 2, one depth at Grid 3, two depths at Grid 4, and two depths at Grid 5. Five of the target depths represented intervals with contaminant concentrations in the tens of mg/kg, and five of the target depths represented intervals with contaminant concentrations in the tens of Fg/kg. As expected, the primary VOCs detected in soil samples were vinyl chloride, cis-1,2-DCE, TCE, and PCE. TCE and cis-1,2-DCE were detected at the highest concentrations. Because the soil texture was relatively homogeneous for each target sampling depth, soil sampling locations for the demonstration were selected based on TCE and cis-1,2-DCE concentration variability within each grid. A depth was deemed acceptable for the demonstration if (1) individual TCE and cis-1,2-DCE concentrations were within a factor of 5, (2) the relative standard deviations for TCE and cis-1,2-DCE concentrations were less than 50 percent, and (3) the soil texture did not change in dominant grain size.

During predemonstration sampling, 12 distinct target depths were sampled at the five grids at the CSC site: two depths at Grid 1, three depths at Grid 2, three depths at Grid 3, two depths at Grid 4, and two depths at Grid 5. Two of the target depths represented intervals with contaminant concentrations

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greater than 200 μg/kg, and ten of the target depths represented intervals with contaminant concentrations less than 200 μg/kg. The primary VOCs detected in soil at the CSC site were 1,1,1-TCA, TCE, and PCE.

Of the 22 distinct target depths sampled during predemonstration activities at the SBA and CSC sites, seven sampling depths at 10 grids were selected for the demonstration. Six sampling depths within nine grids at the SBA and CSC sites (a total of 12 grid-depth combinations) were chosen to meet the contaminant concentration and soil texture requirements stated above. In addition, one sampling depth at one grid (40 feet bgs at Grid 5) at the CSC site was selected to evaluate the reliability and sample recovery of the Dual Tube Liner Sampler in saturated sandy soil. The sampling depths and grids selected for the Dual Tube Liner Sampler demonstration at the SBA and CSC sites are listed in Table 3-1. The locations of the sampling grids are shown in Figures 3-1 and 3-2.

Table 3-1. Sampling Depths Selected for the Dual Tube Liner Sampler Demonstration

Site	Grid	Concentration Zone	Depth (feet)
SBA (Clay Soil)	1	High	9.5
		High	13.5
	2	Low	3.5
	3	High	9.5
	4	Low	9.5
	5	Low	13.5
CSC (Sandy Soil)	1	High	3.0
		Low	6.5
	2	High	3.0
	3	High	3.0
		Low	7.5
	4	Low	6.5
	5[a]	Low	40.0[a]

[a] Performance test sampling location only; samples collected but not analyzed. Sampling location selected to evaluate the reliability and sample recovery of the Dual Tube Liner Sampler in saturated sandy soil.

Demonstration Design

The demonstration was designed to evaluate the Dual Tube Liner Sampler in comparison to the reference sampling method in terms of the following parameters: (1) sample recovery, (2) VOC concentration in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost. These parameters were assessed in two different soil textures (clay soil at the SBA site and sandy soil at the CSC site), and in high- and low-concentration areas at each site. The demonstration design is described in detail in the demonstration plan (PRC, 1997) and is summarized below.

Predemonstration sampling identified 12 target grid-depth combinations (See Table 3-1) for the demonstration that exhibited consistent soil texture, acceptable VOC concentrations, and acceptable variability in VOC concentrations. One additional grid-depth combination was selected for the demonstration to evaluate the performance of the Dual Tube Liner Sampler in saturated sandy soil. Each grid was 10.5 feet by 10.5 feet in area and was divided into seven rows and seven columns, producing 49, 18- by 18-inch sampling cells (Figure 3-3). Each target depth was sampled in each of the seven columns (labeled A through G) using the Dual Tube Liner Sampler and the reference sampling method. The cell that was sampled in each column was selected randomly. The procedure used to collect samples using the Dual Tube Liner Sampler is described in Chapter 2, and the procedure used to collect samples using the reference sampling method is described in Chapter 4. In addition, Chapters 4 and 5 summarize the data collected at each grid for the reference method and Dual Tube Liner Sampler.

Sample Recovery

Sample recoveries for each Dual Tube Liner Sampler and reference method sample were calculated by comparing the length of sampler advancement to the length of sample core obtained for each attempt. Sample recovery is defined as the length of recovered sample core divided by the length of sampler advancement and is expressed as a percentage. In some instances, the length of recovered sample was reported as greater than the length of sampler advancement. In these cases, sample recovery was reported as 100 percent. Sample recoveries were calculated to assess the recovery range and mean for both the Dual Tube Liner Sampler and the reference sampling method.

Volatile Organic Compound Concentrations

Once a sample was collected, the soil core was exposed and a subsample was collected at the designated sampling depth. The subsample was used for on-site VOC analysis according to either a low-concentration or a high-concentration method using modified SW-846 methods. The low-concentration method was used for sampling depths believed to exhibit VOC concentrations of less than 200 μg/kg. The high-concentration method was used for sampling depths believed to exhibit concentrations greater than 200 μg/kg. The method detection limits for the low- and high-concentration methods were 1 μg/kg and 100 μg/kg, respectively. Predemonstration sampling results were used to classify target sampling depths as low or high concentration. Samples for VOC analysis were collected by a single sampling team using the same procedures for both the Dual Tube Liner Sampler and reference sampling method.

Samples from low-concentration sampling depths were collected as two 5-gram (g) aliquots. These aliquots were collected using a disposable 5-cubic centimeter (cc) syringe with the tip cut off and the rubber plunger tip removed. The syringe was pushed into the sample to the point that 3 to 3.5 cc of

	A	B	C	D	E	F	G
1				AMS™			
2		Ref.	Ref.			Ref.	AMS™
3	Ref.	AMS™					
4			AMS™	Ref.	Ref.		
5					AMS™		
6							
7	AMS™					AMS™	Ref.

10.5 feet (vertical)

10.5 feet (horizontal)
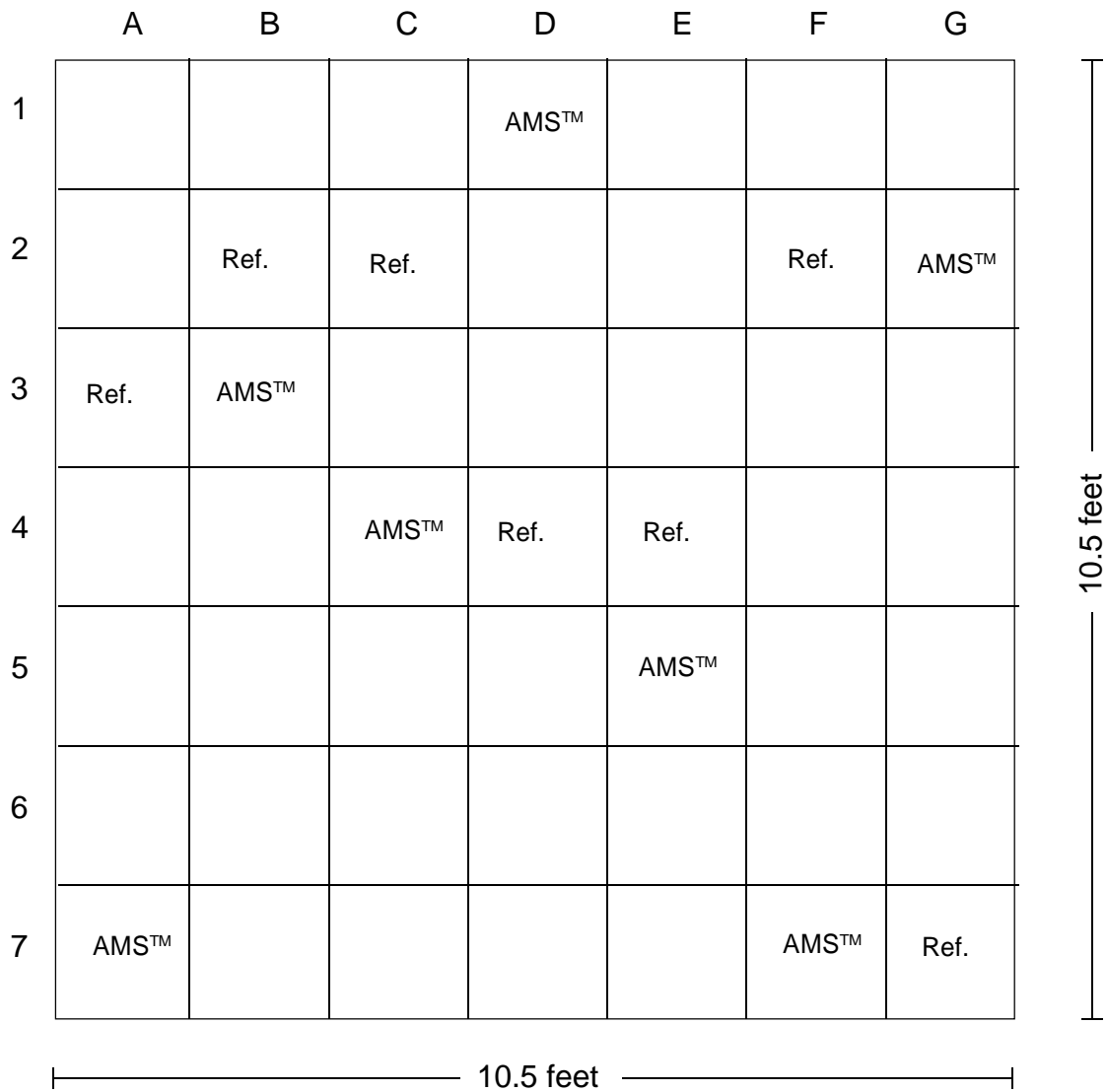
AMS™ Dual Tube Liner Sampler

Ref. Reference Sampling Method Location

Figure 3-3. Typical Sampling Locations and Random Sampling Grid

soil was contained in the syringe. The soil core in the syringe was extruded directly into a 22-milliliter (mL) headspace vial, and 5.0 mL of distilled water was added immediately. The headspace vial was sealed with a crimp-top septum cap within 5 seconds of adding the organic-free water. The headspace vial was labeled according to the technology, the sample grid and cell from which the sample was collected, and the sampling depth. These data, along with the U.S. Department of Agriculture soil texture, were recorded on field data sheets. For each subsurface soil sample, two collocated samples were collected for analysis. The second sample was intended as a backup sample for reanalysis or in case a sample was accidentally opened or destroyed prior to analysis.

Samples from high-concentration sampling depths were also collected with disposable syringes as described above. Each 3 to 3.5 cc of soil was extruded directly into a 40-mL vial and capped with a Teflon[TM]-lined septum screw cap. Each vial contained 10 mL of pesticide-grade methanol. The 40-mL vials were labeled in the same manner as the low-concentration samples, and the sample number and the U.S. Department of Agriculture soil texture were recorded on field data sheets. For each soil sample, two collocated samples were collected.

To minimize VOC loss, samples were handled as efficiently and consistently as possible. Throughout the demonstration, sample handling was timed from the moment the soil sample was exposed to the atmosphere to the moment the sample vials were sealed. Sample handling times ranged from 40 to 60 seconds for headspace sampling and from 30 to 47 seconds for methanol flood sampling.

Samples were analyzed for VOCs by combining automated headspace sampling with gas chromatography (GC) analysis according to the standard operating guideline provided in the demonstration plan (PRC, 1997). The standard operating guideline incorporates the protocols presented in SW-846 Methods 5021, 8000, 8010, 8015, and 8021 from the EPA Office of Solid Waste and Emergency Response, "Test Methods for Evaluating Solid Waste" (EPA, 1986). The target VOCs for this demonstration were vinyl chloride, cis-1,2-DCE, 1,1,1-TCA, TCE, and PCE. However, during the demonstration, vinyl chloride was removed from the target compound list because of resolution problems caused by coelution of methanol.

To report the VOC data on a dry weight basis, samples were collected to measure soil moisture content. For each sampling depth, a sample weighing approximately 100 g was collected from one of the reference method subsurface soil samples. The moisture samples were collected from the soil core within 1 inch of the VOC sampling location using a disposable steel teaspoon.

An F test for variance homogeneity was run on the VOC data to assess their suitability for parametric analysis. The data set variances failed the F test, indicating that parametric analysis was inappropriate for hypothesis testing. To illustrate this variability and heterogeneity of contaminant concentrations in soil, predemonstration and demonstration soil sample results (obtained using the reference sampling method for a grid depth combination with high variability and a grid depth combination with low variability) are provided as Figures 3-4 and 3-5.

Because the data set variance failed the F test, a nonparametric method, the Mann-Whitney test, was used for the statistical analysis. The Mann-Whitney statistic was chosen because (1) it is historically acceptable, (2) it is easy to apply to small data sets, (3) it requires no assumptions regarding normality, and (4) it assumes only that differences between two reported data values, in this case the reported chemical concentrations, can be determined. A description of the application of the Mann-Whitney test and the conditions under which it was used is presented in Appendix A1. A statistician should be consulted before applying the Mann-Whitney test to other data sets.

	A	B	C	D	E	F	G
1	80,100						217,000
2		70,200	251,000			276,000	
3	52,800						
4				419,000	291,000		
5							
6							
7	57,900						258,000

10.5 feet (vertical)

10.5 feet (horizontal)
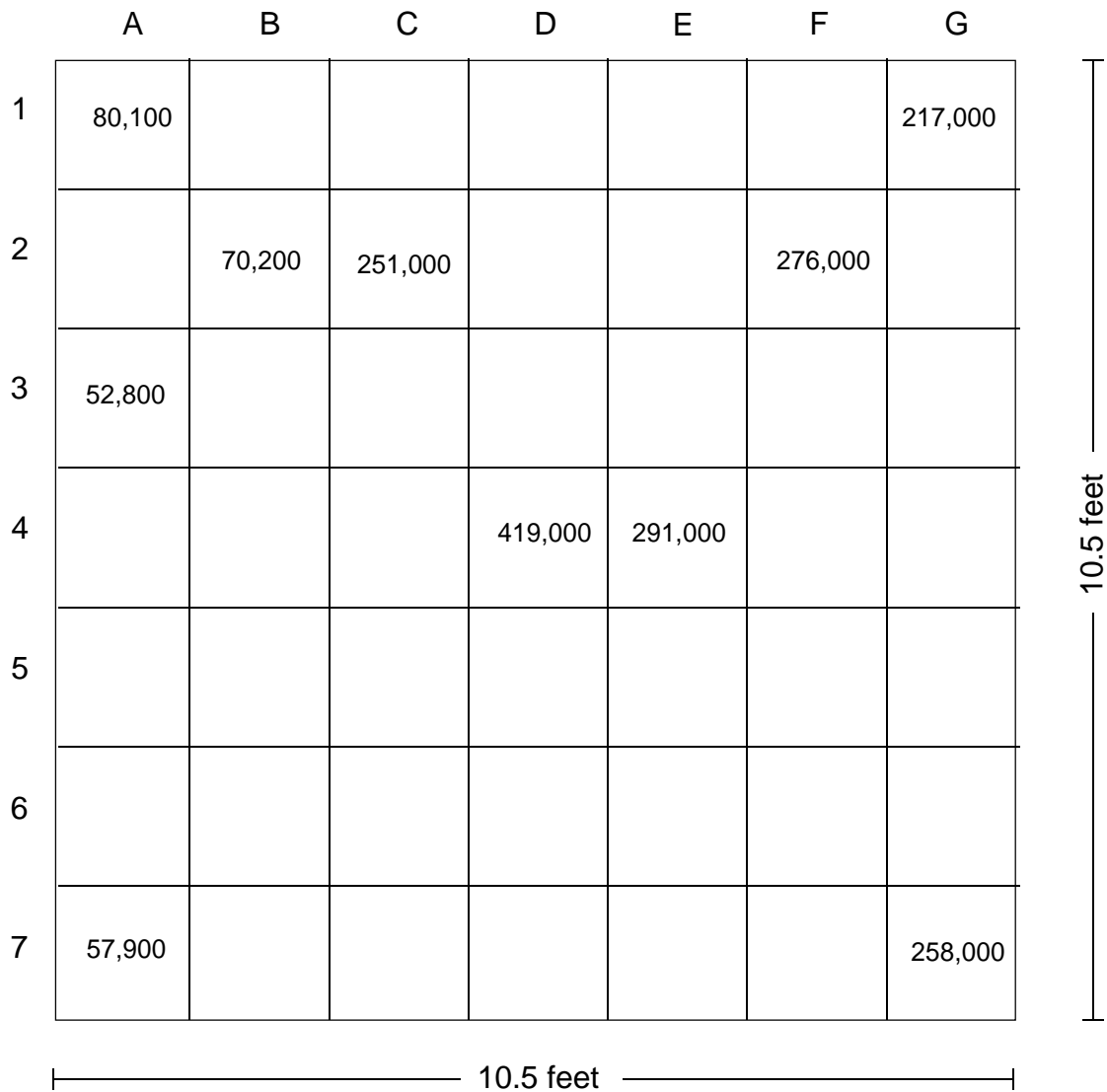
Units - micrograms per kilogram

Figure 3-4. Sampling Grid with High Contaminant Concentration Variability

	A	B	C	D	E	F	G
1	32,600						32,600
2		40,500	48,700			26,700	
3	33,700						
4				33,900	41,000		
5							
6							
7	92,200						45,800

10.5 feet

10.5 feet
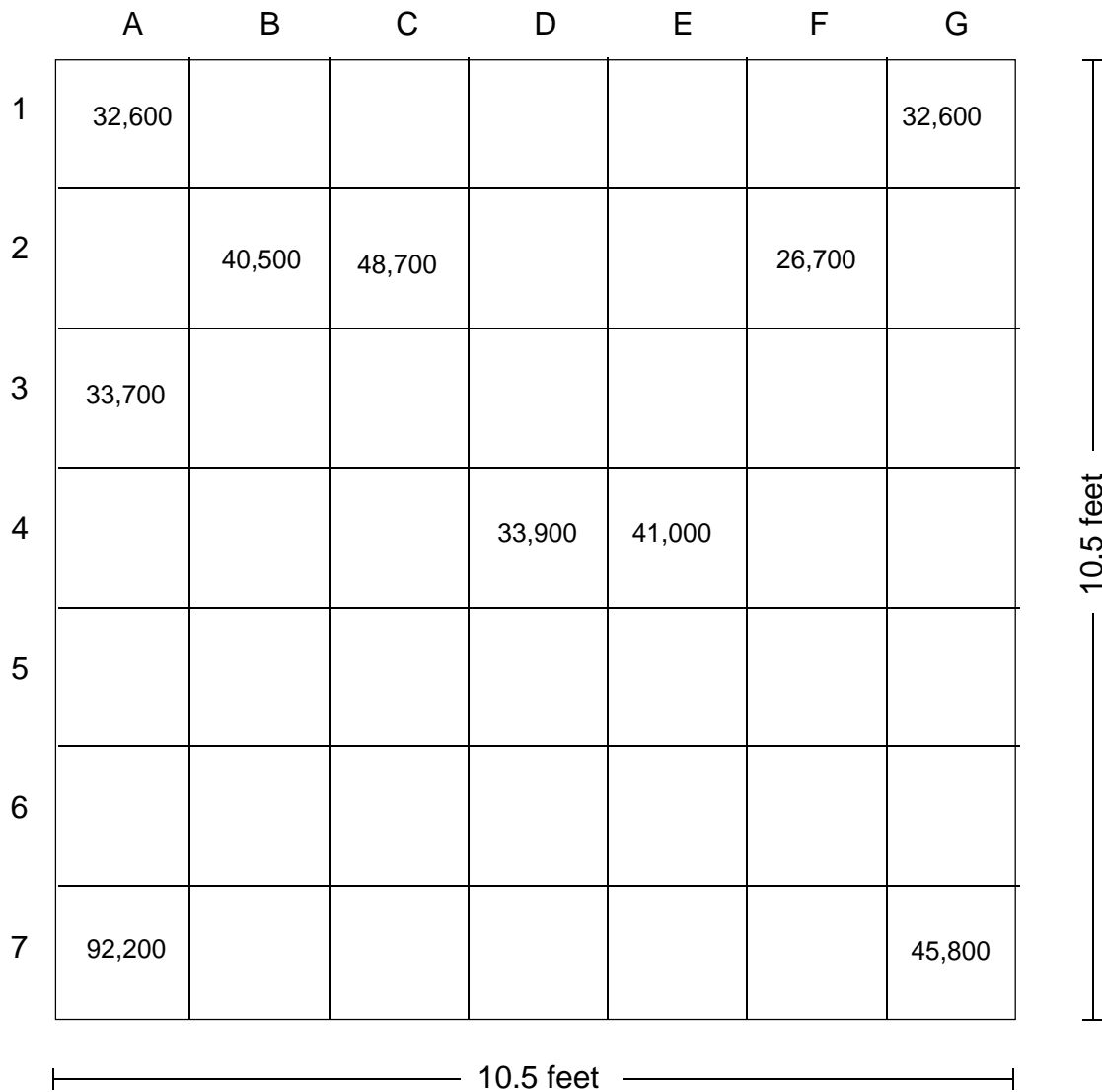
Units - micrograms per kilogram

Figure 3-5. Sampling Grid with Low Contaminant Concentration Variability

The Mann-Whitney statistical evaluation of the VOC concentration data was conducted based on the null hypothesis (H_o) that there is no difference between the median contaminant concentrations obtained by the Dual Tube Liner Sampler and the reference sampling method. A two-tailed 95 percent confidence limit was used. The calculated two-tailed significance level for the null hypothesis thus becomes 5 percent (p 0.05). A two-tailed test was used because there is no reason to suspect *a priori* that one method would result in greater concentrations than the other.

Specifically, the test evaluates the scenario wherein samples (soil samples, in this instance) would be drawn from a common universe with different sampling methods (reference versus Dual Tube Liner Sampler). If, in fact, the sampling universe is uniform and there is no sampling bias, the median value (median VOC concentration) for each data set should be statistically equivalent. Sampling, however, is random; therefore, the probability also exists that dissimilar values (particularly in small data sets) may be "withdrawn" even from an identical sampling universe. The 95 percent confidence limit used in this test was selected such that differences, should they be inferred statistically, should occur no more than 5 percent of the time.

Additionally, the sign test was used to examine the potential for sampling and analytical bias between the Dual Tube Liner Sampler and the reference sampling method. The sign test is nonparametric and counts the number of positive and negative signs among the differences. The differences tested, in this instance, were the differences in the median concentrations of paired data sets (within a site, within a grid, at a depth, and for each analyte). From the data sets, counts were made up of (1) the number of pairs in which the reference sampling method median concentrations were higher than the Dual Tube Liner Sampler median concentrations and (2) the number of pairs in which the Dual Tube Liner Sampler median concentrations were higher than the reference sampling method median concentrations. The total number of pairs in which the median concentrations were higher for the Dual Tube Liner Sampler was then compared to the total number of pairs in which the median concentrations for the reference sampling method were higher. If no bias is present in the data sets, the probability of the total number of pairs for one or the other test method being higher is equivalent; that is, the probability of the number of pairs in which the median concentrations in the Dual Tube Liner Sampler are higher is equal to the probability of the number of pairs in which the median concentrations in the reference sampling method are higher. To determine the exact probability of the number of data sets in which the median concentrations in the Dual Tube Liner Sampler and reference sampling method were higher, a binomial expansion was used. If the calculated probability is less than 5 percent ($p < 0.05$), then a significant difference is present between the Dual Tube Liner Sampler and reference sampling method.

The sign test was chosen because it (1) reduces sensitivity to random analysis error and matrix variabilities by using the median VOC concentration across each grid depth, (2) enlarges the sample sizes as compared to the Mann-Whitney test, and (3) is easy to use. A description of the application of the sign test and the conditions under which it was used is presented in Appendix A1.

For the demonstration data, certain VOCs were not detected in some, or all, of the samples in many data sets. There is no strict guidance regarding the appropriate number of values that must be reported within a data set to yield statistically valid results. For purposes of this demonstration, the maximum number of "nondetects" allowed within any given data set was set arbitrarily at three. That is, there must be at least four reported values within each data set to use the Mann-Whitney and sign tests.

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Sample Integrity

The integrity tests were conducted by advancing a sampler filled with uncontaminated potting soil into a zone of grossly contaminated soil. The potting soil was analyzed prior to use and no target VOCs were detected. Potting soil has an organic carbon content many times greater than typical soils, 0.5 to 5 percent by weight (Bohn and George, 1979), representing a worst-case scenario for VOC absorbance. The integrity samples were advanced through a contaminated zone that was a minimum of 2 feet thick and exhibited VOC contamination in the tens of thousands of mg/kg. All of the integrity samples were packed to approximately the same density. The samplers filled with the uncontaminated potting soil were advanced 2 feet into the contaminated zone and left in place for approximately 2 minutes. The samplers were then withdrawn and the potting soil was sampled and analyzed for VOCs. In each case, the sampling team collected the potting soil samples for analysis from approximately the center of the potting soil core.

Five integrity samples were collected at the SBA site using the Dual Tube Liner Sampler and seven integrity samples were collected using the reference sampling method. At the CSC site, seven integrity samples were collected using Dual Tube Liner Sampler and five integrity samples were collected when the reference sampling method was used. Sample liners were used on both the Dual Tube Liner Sampler and the reference sampling method during collection of all the integrity samples. All integrity samples were collected from Grid 1 at both of the sites, because Grid 1 was the most contaminated grid at each site. The sample integrity data were used to directly indicate the potential for cross-contamination of the soil sample during sample collection.

Reliability and Throughput

Reliability was assessed by documenting the initial sampling success rate and the number of sampling attempts necessary to obtain an adequate sample from that depth. The cause of any failure of initial or subsequent sampling attempts was also documented. Throughput was assessed by examining sample retrieval time, which was measured as the time required to set up on a sampling point, collect the specified sample, grout the hole, decontaminate the sampler, and move to a new sampling location. In addition, a performance test was conducted in Grid 5 at the CSC site to evaluate the ability of the sampling methods to collect samples in saturated sandy material at a depth of 40 feet bgs.

Cost

The cost estimate focused on the range of costs for using the Dual Tube Liner Sampler and reference split-spoon sampler to collect 42 subsurface soil samples at a clay soil site (similar to the SBA site) and a sandy soil site (similar to the CSC site). The cost analysis is based on results and experience gained from the demonstration and on cost information provided by AMS™. Factors that could affect the cost of operating the Dual Tube Liner Sampler and the reference split-spoon sampler include:

- Equipment costs
- Operating costs
- Oversight costs
- Disposal costs
- Site restoration costs

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Deviations from the Demonstration Plan

Six project-wide deviations from the approved demonstration plan are described below: (1) the nonparametric Mann-Whitney test was used instead of ANOVA to determine whether there is a statistical difference between the VOC concentrations from the Dual Tube Liner Sampler and the reference sampling method; (2) the nonparametric sign test was used to assess potential bias between VOC concentrations determined from the Dual Tube Liner Sampler and the reference sampling method; (3) vinyl chloride was eliminated from the target compound list because of a coelution problem with methanol; (4) the drill rig, large tools, and augers were decontaminated between each grid instead of between each boring; (5) 24-inch split spoon samplers instead of 18-inch samplers were used and were driven 15 to 20 inches during sample collection; and (6) the reference split-spoon sampler was used with and without acetate liners. Cases where the performance of an individual sampling technology caused it to deviate from the demonstration plan are discussed on a technology-specific basis in Chapters 4 (reference method) and 5 (Dual Tube Liner Sampler) of this ETVR.

Chapter 4
Description and Performance of the Reference Method

This chapter describes the reference soil sampling method, including background information, components and accessories, platform description, demonstration operating procedures, qualitative performance factors, quantitative performance factors, and data quality. The reference method chosen for this demonstration was hollow-stem auger drilling and split-spoon sampling.

Background

Several drilling methods have evolved to accommodate various stratigraphic conditions and the end use of the boring. Although there is no single preferred drilling method for all stratigraphic conditions and well installations, the hollow-stem auger method has become the most popular and widely used for environmental drilling and sampling. Hollow-stem augers have also been used extensively in the environmental field because soil samples can readily be collected and monitoring wells can easily be installed with this equipment (EPA, 1987). Use of hollow-stem augers as a method of drilling boreholes for soil investigations, installing groundwater monitoring wells, and completing other geotechnical work is widely accepted by federal, state, and local regulators. Because hollow-stem augers are the most commonly used drilling equipment for environmental applications, this method was selected as the reference drilling method for this demonstration.

Components and Accessories

The most common sampler used with hollow-stem augers for environmental applications is the split- spoon. The split-spoon sampler is a thick-walled steel tube that is split lengthwise (Figure 4-1). The split-spoon samplers used for this demonstration measured 24 inches long with an internal diameter of 2 inches and an external diameter of 2.5 inches. A cutting shoe is attached to the lower end, and the upper end contains a check valve and is connected to the drill rods. Split-spoon samplers are typically driven 18 to 24 inches beyond the auger head into the formation by a hammer drop system. The split-spoon sampler is used to collect a sample of material from the subsurface and to measure the resistance of the material to penetration by the sampler in the standard penetration test. The degree of soil compaction can be determined by counting the number of blows of the drop weight required to drive the split spoon a distance of 1 foot. A weight of 140 pounds and a height of fall of 30 inches are considered standard (Terzaghi and Peck, 1967).

Description of Platform

Hollow-stem augers are typically used with a truck- or trailer-mounted drill rig that is either mechanically or hydraulically powered. Trucks, vans, all-terrain vehicles, and crawler tractors are

Head Assembly

Split Barrel

Liner

Spacer

Shoe
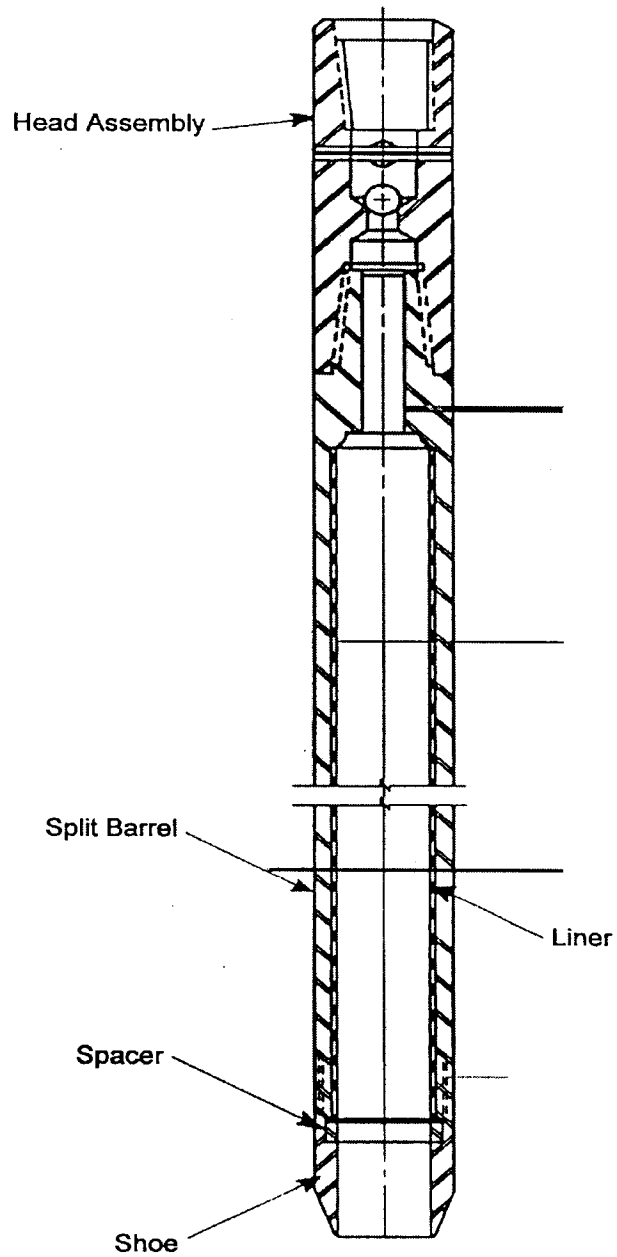
Figure 4-1. Split-Spoon Soil Sampler (modified from Central Mine Equipment Co., 1994)

often used as the transport vehicle because of their easy mobilization. A variety of drill rig specifications are available based on the project-specific operation requirements and the geological conditions anticipated (EPA, 1987).

Hollow-stem auger drilling is accomplished by using a series of interconnected auger sections with a cutting head at the lowest end. The hollow-stem auger consists of (1) a section of seamless steel tube with a spiral flight attached to a carbide-tooth auger head at the bottom and an adapter cap at the top, and (2) a center drill stem composed of drill rods attached to a center plug with a drag bit at the bottom and an adapter at the top. The center of the core of augers is open, but can be closed by the center plug attached to the bottom of the drill rods. As the hole is drilled, additional lengths of hollow-stem flights and center stem are added. The center stem and plug may be removed at any time during drilling to permit sampling below the bottom of the cutter head. Typical components of a hollow-stem auger are shown in Figure 4-2 (Central Mine Equipment Company [CME], 1994).

The dimensions of hollow-stem auger sections and the corresponding auger head used with each lead auger section are not standardized among the various auger manufacturers. Drilling at the SBA site was accomplished with a Mobile B-47 drill rig using 3.25-inch inside-diameter and 6.25-inch outside diameter CME hollow-stem augers. Drilling at the CSC site was accomplished with a Mobile D-5 and a Mobile B-47 drill rig using 3.25-inch inside-diameter and 6.25-inch outside-diameter CME hollow-stem augers. The Mobile B-47 used a pulley assembly to operate the hammer that drove the split-spoon samplers, and the Mobile D-5 used an automatic hydraulic hammer to drive the split-spoon samplers. The Mobile D-5 drill rig was used at the CSC site because the Mobile B-47 drill rig experienced mechanical problems en route to the CSC site, delaying its arrival at the site. The same drill crew operated both drill rigs; the use of the two drill rigs at the CSC site is not expected to affect the results of the demonstration.

Demonstration Operating Procedures

To collect the samples for this demonstration, the hollow-stem augers were first rotated and advanced to 9 inches above the target sampling depth. As the augers were rotated and pressed downward, the cutting teeth on the auger head broke up the formation materials, and the cuttings were rotated up the continuous flights to the ground surface, where they were stored in drums as investigation-derived waste (IDW). At the point 9-inches above the sampling depth, the drill rods and the attached center plug were removed, and the split-spoon samplers were placed on the lower end of the drill rods and lowered through the hollow-stem augers to the bottom of the borehole. The split-spoon sampler was then driven approximately 18 inches to collect a soil sample, with the target sampling depth positioned in the center of the soil core. The loaded sampler and sampling rod were removed from the auger column. If a lower depth was to be sampled, the pilot assembly and center rod were reinserted.

During the demonstration, split-spoon samplers were used with and without acetate liners because formations that are weakly cohesive or hard commonly produce poor recovery with liners. Several boreholes were initially installed at each site to determine whether liners would be used, based on the driller's experience and the cohesiveness of the soil. Liners were used at SBA site Grid 1 and at half of the cells at Grid 3. Liners were also used for target sampling depths at half of the 3-foot depth intervals at CSC site Grid 1, and at the 7.5-foot sampling depth at Grid 3. Overall, sample liners were used during collection of about one-third of the reference method samples, including all samples collected to evaluate sample integrity.
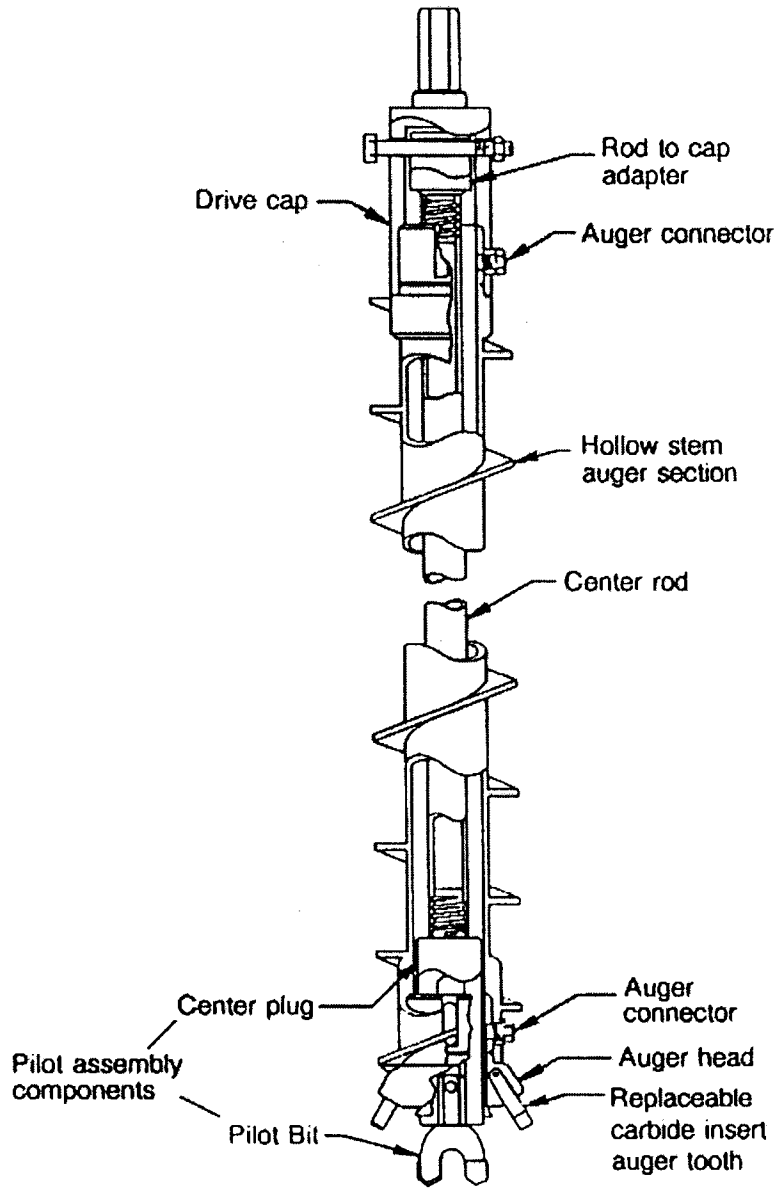
Figure 4-2. Typical Components of a Hollow-Stem Auger (Central Mine Equipment Co., 1994)

Once a split-spoon sampler was retrieved from the borehole, the drive head and cutting shoe were loosened. If the sampler contained a liner, the liner was removed, capped, and taken directly to the sample preparation table for subsampling and sample packaging. If the split spoon did not contain a liner, the sampler was taken directly to the sample preparation table and opened for immediate subsampling and sample packaging.

Split-spoon samplers were decontaminated before each use by scrubbing the disassembled sampler parts with a stiff-bristle brush in a phosphate-free soap and water solution. This process was intended to remove the residual soil as well as chemical contaminants. After washing, the sampler parts were rinsed in potable water and reassembled for use at the next sampling point. Augers, larger tools, and the drill rig were decontaminated between each grid with a high-pressure hot water wash.

Qualitative Performance Factors

The following qualitative performance factors were assessed for the reference sampling method: (1) reliability and ruggedness under the test conditions, (2) training requirements and ease of operation, (3) logistical requirements, (4) sample handling, (5) performance range, and (6) quantity of IDW generated during the demonstration.

Reliability and Ruggedness

Overall, the initial sampling success rate for the reference sampling method, defined as the rate of success in obtaining a sample on the initial attempt, was 93 percent. At the SBA site, the reference sampling method did not collect a sample on the initial drive in four of 42 attempts, resulting in an initial sampling success rate of 90 percent. At this site, two of the samples had insufficient recovery; one sample was not collected because drilling refusal was encountered above the target sampling depth, and one sample was not collected because the boring was drilled beyond the target sampling depth. At the CSC site, the reference sampling method did not collect a sample on the initial drive in two of 41 attempts, resulting in an initial sampling success rate of 95 percent. At this site, two samples were not collected because the borings were drilled beyond the target sampling depth. Drilling beyond the target depth is considered an operator error and was not caused by the sampling tool. Target sampling depths were determined by measuring the height of the auger above the ground surface, and subtracting the measured value from the total length of augers in use. During the saturated sand recovery test at Grid 5 at the CSC site, the reference method collected all seven samples on the initial try.

During the sampling at the SBA and CSC sites, the driller attempted sampling with and without sample liners to optimize soil sample recovery. In general, the greatest sample recovery was obtained without the use of liners.

Sampling downtime occurred three times during the demonstration. Each of these events occurred at the SBA site and are described as follows:

1. The main hydraulic cylinder on the drill rig began to leak at the start of drilling at Grid 5, resulting in the loss of less than 1 quart of hydraulic oil. The hose was repaired by a local farm implement dealer soon after it was removed from the rig. This breakdown resulted in approximately 2.5 hours of sampling downtime.

2. Drilling at Grid 5 was conducted with the mast down due to the proximity of overhead power lines. This arrangement prohibited the use of the drill rig winches to remove the augers and drill rod from the boring. While lifting out the center plug and attaching the drill rod, the rod

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fell back into the hole. The top of the fallen rod was well below the open end of the auger string. The drillers required approximately 10 minutes to retrieve the fallen drill rod.

3. During drilling at one sampling cell, material entered the auger bit and caused the center plug to jam. Drilling proceeded to the target depth, but the drillers required several minutes to free the center plug.

As discussed above, the Mobile B-47 drill rig experienced mechanical problems en route to the CSC site, delaying its arrival at the site. Because of this delay, a Mobile D-5 drill rig was obtained from a local drilling company and was used to advance soil borings and collect soil samples until the Mobile B-47 arrived. Although drilling startup was delayed a half day because of the last-minute change in drill rigs, no sampling downtime occurred during drilling and no additional drilling costs were incurred.

Training Requirements and Ease of Operation

Operation of the drill rig requires training and experience. The lead driller for this project had 17 years of environmental drilling experience and was a licensed driller in the states of Iowa and Colorado. Although the various drill rig manufacturers offer training in specific drilling techniques, much of a driller's training is obtained on the job, in a fashion similar to an apprenticeship. The state licenses require the driller to pass a written test and to renew the drilling license periodically.

The moving parts of a drill rig pose a risk of injury to the head, eyes, and feet, which can be protected with hard hat, safety glasses, and steel-toed boots. Leather gloves facilitate the safe assembly and disassembly of the split-spoon sampler. Additional personal protective equipment may be required in accordance with site-specific health and safety requirements.

Logistical Requirements

Some states require licenses for personnel conducting subsurface sampling. The sampler or equipment operator must contact appropriate state or local agencies to determine the applicability of any license or permit requirements. Additionally, underground utility clearances are usually needed before sampling with any intrusive subsurface equipment.

The augers created 6.25-inch-diameter boreholes, which were filled using neat-Portland cement grout at the SBA site and dry granular bentonite at the CSC site. Demonstration drilling generated 15 drums of soil cuttings at the SBA site and three drums of soil cuttings at the CSC site.

The drill rigs used in the demonstration were powered by an on-board engine and needed no external power source (other than fuel). Decontamination water can be carried on the truck, but a support truck with a 250-gallon tank was used to transport, store, and provide water for decontamination for the demonstration. Small tools and split-spoon samplers were decontaminated in a steel stock tank, while augers and drill rods were decontaminated in an on-site decontamination containment area with a high-pressure hot water washer.

Sample Handling

During the demonstration, liners were not used in the collection of approximately two-thirds of the split-spoon samples. This method allowed easy access to the sample by removing the drive head and cutting shoe and separating the two halves of the sampler. Liners were used in noncohesive soils

because opening the split spoon without a liner would have allowed the sample core to collapse and disrupt sample integrity. After the liner was removed from the split spoon, it was capped and taken immediately to the sample packaging area for processing. Prior to sampling, the liner was split open to allow access to the soil for subsampling.

Performance Range

The depth limitations of the reference method are based on the torque provided by the drill rig, the strength of the augers, the diameter of the augers, and the textures of the formations penetrated. During the demonstration, samples were collected from a maximum depth of 40 feet bgs in Grid 5 at the CSC site. However, depths of 300 feet or more have been drilled with high-torque drill rigs using high-strength augers. This drilling and sampling method is inappropriate for unconsolidated formations containing large cobbles or boulders. In addition, the use of this method below the water table in sandy, noncohesive formations generally leads to sand heave into the augers, making borehole advancement and sampling difficult.

Investigation-Derived Waste

The IDW for the reference method primarily consisted of decontamination fluids and soil cuttings. Approximately 100 gallons of decontamination wastewater was generated at the SBA site, and approximately 50 gallons of decontamination wastewater was generated at the CSC site.

Soil cuttings were also generated during advancement of the boreholes. Eighteen 55-gallon drums of soil cuttings were generated during this demonstration: three at the CSC site and 15 at the SBA site. Fewer drums were generated at the CSC site due to the shallower sampling depths and the noncohesive nature of the soil. Reverse rotation during auger withdrawal allowed most of the sand to travel down the auger flights and back into the borehole at the CSC site. In addition to decontamination fluids and soil cuttings, sample liners and other materials were generated as IDW.

Quantitative Performance Factors

The following quantitative performance indicators were measured for the reference sampling method: (1) sample recovery, (2) VOC concentrations in recovered samples, (3) sample integrity, and (4) sample throughput.

Sample Recovery

Sample recoveries for the reference sampling method were calculated by comparing the length of sampler advancement to the length of sample core obtained for each attempt. Sample recovery is defined as the length of recovered sample core divided by the length of sampler advancement and is expressed as a percentage. At the SBA site, sample recoveries ranged from 40 percent to 100 percent, with an average of 88 percent. At the CSC site, recoveries ranged from 53 percent to 100 percent, with an average of 87 percent. Sample recovery data for each sample collected are summarized in Appendix A2, Table A2.

Volatile Organic Compound Concentrations

Samples were collected using the reference sampling method at each sampling depth, as described in Chapter 3. Samples were analyzed for VOCs by combining headspace sampling with GC analysis

according to the standard operating procedure (SOP) provided in the demonstration plan (PRC, 1997). Table 4-1 presents the range and median VOC concentrations for samples collected using the reference sampling method. The VOC results for each sample collected are summarized in Appendix A3, Table A3. For seven of the 12 sampling grid-depth combinations, VOC data for some samples collected are not available due to laboratory error; in these cases, the range and median were calculated from the remaining sample data.

Data are reported on a dry-weight basis. Chapter 5 presents a statistical comparison of the analytical results obtained using the reference method to those obtained using the Dual Tube Liner Sampler.

Sample Integrity

Seven integrity samples were collected using the reference sampling method in Grid 1 at the SBA site, and five integrity samples were collected using the reference sampling method in Grid 1 at the CSC site. No VOCs were detected in any of the integrity samples collected using the reference sampling method (the method detection limit for these analyses was 1 μg/kg). Sample liners were used during collection of the integrity samples at both the SBA and CSC sites, but liners were not used in collecting approximately two-thirds of the soil samples collected during the demonstration. Because of this sampling deviation, the integrity of all samples collected using the reference method cannot be verified.

Sample Throughput

The average sample retrieval time for the reference sampling method was 26 minutes per sample for the SBA site and 8.4 minutes per sample for the CSC site. Sample retrieval time was measured as the amount of time required per sample to set up at a sampling point, collect the specified sample, grout the hole, decontaminate the sampling equipment, and move to a new sampling location. A three-person sampling crew collected soil samples using the reference sampling method at both sites. One additional person was present at the CSC site to direct drilling operations and assist with demonstration sampling, as necessary. The large discrepancy in the sample retrieval time between the SBA and CSC sites is due, in part, to the difference in average sampling depth (10 feet at the SBA site versus 5 feet at the CSC site) and soil type (clay versus sandy soil).

Data Quality

Data quality was assessed throughout this demonstration by implementing an approved quality assurance project plan (PRC, 1997). The QA/QC procedures included the consistent application of approved methods for sample collection, chemical analysis, and data reduction. Based on the intended use of the data, QA objectives for precision, accuracy, representativeness, comparability, and completeness were established, and QC samples were collected to assess whether the QA objectives were met. Based on the results of a field audit conducted by the EPA and a detailed validation of the demonstration data by Tetra Tech, the data have been deemed acceptable for use as described in the demonstration design (Chapter 3). The results of the QC indicators used for this demonstration for both the reference sampling method and Dual Tube Liner Sampler are provided in the technology evaluation report for this demonstration (Tetra Tech, 1997) and are summarized here.

The VOC data quality was assessed through the incorporation of QC samples into the analytical process for each sample delivery group, and through a full data validation review on 20 percent of the samples. Specific QC samples that were processed to assess precision and accuracy included matrix spike/matrix

Table 4-1. Volatile Organic Compound Concentrations in Samples Collected Using the Reference Sampling Method

		Concentration (μg/kg)							
		cis-1,2-DCE		1,1,1-TCA		TCE		PCE	
Site	Grid - Depth	Range	Median	Range	Median	Range	Median	Range	Median
SBA	1 - 9.5 feet	49,700 - 147,000	86,700	<100	NC	52,800 - 419,000	276,000	<100 - 4,510	1,630
SBA	1 - 13.5 feet	1,360 - 44,900	14,500	<100	NC	26,700 - 433,000	40,500	<100 - 2,400	NC
SBA	2 - 3.5 feet	<1 - 2.18	NC	<1	NC	22.6 - 88.8	56.9	<1	NC
SBA	3 - 9.5 feet[*]	796 - 1,460	903	<100	NC	34,100 - 63,700	38,500	<100	NC
SBA	4 - 9.5 feet	6.68 - 22.1	13.2	<1	NC	847 - 2,080	1,710	<1	NC
SBA	5 - 13.5 feet[†]	33.7 - 147	93.6	<1	NC	<1 - 138	21.0	<1	NC
CSC	1 - 3.0 feet[†]	<100	NC	<100 - 659	NC	<100	NC	1,880 - 6,220	2,530
CSC	1 - 6.5 feet[†]	<1 - 5.81	2.20	13.1 - 54.6	26.0	3.47 - 22.4	6.45	58.5 - 848	112
CSC	2 - 3.0 feet	<100	NC	<100 - 984	NC	<100 - 435	126	1,560 - 2,910	2,000
CSC	3 - 3.0 feet[†]	<100	NC	<100 - 313	NC	<100	NC	1,030 - 2,110	1,490
CSC	3 - 7.5 feet[*]	<1 - 7.35	4.12	3.81 - 21.9	13.9	2.48 - 31.7	14.9	21.1 - 177	73.0
CSC	4 - 6.5 feet[††]	<1 - 5.72	NC	<1 - 51.4	8.09	<1 - 43.3	2.37	5.55 - 749	50.3

μg/kg	Micrograms per kilogram	PCE	Tetrachloroethene
cis-1,2-DCE	cis-1,2-Dichloroethene	SBA	Small Business Administration site
1,1,1-TCA	1,1,1-Trichloroethane	TCE	Trichloroethene
CSC	Chemical Sales Company site	†	VOC data for only six samples are available
*	VOC data for only four samples are available	††	VOC data for only five samples are available
		NC	No median calculated because at least half the reported values were below the method detection limit.

spike duplicates (MS/MSDs), laboratory control samples (LCSs), and method blanks. Additionally, surrogate spikes were used in all samples.

The LCSs and matrix spikes were analyzed at frequencies of 8.3 percent and 3.9 percent, respectively. With few exceptions, the QA objective of 50 to 150 percent recovery was met for LCS and MS samples, indicating that acceptable accuracy was achieved. The few exceptions to meeting this objective were primarily for vinyl chloride; these exceptions are attributable to the high volatility of vinyl chloride and apparently result from its vaporization during the analytical process.

Surrogate spike recoveries were also used to evaluate accuracy. Surrogate recoveries were problematic for the methanol flood method for high-concentration samples, indicating a reduced accuracy for these samples. Surrogate recoveries were consistently within the QA objective of 50 percent to 150 percent recovery for low-concentration samples.

Seventeen MS/MSD pairs, representing a 3.6 percent frequency, were analyzed to assess the precision of the analytical method. The relative percent differences (RPDs) of the duplicate results were consistently less than the QA objective of 50 percent; only a few exceptions were noted. Thus, method precision appeared to be adequate for the intended use of the data.

Analysis of method blanks revealed only occasional contamination with low part-per-billion levels of chlorinated hydrocarbons. The frequency and levels of these contaminants were not judged to be sufficient to significantly affect data quality except for those results at or near the detection limit in the specific sample delivery group.

The data validation review noted chromatographic separation and coelution problems for vinyl chloride. As a result, all vinyl chloride data were rejected. Other analytes were flagged as having data quality problems in isolated instances and in response to specific exceptions to the QA objectives, as described generally above. Details of these and all other data quality issues can be found in the technology evaluation report for this demonstration (Tetra Tech, 1997).

Chapter 5
Technology Performance

This chapter describes the performance of the AMS™ Dual Tube Liner Sampler and assesses qualitative and quantitative performance factors. A description of the Dual Tube Liner Sampler is provided in Chapter 2 of this ETVR.

Qualitative Performance Factors

The following qualitative performance factors were assessed for the Dual Tube Liner Sampler: (1) reliability and ruggedness under the test conditions, (2) training requirements and ease of operation, (3) logistical requirements, (4) sample handling, (5) performance range, and (6) quantity of IDW generated during the demonstration.

Reliability and Ruggedness

Overall, the initial sampling success rate for the Dual Tube Liner Sampler, defined as the ratio of the number of successful sampling attempts (sample obtained on the initial attempt) to the total number of sampling attempts, was 98 percent. At the SBA site, the Dual Tube Liner Sampler did not collect a sample in the initial push in one of 42 attempts, resulting in an initial sampling success rate of 98 percent. The sample liner was lost during that attempt due to overfilling. The sample was retrieved on the second attempt. At the CSC site, the Dual Tube Liner Sampler did not collect a sample in the initial push in one of 42 attempts, resulting in an initial sampling success rate of 98 percent. The soil sample was lost when unconsolidated sand fell from the bottom of the liner. The problem was corrected by fashioning retaining baskets out of liner caps. All required samples at both sites were eventually collected by conducting multiple sampling pushes, resulting in 100 percent completeness.

The Dual Tube Liner Sampler was subjected to additional evaluation at Grid 5 at the CSC site to assess efficiency of the sampler in collecting samples in saturated sand. Only one saturated sample was collected at Grid 5 at the CSC site in one attempt, resulting in an initial sampling success rate of 100 percent. The developer did not attempt to collect additional samples from the 40-foot interval due to excessive friction on the outer extension.

Training Requirements and Ease of Operation

Less than 1 hour of hands-on training was required to become proficient in assembling and using the Dual Tube Liner Sampler. To learn the assembly procedure, the sampling team should assemble the Dual Tube Liner Sampler two to three times. The operation of an advancement platform to drive the sampler requires training and experience. The many moving parts pose a risk of injury to the head, eyes, and feet which can be protected with a hard hat, safety glasses, and steel-toed boots. Leather

gloves facilitated the assembly and disassembly of the Dual Tube Liner Sampler. Additional personal protective equipment may be required in accordance with site-specific health and safety requirements.

Logistical Requirements

Some states require licenses for personnel conducting subsurface sampling. The sampler or equipment operator must contact the appropriate state or local agencies to assess the applicability of any license or permit requirements. Additionally, underground utility clearances are needed before sampling with any intrusive subsurface equipment.

The physical impact of demonstration sampling on the site was minimal. The platform used to push the Dual Tube Liner Sampler during the demonstration was mounted on a pickup truck. The push platform used during the demonstration caused minimal wear to the ground in and around the sampling grids. The Dual Tube Liner Sampler left approximately 2-inch-diameter holes, which were grouted with neat-Portland cement at the SBA site and with dry granular bentonite at the CSC site. No drill cuttings were generated during use of the Dual Tube Liner Sampler.

The push platform is powered by an on-board engine and needs no external power source (other than fuel). Only a limited amount of water (approximately 5 gallons per day) and a wash rack attached to the push platform were necessary for adequate sampler decontamination.

Sample Handling

The sample liner was easily accessible by removing the sampler assembly from the outer extension. After a Dual Tube Liner Sampler was retrieved from a borehole, it was immediately taken to the sample packaging area for processing. To minimize volatilization, the sample liners were capped and were not opened until subsampling.

Performance Range

The performance range of the Dual Tube Liner Sampler depends in part on the capability of the platform advancing the sampler. During the demonstration, the Dual Tube Liner Sampler successfully collected samples at depths of up to 13.5 feet bgs. However, when the Dual Tube Liner Sampler attempted to collect a sample from 40 feet bgs in Grid 5 at the CSC site, damage to the pull yoke was observed when retrieving the Dual Tube Liner Sampler. This depth may define a lower performance limit for the sampler and push platform in sandy soil. Because the sampler was not depth-limited in the clay soils at the SBA site, no performance range can be postulated for clay soils.

Investigation-Derived Waste

Minimal IDW was generated by the Dual Tube Liner Sampler during the demonstration. The direct-push advancement platforms generated no soil cuttings, so the only soil waste created was that remaining in the sampler after the demonstration sample was collected for chemical analysis. Approximately 10 gallons of soil was generated at each site by the Dual Tube Liner Sampler.

Decontamination of the Dual Tube Liner Sampler generated approximately 5 gallons of wastewater per day. This quantity was sufficient to decontaminate all sampler components in both Alconox® mixture and rinse water for an 8-hour sampling period. In addition to soil and wastewater, sample liners (when used) and other materials were also generated as IDW.

Table 5-1 presents a comparison of the IDW generated by the Dual Tube Liner Sampler and the reference sampling method during this demonstration.

Table 5-1. Investigation-Derived Waste Generated During the Demonstration

Sampler	Sampling Platform	Soil Generated	Wastewater Generated
Dual Tube Liner Sampler	Push	20 gallons	25 gallons
Reference Sampler	Drilling	990 gallons	150 gallons

Quantitative Performance Assessment

Quantitative measures of the Dual Tube Liner Sampler's performance consisted of (1) sample recovery, (2) VOC concentrations in recovered samples, (3) sample integrity, and (4) sample throughput.

Sample Recovery

Sample recoveries for the Dual Tube Liner Sampler were calculated by comparing the length of sampler advancement to the length of sample core obtained for each attempt. Sample recovery is defined as the length of recovered sample core divided by the length of sampler advancement and is expressed as a percentage. At the SBA site, sample recoveries ranged from 42 percent to 100 percent with an average of 91 percent. At the CSC site, the recoveries ranged from 46 percent to 88 percent with an average of 70 percent. Sample recovery data for each sample collected are summarized in Appendix A2, Table A2.

Average sample recoveries for the Dual Tube Liner Sampler were greater at the SBA site because the clay soils helped to hold the soil in the sampler. Filling the sampler and holding the less-cohesive, sandy soils at the CSC site were more difficult.

Table 5-2 presents a comparison of sample recoveries achieved by the Dual Tube Liner Sampler and the reference sampling method during this demonstration. Compared to the reference method, average sample recoveries for the Dual Tube Liner Sampler were higher in clay soil and lower in sandy soil.

A possible explanation for the different sample recoveries achieved by the Dual Tube Liner Sampler and the reference sampler at the CSC site is that the Dual Tube Liner Sampler was not equipped with an engineered retaining basket, potentially causing the loss of material loosely compacted in the Dual Tube Liner Sampler.

Volatile Organic Compound Concentrations

Samples were collected with the Dual Tube Liner Sampler at each sampling grid-depth described in Chapter 3. Samples were analyzed for VOCs by combining headspace sampling with gas chromatography analysis according to the SOP provided in the demonstration plan (PRC, 1997).

Table 5-2. Sample Recoveries for the Dual Tube Liner Sampler and the Reference Sampling Method

		Sample Recovery (percent)	
Sampler	Site	Range	Average
Dual Tube Liner Sampler	SBA	42 to 100	91
Reference Sampler	SBA	40 to 100	88
Dual Tube Liner Sampler	CSC	46 to 88	70
Reference Sampler	CSC	53 to 100	87

Table 5-3 presents the range and median VOC concentrations for samples collected using the Dual Tube Liner Sampler. Data are reported on a dry-weight basis. For three of the 12 sampling grid-depth combinations, VOC data for some samples collected are unavailable due to laboratory error; in these cases, the range and median were determined from the remaining sample data. A summary of the number of samples collected and analyzed for each analyte at each site is presented in Table 5-4.

As described in Chapter 3, two statistical evaluations of the VOC concentration data were conducted: one using the Mann-Whitney test and the other using the sign test. Table 5-4 lists the number of analyte values used in the statistical evaluations. For the Mann-Whitney test, a statistical evaluation of the VOC concentration data was conducted based on the null hypothesis that there is no difference between the median contaminant concentrations obtained by the Dual Tube Liner Sampler and the reference sampling method described in Chapter 4. In addition, statistical evaluations using the Mann-Whitney and sign tests were conducted only when at least half of the reported values were above the method detection limit for the grid, depth, and analyte combination.

The two-tailed significance level for this null hypothesis was set at 5 percent (2.5 percent for one-tailed); that is, if a two-tailed statistical analysis indicates a probability of greater than 5 percent that there is no significant difference between data sets, it will be concluded that there is no significant difference between the data sets. Because the data are not normally distributed, the Mann-Whitney test, a nonparametric method, was used to test the statistical hypothesis for VOC concentrations. The Mann-Whitney test makes no assumptions regarding normality and assumes only that the differences between the medians of two independent random samples may be determined—in this case, the reported chemical concentrations of soils collected by two different sampling systems. The Mann-Whitney test was used because of its historical acceptability and ease of application to small data sets.

Table 5-5 lists the median VOC concentrations calculated from data for samples collected with the Dual Tube Liner Sampler and the reference sampling method and indicates whether there is a significant difference (p $\leq$ 0.05) in VOC data sets for each sampling grid and depth for each analyte based on the Mann-Whitney test. A comparative summary of the Mann-Whitney statistics for the Dual Tube Liner Sampler and reference sampling method is presented in Appendix A4, Table A4. A total of 48 grid,

Table 5-3. Volatile Organic Compound Concentrations in Samples Collected Using the Dual Tube Liner Sampler

		Concentration (μg/kg)							
		cis-1,2-DCE		1,1,1-TCA		TCE		PCE	
Site	Grid - Depth	Range	Median	Range	Median	Range	Median	Range	Median
SBA	1 - 9.5 feet	38,100 - 156,000	80,200	<100	NC	64,800 - 238,000	167,000	<100 - 1,730	990
SBA	1 - 13.5 feet	1,100 - 42,500	9,900	<100	NC	24,800 - 332,000	47,500	<100 - 1,670	NC
SBA	2 - 3.5 feet	<1 - 4.24	NC	<1	NC	33.6 - 95.5	86.9	<1	NC
SBA	3 - 9.5 feet	<100 - 601	537	<100	NC	12,000 - 48,000	19,800	<100	NC
SBA	4 - 9.5 feet	7.55 - 47.7	25.2	<1	NC	1,020 - 3,180	1,910	<1	NC
SBA	5 - 13.5 feet	69.2 - 374	166	<1	NC	12.0 - 252	106	<1	NC
CSC	1 - 3.0 feet	<100	NC	<100 - 197	NC	<100	NC	445 - 3,150	903
CSC	1 - 6.5 feet [†]	<1 - 11.8	3.76	<1 - 75.5	26.9	<1 - 12.1	4.23	11.4 - 109	71.4
CSC	2 - 3.0 feet	<100	NC	<100	NC	<100	NC	483 - 1,790	676
CSC	3 - 3.0 feet [††]	<100	NC	<100	NC	<100	NC	1,500 - 2,210	1,620
CSC	3 - 7.5 feet	<1 - 3.77	NC	18.6 - 45.1	20.3	5.18 - 14.6	8.04	17.0 - 98.8	35.0
CSC	4 - 6.5 feet [†]	<1	NC	<1 - 22.0	11.3	<1 - 3.84	2.70	11.2 - 65.7	39.2

μg/kg	Micrograms per kilogram	PCE	Tetrachloroethene
cis-1,2-DCE	cis-1,2-Dichloroethene	SBA	Small Business Administration site
1,1,1-TCA	1,1,1-Trichloroethane	TCE	Trichloroethene
CSC	Chemical Sales Company site	†	VOC data for only six samples are available
NC	No median calculated because at least half the reported values were below the method detection limit.	††	VOC data for only five samples are available

Table 5-4. Demonstration Data Summary for the Dual Tube Liner Sampler and Reference Sampling Method

Site	Grid	Depth (feet)	Number of Samples Analyzed	Number of Data Points Above the Method Detection Limit			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
SBA			**Dual Tube Liner Sampler**				
	1	9.5	7	7	0	7	6
	1	13.5	7	7	0	7	1
	2	3.5	7	1	0	7	0
	3	9.5	7	6	0	7	0
	4	9.5	7	7	0	7	0
	5	13.5	7	7	0	7	0
			Reference Sampling Method				
	1	9.5	7	7	0	7	6
	1	13.5	7	7	0	7	1
	2	3.5	7	1	0	7	0
	3	9.5	4	4	0	4	0
	4	9.5	7	7	0	7	0
	5	13.5	6	6	0	5	0
CSC			**Dual Tube Liner Sampler**				
	1	3.0	7	0	1	0	7
	1	6.5	6	4	5	4	6
	2	3.0	7	0	0	0	7
	3	3.0	5	0	0	0	5
	3	7.5	7	1	7	7	7
	4	6.5	6	0	5	4	6
			Reference Sampling Method				
	1	3.0	6	0	3	0	6
	1	6.5	6	4	6	6	6
	2	3.0	7	0	3	4	7
	3	3.0	6	0	1	0	6
	3	7.5	4	3	4	4	4
	4	6.5	5	2	4	3	5

Note: Medians were not calculated for data sets when at least half of the reported values within the data set were below the method detection limit.

Table 5-5. **Comparison of Median Volatile Organic Compound Concentrations of Dual Tube Liner Sampler and Reference Sampler Data and Statistical Significance**

		Median Concentration (μg/kg) and Significance												
		cis-1,2-DCE			1,1,1-TCA			TCE			PCE		
Site	Grid - Depth	AMS[TM]	Ref.	Sign.	AMS[TM]	Ref.	Sign.	AMS[TM]	Ref.	Sign.	AMS[TM]	Ref.	Sign.
SBA	1 - 9.5 feet	80,200	86,700	No	NC	NC	*	167,000	276,000	No	990	1,630	No
SBA	1 - 13.5 feet	9,900	14,500	No	NC	NC	*	47,500	40,500	No	NC	NC	*
SBA	2 - 3.5 feet	NC	NC	*	NC	NC	*	86.9	56.9	No	NC	NC	*
SBA	3 - 9.5 feet	537	903	Yes	NC	NC	*	19,800	38,500	No	NC	NC	*
SBA	4 - 9.5 feet	25.2	13.2	No	NC	NC	*	1,910	1,710	No	NC	NC	*
SBA	5 - 13.5 feet	166	93.6	No	NC	NC	*	106	21.0	No	NC	NC	*
CSC	1 - 3.0 feet	NC	NC	*	NC	NC	*	NC	NC	*	903	2,530	Yes
CSC	1 - 6.5 feet	3.76	2.20	No	26.9	26.0	No	4.23	6.45	No	71.4	112	No
CSC	2 - 3.0 feet	NC	NC	*	NC	NC	*	NC	126	*	676	2,000	Yes
CSC	3 - 3.0 feet	NC	NC	*	NC	NC	*	NC	NC	*	1,620	1,480	No
CSC	3 - 7.5 feet	NC	4.12	*	20.3	13.9	Yes	8.04	14.9	No	35.0	73.0	No
CSC	4 - 6.5 feet	NC	NC	*	11.3	8.09	No	2.70	2.37	No	39.2	50.3	No

μg/kg	Micrograms per kilogram	PCE	Tetrachloroethene
cis-1,2-DCE	cis-1,2-Dichloroethene	AMS[TM]	Dual Tube Liner Sampler
1,1,1-TCA	1,1,1-Trichloroethane	Ref.	Reference sampling method
TCE	Trichloroethene	Sign.	Significance
SBA	Small Business Administration site	CSC	Chemical Sales Company site
NC	No median calculated because at least half the reported values were below the method detection limit.	*	A statistical comparison could not be made because an insufficient number of VOC concentrations were detected

depth, and analyte combination pairs were collected during the demonstration. Of the 48 pairs, only 25 data sets were obtained: 12 from the SBA site and 13 from the CSC site. A statistical comparison could not be made for the remaining data sets because at least half of the reported values from the Dual Tube Liner Sampler or reference sampling method were below the method detection limit. According to the Mann-Whitney test, there is a statistically-significant difference in the data sets collected using the Dual Tube Liner Sampler and the reference sampling method in four of 25 cases. Statistically significant differences were identified in one pair at the SBA site and in three pairs at the CSC site. The statistically significant difference at the SBA site involved data collected from Grid 3 at the 9.5-foot sampling depth for the analyte cis-1,2-DCE. The statistically significant difference at the CSC site involved data collected from Grid 1 at the 3-foot sampling depth for the analyte PCE, Grid 2 at the 3-foot sampling depth for the analyte PCE, and Grid 3 at the 7.5-foot sampling depth for the analyte 1,1,1-TCA. Figure 5-1 presents a graphic representation of median VOC concentrations of the Dual Tube Liner Sampler versus the median VOC concentrations of the reference sampling method for each contaminant at each depth.

To test potential bias between the data sets, a statistical analysis using the sign test was conducted. As discussed in Chapter 3, the sign test is a nonparametric statistical method that counts the number of positive and negative signs among the differences. The differences tested, in this instance, were the differences in the medians of paired data sets (within a site, within a grid, at a depth, and for each analyte). From the data sets, counts were made of (1) the number of pairs in which the reference sampling method median concentrations were higher than the Dual Tube Liner Sampler median concentrations and (2) the number of pairs in which the Dual Tube Liner Sampler median concentrations were higher than the reference sampling method median concentrations. The total number of pairs in which the median concentrations were higher with the Dual Tube Liner Sampler were then compared with the total number of pairs in which the median concentrations were higher with the reference sampling method. If no bias is present in the data sets, the probability of the total number of pairs for one or the other test method being higher is equivalent; that is, the probability of the number of pairs in which the median concentrations in the Dual Tube Liner Sampler are higher is equal to the probability of the number of pairs in which the median concentrations in the reference sampling method are higher. To determine the exact probability of the number of data sets in which the median concentrations in the Dual Tube Liner Sampler and reference sampling method were higher, a binomial expansion was used. If the calculated probability is less than 5 percent ($p < 0.05$), then a significant difference is present between the Dual Tube Liner Sampler and reference sampling method.

The sign test data are provided in Table 5-6 and are summarized in Appendix A5, Table A5. At both the SBA and CSC sites, the calculated probabilities are greater than 0.05; therefore, the differences are not statistically significant.

Sample Integrity

Five integrity test samples were collected with the Dual Tube Liner Sampler in Grid 1 at the SBA site, and seven integrity samples were collected in Grid 1 at the CSC to determine if potting soil in a lined sampler interior became contaminated after it is advanced through a zone of high VOC concentrations. For the Dual Tube Liner Sampler, VOCs were detected in only one of the 12 integrity samples. The sample was collected at the CSC site. The VOC detected in potting soil at the CSC site was cis-1,2-DCE at a concentration of 6.07 μg/kg. These results indicate that the integrity of a lined chamber in

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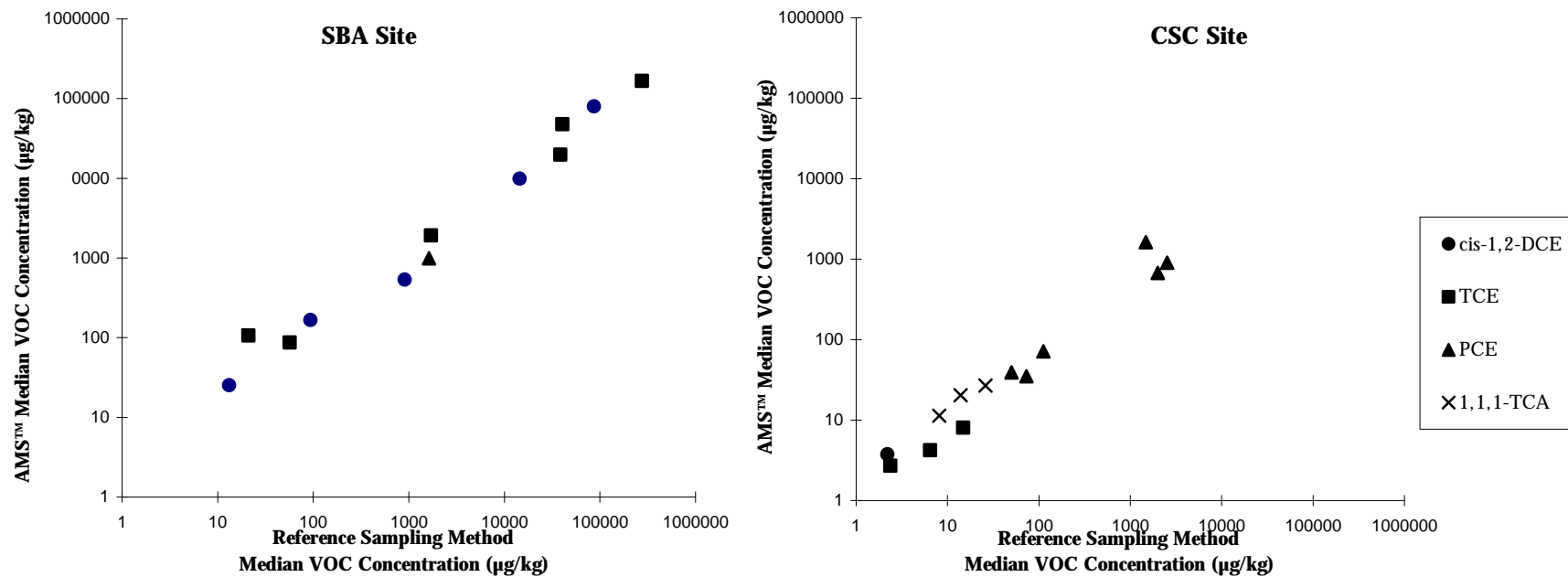
Note: μg/kg = micrograms per kilogram

Figure 5-1.   Comparative Plot of Median VOC Concentrations for the Dual Tube Liner Sampler and the Reference Sampling Method at the SBA and CSC Sites

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Table 5-6. Sign Test Results for the Dual Tube Liner Sampler and the Reference Sampling Method

	Number of Pairs in which the Median Concentration Is Higher than other Method	
Sampler	**SBA Site**	**CSC Site**
Reference Sampler	6	7
Dual Tube Liner Sampler	6	6
Total Comparisons	12	13
Calculated Probability	0.226	0.157

the Dual Tube Liner Sampler is generally well preserved when the sampler is advanced through highly contaminated soils. Results of sample integrity tests for the reference sampling method indicate no contamination in the potting soil after advancement through a zone of high VOC concentrations. Because potting soil has an organic carbon content many times greater than typical soils, the integrity tests represent a worst-case scenario for VOC absorbance and may not be representative of cross-contamination under normal field conditions.

Sample Throughput

Sample retrieval time was measured as the amount of time required to set up at a sampling point, collect the specified sample, grout the hole, decontaminate the sampling equipment, and move to a new sampling location. The average sample retrieval times for the Dual Tube Liner Sampler was 16.4 minutes per sample for the SBA site and 10.9 minutes per sample for the CSC site. Two people collected soil samples at both the SBA and CSC sites. Table 5-7 presents a comparison of average sample retrieval times for the Dual Tube Liner Sampler and the reference sampling method. The average sample retrieval rates for the Dual Tube Liner Sampler were quicker than the reference sampling method when collecting samples in the clay soils at the SBA site and slower when collecting samples in the sandy soils at the CSC site.

Data Quality

Data quality was assessed throughout this demonstration by implementing an approved quality assurance project plan (PRC, 1997). The QA/QC procedures included the consistent application of approved methods for sample collection, chemical analysis, and data reduction. Based on the intended use of the data, QA objectives for precision, accuracy, representativeness, comparability, and completeness were established and QC samples were collected to assess whether the QA objectives were met. Based on the results of a field audit conducted by the EPA and a detailed validation of the demonstration data by Tetra Tech, the data have been deemed acceptable for use as described in the demonstration design (Chapter 3). The results of the QC indicators used for this demonstration for both the Dual Tube Liner Sampler and reference sampling method are provided in the Technology Evaluation Report for this demonstration (Tetra Tech, 1997) and are summarized in the data quality section of Chapter 4 of this ETVR.

**Table 5-7. Average Sample Retrieval Times for the Dual Tube Liner Sampler and the
Reference Sampling Method**

Sampler	Average Sample Retrieval Time (minutes per sample)	
	SBA Site	CSC Site
Dual Tube Liner Sampler	16.4	10.9
Reference Sampling Method	26	8.4

Note: Two people collected soil samples using the Dual Tube Liner Sampler at both the SBA and CSC sites, and
three people collected soil samples using the reference sampling method at both sites. Additional
personnel were present at both sites to observe and assist with demonstration sampling, as necessary.

Chapter 6
Economic Analysis

The Dual Tube Liner Sampler was demonstrated at two sites that varied geologically and were contaminated with VOCs at a range of concentrations. This chapter presents an economic analysis for applying the Dual Tube Liner Sampler at sites similar to those used in this demonstration. The demonstration costs for the reference sampling method are also provided.

This economic analysis estimates the range of costs for using an AMS[TM] Dual Tube Liner Sampler to collect 42 subsurface soil samples at a clay soil site (400 feet total depth, similar to the SBA site) and a sandy soil site (200 feet total depth, similar to the CSC site). The analysis is based on the results and experience gained from this demonstration and on costs provided by Art's Manufacturing and Supply. To account for variability in cost data and assumptions, the economic analysis is presented as a list of cost elements and a range of costs for collecting samples using the Dual Tube Liner Sampler.

Assumptions

Several factors affect the cost of subsurface soil sampling. Wherever possible, these factors are identified so that decision-makers can independently complete a site-specific economic analysis. For example, this cost estimate is based on collecting soil samples from clay and sandy soil sites at sampling depths ranging from 3 feet bgs to 13.5 feet bgs and using the average sample retrieval times calculated during the demonstrations of 16.4 minutes per sample for the clay soil site and 10.9 minutes per sample at the sandy soil site. This cost estimate also assumes that a direct-push platform is used to advance the Dual Tube Liner Sampler and that a hollow-stem auger drilling platform is used to advance the reference method.

Dual Tube Liner Sampler

The costs for collecting soil samples using the Dual Tube Liner Sampler are presented in two categories: (1) equipment costs, which include purchase of the Dual Tube Liner Sampler and rental costs for the push platform, and (2) sampler operating and oversight costs, which include labor costs for sampling and oversight and other direct costs such as supplies, IDW disposal, and site restoration.

The cost categories and associated cost elements are defined and discussed below and serve as the basis for the estimated cost ranges presented in Table 6-1.

Equipment Costs. Equipment costs include the direct-push platform and the Dual Tube Liner Sampler. Direct-push platform costs are limited to weekly equipment rental, including mobilization/ demobilization costs for a PowerProbe 9600 ($1,800 per week). Based on the average retrieval time

Table 6-1. Estimated Subsurface Soil Sampling Costs for the Dual Tube Liner Sampler

Equipment Costs

Rental of PowerProbe 9600 = $1,800 per week
Purchase of Dual Tube Liner Sampler = $1,890

Operating and Oversight Costs

Clay Soil Site		**Sandy Soil Site**	
Total Sampling Time = 11 to 15 hours (2 days)		Total Sampling Time = 8 to 10 hours (1 day)	
Total Samples Collected = 42		Total Samples Collected = 42	
Total Sample Depth = 400 feet		Total Sample Depth = 200 feet	
Sample Crew Size = 2 People		Sample Crew Size = 2 People	
Operating Costs		Operating Costs	
Sample Collection	$1,100 - $1,500	Sample Collection	$800 - $1,000
Per Diem	0 - $600	Per Diem	0 - $300
Oversight Costs		Oversight Costs	
Mobilization/Demobilization	$300 - $500	Mobilization/Demobilization	$300 - $500
Travel	$6 - $30	Travel	$6 - $30
Per Diem	0 - $300	Per Diem	0 - $150
Sampling Oversight	$550 - $750	Sampling Oversight	$400 - $500
Other Direct Costs		Other Direct Costs	
Supplies	$25 - $75	Supplies	$25 - $75
IDW Disposal	$200 - $300	IDW Disposal	$200 - $300
Site Restoration	$100 - $200	Site Restoration	$100 - $200
Range of Operating and Oversight Costs*	**$2,280 - $4,260**		**$1,830 - $3,060**

* The Range of Operating and Oversight Costs is rounded to the nearest tens of dollars and does not include Equipment Costs.

during the demonstration and collecting 42 samples at each site, it is assumed that the direct-push platform will be required for 2 days at the clay soil site and 1 day at the sandy soil site. The Dual Tube Liner Sampler is currently unavailable for rent from AMS™, so only the Dual Tube Liner Sampler purchase cost is presented. The purchase cost for the Dual Tube Liner Sampler is estimated to be $1,890, which includes one plastic grabber ($95), one drive head adapter ($175), one thread protector cap ($75), one drive shoe ($95), five inner 4-foot extensions ($105 each), five outer 4-foot extensions ($148 each), and 42 liners ($4.38 each).

Operating Costs. Operating costs are limited to sample collection labor and per diem. Mobilization/ demobilization labor and travel costs for sampler operation are included in the weekly push platform rental rate. Additional mobilization/demobilization, travel, and per diem costs will apply if the site is greater than 100 miles from the push platform operator.

- Sample Collection Labor Costs — On-site labor includes two equipment operators to collect soil samples. Based on the average demonstration sample retrieval rates, sample collection labor is estimated to be 11 to 15 hours each for two personnel at the clay soil site, and 8 to 10 hours each for two personnel at the sandy soil site. Labor rates are estimated at $50 per hour. This labor estimate includes time for decontamination and site restoration.

- Per Diem Costs — This cost element includes food, lodging, and incidental expenses, and is estimated to range from zero (for a local site) to $150 per day per person for two people for 2 days at the clay soil site (2 days for sample collection, mobilization/demobilization, and site restoration) and for 1 day at the sandy soil site (1 day for sample collection, mobilization/ demobilization, and site restoration).

Oversight Costs. Oversight costs are presented as a range to provide an estimate of oversight costs that may be incurred. Costs for overseeing sampling using the Dual Tube Liner Sampler are segregated into labor costs and other direct costs, as shown below.

Labor costs include mobilization/demobilization, travel, per diem, and sampling oversight costs.

- Mobilization/Demobilization Labor Costs — This cost element includes the time for one person to prepare for and travel to each site, set up and pack up equipment, and return from the field, and includes 6 to 10 hours for one person at a rate of $50 per hour.

- Travel Costs — Travel costs for each site are limited to round-trip mileage costs and are estimated to be between 20 to 100 miles at a rate of $0.30 per mile.

- Per Diem Costs — This cost element includes food, lodging, and incidental expenses, and is estimated to range from zero (for a local site) to $150 per day per person for one person for 2 days at the clay soil site (2 days for sample collection, mobilization/demobilization), and for 1 day at the sandy soil site (1 day for sample collection, mobilization/demobilization, and site restoration).

- Sampling Oversight Labor Costs — On-site labor, often a registered geologist, is required to oversee sample collection. Based on the average demonstration sample retrieval times, oversight labor times are estimated to be 11 to 15 hours for one person at the clay soil site, and 8 to 10 hours for one person at the sandy soil site. Labor rates are estimated at $50 per hour.

Other direct costs include supplies, IDW disposal, and site restoration.

- Supplies — This cost element includes decontamination supplies, such as buckets, soap, high-purity rinse water, and brushes, as well as personal protective equipment (Level D, the minimum level of protection, is assumed). Supplies are estimated to cost between $25 and $75.

- IDW Disposal — Disposal costs for each site are limited to the cost of disposing of one 55-gallon drum of IDW for $200 to $300 (typically, the minimum IDW disposal unit is one 55-gallon drum). Limited volumes of IDW were generated during the demonstration using the Dual Tube Liner Sampler because of the direct-push nature of the sampler advancement unit. No costs are included for wastewater disposal.

- Site Restoration — Site restoration costs include grouting the sample boreholes and site restoration labor. Grouting costs for each site are limited to grout and grouting tools and are estimated to range from $100 to $200.

Reference Sampling Method

The costs for implementing the reference sampling method during the demonstration include driller's costs and oversight costs, as presented in Table 6-2 and discussed below.

Driller's Costs. Total lump sum driller's cost was $13,400 for the clay soil site and $7,700 for the sandy soil site and included:

- Mobilization and demobilization ($2,700 per site)
- Drilling footage ($7 per linear foot)
- Split-spoon sampling ($45 per sample)
- Grouting boreholes ($3 per linear foot)
- Waste collection and containerization ($45 per drum)
- Standby time ($80 per hour)
- Decontamination time ($80 per hour)
- Drum moving time ($80 per hour)
- Difficult move time ($80 per hour)
- Site restoration and cleanup ($50 per hour)
- Per diem for the drilling crew (3 people)
- Drilling crew labor costs (3 people)

These rates are based on the demonstration data and vendor-supplied information for collecting soil samples at clay soil and sandy soil sites similar to the SBA and CSC sites.

Oversight Costs. Oversight costs are presented as ranges to provide an estimate of oversight costs that may be incurred at other sites. Costs for overseeing the reference sampling method are segregated into labor costs and other direct costs, as shown below.

Labor costs include mobilization/demobilization, travel, per diem, and sampling oversight costs.

- Mobilization/Demobilization Labor Costs — This cost element includes the time for one person to prepare for and travel to each site, set up and pack up equipment, and return from the field and includes 6 to 10 hours for one person at a rate of $50 per hour.

- Travel Costs — Travel costs for each site are limited to round-trip mileage costs and are estimated to be between 20 to 100 miles at a rate of $0.30 per mile.

- Per Diem Costs — This cost element includes food, lodging, and incidental expenses, and is estimated to range from zero (for a local site) to $150 per day per person for one person for 2 days at the clay soil site (2 days for sample collection, mobilization/demobilization and site restoration), and one person for 1 day at the sandy soil site (1 day for sample collection, mobilization/demobilization, and site restoration).

Table 6-2. Estimated Subsurface Soil Sampling Costs for the Reference Sampling Method

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Driller's Costs

Lump Sum = $21,100 ($13,400 for the clay soil site and $7,700 for the sandy soil site)

Oversight Costs

Clay Soil Site		Sandy Soil Site	
Total Sampling Time = 18 to 22 hours (2 days)		Total Sampling Time = 6 to 8 hours (1 day)	
Total Samples Collected = 42		Total Samples Collected = 42	
Total Sample Depth = 400 feet		Total Sample Depth = 200 feet	
Sampling Crew Size = 3 People		Sampling Crew Size = 3 People	
Labor Costs		Labor Costs	
Mobilization/Demobilization	$300 - $500	Mobilization/Demobilization	$300 - $500
Travel	$6 - $30	Travel	$6 - $30
Per Diem	0 - $300	Per Diem	0 - $150
Sample Collection	$900 - $1,100	Sample Collection	$300 - $400
Other Direct Costs		Other Direct Costs	
Supplies	$25 - $75	Supplies	$25 - $75
IDW Disposal	$3,000 - $4,500	IDW Disposal	$600 - $900
Range of Oversight Costs*	**$4,230 - $6,510**		**$1,230 - $2,060**

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*   The Range of Oversight Costs is rounded to the nearest tens of dollars and does not include Driller's Costs.

C   Sampling Oversight Labor Costs — On-site labor, often a registered geologist, is required to oversee sample collection. This cost element does not include the drill crew, which is covered in the lump sum driller's cost. Based on the average demonstration sample retrieval times, oversight labor times are estimated to be 18 to 22 hours for one person at the clay soil site, and 6 to 8 hours for one person at the sandy soil site. Labor rates are estimated at $50 per hour.

Other direct costs include supplies and IDW disposal.

C   Supplies — This cost element includes personal protective equipment (Level D, the minimum level of protection, is assumed) and other miscellaneous field supplies. Supplies are estimated to cost between $25 and $75.

C   IDW Disposal — Disposal costs for each site are limited to the cost of disposing of 15, 55-gallon drums for the clay soil site and three 55-gallon drums for the sandy soil site at a cost of $200 to $300 per drum.

Chapter 7
Summary of Demonstration Results

This chapter summarizes the technology performance results. The AMS^{TM} Dual Tube Liner Sampler was compared to a reference subsurface soil sampling method (hollow-stem auger drilling and split-spoon sampling) in terms of the following parameters: (1) sample recovery, (2) VOC concentrations in recovered samples, (3) sample integrity, (4) reliability and throughput, and (5) cost.

The demonstration data indicate the following performance characteristics for the AMS^{TM} Dual Tube Liner Sampler:

- **Sample Recovery**: For the purposes of this demonstration, sample recovery was defined as the ratio of the length of recovered sample to the length of sampler advancement. Sample recoveries from 42 samples collected at the SBA site ranged from 42 to 100 percent, with an average sample recovery of 91 percent. Sample recoveries from 42 samples collected at the CSC site ranged from 46 to 88 percent, with an average sample recovery of 70 percent. Using the reference method, sample recoveries from 42 samples collected at the SBA site ranged from 40 to 100 percent, with an average recovery of 88 percent. Sample recoveries from the 41 samples collected at the CSC site ranged from 53 to 100 percent, with an average recovery of 87 percent. A comparison of recovery data from the Dual Tube Liner Sampler and the reference sampler indicates that the Dual Tube Liner Sampler achieved higher recoveries in the clay soil at the SBA site and lower sample recoveries in the sandy soil at the CSC site relative to the sample recoveries achieved by the reference sampling method.

- **Volatile Organic Compound Concentrations**: Soil samples collected using the Dual Tube Liner Sampler and the reference sampling method at six sampling depths in nine grids (five at the SBA site and four at the CSC site) were analyzed for VOCs. For 21 of the 25 Dual Tube Liner Sampler and reference sampling method pairs (12 at the SBA site and 13 at the CSC site), a statistical analysis using the Mann-Whitney test indicated no significant statistical difference at the 95 percent confidence level between the VOC concentrations in samples collected with the Dual Tube Liner Sampler and those collected with the reference sampling method. Of the sample pairs where a statistically significant difference was identified, one was at the SBA site and three were at the CSC site. Analysis of the CSC site data, using the sign test, indicated no statistical difference between data obtained by the Dual Tube Liner Sampler and the reference method at the CSC and SBA sites.

- **Sample Integrity**: A total of 12 integrity samples were collected with both sampling methods at each site to determine if potting soil in sampler interiors became contaminated after it was advanced through a zone of high VOC concentrations. For the Dual Tube Liner Sampler, VOCs were detected in only one of the 12 integrity samples. The sample was collected at the CSC site. The VOC detected in the potting soil at the CSC site was cis-1,2-DCE at a

concentration of 6.07 micrograms per kilogram (μg/kg). These results indicate that the integrity of a lined chamber in the Dual Tube Liner Sampler is generally well preserved when the sampler is advanced through highly contaminated soils. Results of sample integrity tests for the reference sampling method indicate no contamination in the potting soil after advancement through a zone of high VOC concentrations. Because potting soil has an organic carbon content many times greater than typical soils, the integrity tests represent a worst-case scenario for VOC absorbance and may not be representative of cross-contamination under normal field conditions.

- **Reliability and Throughput**: At the SBA site, the Dual Tube Liner Sampler collected a sample from the desired depth on the initial attempt 98 percent of the time. Sample collection in the initial push was also achieved 98 percent of the time at the CSC site. At the SBA site, the Dual Tube Liner Sampler did not collect a sample in the initial push in only one instance. The sample liner was lost during that attempt due to overfilling. The sample was retrieved on the second attempt, resulting in 100 percent sample completeness. At the CSC site, the Dual Tube Liner Sampler did not collect a sample in the initial push in only one instance. The sample was lost when unconsolidated sand fell from the bottom of the liner. The problem was corrected by fashioning retaining baskets out of liner caps and the sample was collected on the subsequent push, resulting in 100 percent sample completeness. One sample was collected in the saturated zone at Grid 5 at the CSC site in one attempt, resulting in an initial sampling success rate of 100 percent. The developer did not attempt to collect additional samples from the 40-foot interval due to excessive friction on the outer extension. For the reference sampling method, the initial sampling success rates at the SBA and CSC sites were 90 and 95 percent, respectively. Success rates for the reference sampling method were less than 100 percent due to (1) drilling beyond the target sampling depth, (2) insufficient sample recovery, or (3) auger refusal. The average sample retrieval time for the Dual Tube Liner Sampler to set up on a sampling point, collect the specified sample, grout the hole, decontaminate the sampler, and move to a new sampling location was 16.4 minutes per sample at the SBA site and 10.9 minutes per sample at the CSC site. For the reference sampling method, the average sample retrieval time at the SBA and CSC sites were 26 and 8.4 minutes per sample, respectively. Two people collected soil samples with the Dual Tube Soil Sampler at both the SBA and CSC sites, and a three-person sampling crew collected soil samples using the reference sampling method at both sites. Additional personnel were present at both sites to observe and assist with demonstration sampling, as necessary.

- **Cost**: Based on the demonstration results and information provided by the vendor, the Dual Tube Liner Sampler can be purchased for $1,890 and the PowerProbe 9600 direct push rig rented for $1,800 per week. Operating costs for the Dual Tube Liner Sampler ranged from $2,280 to $4,260 at the clay soil site and $1,830 to $3,060 at the sandy soil site. For this demonstration, reference sampling was procured at a lump sum of $13,400 for the clay soil site and $7,700 for the sandy soil site. Oversight costs for the reference sampling ranged from $4,230 to $6,510 at the clay soil site and $1,230 to $2,060 at the sandy soil site. A site-specific cost analysis is recommended before selecting a subsurface soil sampling method.

In general, the data quality indicators selected for this demonstration met the established quality assurance objectives and support the usefulness of the demonstration results in verifying the Dual Tube Liner Sampler's performance.

A qualitative performance assessment of the AMS^{TM} Dual Tube Liner Sampler indicated that (1) the sampler is easy to use and requires less than 1 hour of training to operate; (2) logistical requirements

are similar to those of the reference sampling method; (3) sample handling is similar to the reference method; (4) the performance range is primarily a function of the advancement platform; and (5) no drill cuttings are generated when using the Dual Tube Liner Sampler with a push platform.

The demonstration results indicate that the Dual Tube Liner Sampler can provide useful, cost-effective samples for environmental problem-solving. However, in some cases, VOC data collected using the Dual Tube Liner Sampler may be statistically different from VOC data collected using the reference sampling method. As with any technology selection, the user must determine what is appropriate for the application and project data quality objectives.

Chapter 8
Technology Update

As a direct result of the SITE demonstration the AMS™ PowerProbe pull yoke has been redesigned to provide effective transfer of the available 37,000 pounds (lb) of pull to the tooling.

At the CSC site Grid 1, penetration of asphalt pavement was required. AMS™ has now developed a pavement drill that may be used with the built-in auger capability on the AMS™ PowerProbe System. This new drill would have reduced the time taken on this grid to penetrate the asphalt. This AMS™ pavement drill may be used to penetrate concrete as well.

All sample liners used by all the technologies at both sites were opened with the AMS™ Sample Preparation Station. This accessory would normally be used at the probing location and is usually supplied with the AMS™ PowerProbe System.

The hand-fabricated Liner Core Catcher Caps used at the CSC site are now available as a manufactured item along with the corresponding drive tip.

The AMS™ Liner Sampler System provides an extended range of drive shoes to accommodate different soil conditions. At the SITE demonstration, AMS™ used its standard Liner Sampler Drive Shoe at the SBA site and the Liner Sampler Core Catcher Shoe at the CSC site. These are now available in oversizes to assist in reducing friction on the extensions as they are being driven. A new Liner Sampler Drive Shoe for use in expanding clays has been introduced. This shoe cuts a smaller core and feeds it directly into the liner to reduce overfilling when sampling these materials.

In addition to the 1-1/2-inch-diameter liner sampler used for this demonstration, AMS™ has a smaller 1-1/8-inch Liner Sampler System that uses a 1-3/4-inch o.d. outer extension and the same 1-1/8-inch inner extension.

A new sampler has been designed (patent pending) that will allow sampling of saturated flowing sands, using the AMS™ Dual Tube System along with the AMS™ Liner Sampler for collecting samples of soils above the saturated or flowing sands.

Chapter 8 was written solely by AMS™ and edited for format. The statements presented in this chapter represent the vendor's point of view and summarize the claims made by the vendor regarding the Dual Tube Liner Sampler. Publication of this material does not represent the EPA's approval or endorsement of the statements made in this chapter; results of the performance evaluation of the Dual Tube Liner Sampler are discussed in other chapters of this report.

The EPA SITE Program demonstration was conducted using a Stanley SK-58 hammer with a 50-foot-pounds (ft.lb.) impact force at 1,200 beats per minute. An alternative hammer, the BR-87 with 90-ft.lb impact force at 1,100 beats per minute may have allowed us to probe faster at the CSC site. A new hammer, the T-300 with 150-ft.lb. impact force and up to 1,600 beats per minute, has now been introduced to further extend the capabilities of the AMS™ PowerProbe System and the use of the AMS™ Liner Sampler.

The SITE Program demonstration did not allow us to demonstrate the auger capability of the AMS™ PowerProbe System. Most PowerProbes sold today include this feature with rotational torques of either 500, 1,000 or 2,400 ft.lb. The hollow stem augers are completely compatible with the two sizes of the AMS™ Dual Tube Probing System and the AMS™ Liner Sampler System.

The AMS™ Liner Sampler System may now be used to sample soils and then install a prepacked well screen and casing in the same hole. This new development reduces the time necessary to conduct a site investigation and provide extended information on groundwater.

The AMS™ Wash Station used during this demonstration for tool washing and decontamination has been improved with the introduction of a new model featuring smaller, 14-gallon, dual tanks and hoses with wands on retractable reels. This smaller system provides all the benefits of that used for this demonstration in a smaller package, suited for installation on small vehicle beds.

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Chapter 9
Previous Deployment

AMS^{TM} has been in the soil and groundwater sampling equipment market since its founding in 1942. The earliest record of the use of hydraulics to sample soils was a hydraulic coring sampler mounted on an agricultural tractor in 1960. Subsequent to the introduction of this product, truck-mounted hydraulic core and probe pushers were supplied to all parts of the United States for use in soil gas and soil sampling projects.

In 1994, AMS^{TM} introduced the AMS^{TM} Envirodrill, a truck- or trailer-mounted system for hollow stem augering with an optional hydraulic hammer for direct push probing. At that time, AMS^{TM} extended the capabilities of the auger rig with dual tube tooling developed for this system. The PowerProbe 9600 evolved from this product and was introduced in 1995; the AMS^{TM} Dual Tube Liner Sampler followed later in 1995.

Today AMS^{TM} PowerProbe systems are in use in 23 states of the United States as well as in Korea, Taiwan, Japan, Germany, and South Africa. The AMS^{TM} Dual Tube Liner Sampler is an integral part of all these systems. In addition, AMS^{TM} Dual Tube Liner Sampler Systems have been acquired by owners of other probing rigs in many parts of the United States and overseas, including Europe and Scandinavia.

The AMS^{TM} Liner Sampler System is now routinely used for site investigations where soil and groundwater samples are required. In soil conditions where the upper layers are characterized as heavily compacted or contain other materials or present conditions that make probing difficult or impossible, the AMS^{TM} Hollow Stem Auger is used. After penetrating these difficult soils, the AMS^{TM} Dual Tube Liner Sampling System is installed through the Hollow Stem Auger and used to probe and sample to the target depth.

Multimedia sampling is routinely used by many AMS^{TM} customers. They use the Liner Sampler System to probe and collect either continuous cores or samples at discrete target depths. Once the water table has been penetrated, they use the AMS^{TM} Direct Push Retract-A-Tip probe through the

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outer extension to collect water samples at specific depths in the saturated soils. AMS™ PowerProbe Systems are used for sampling sandfills either with vertical or angled probes. In some areas, the contractor will sample with the AMS™ Liner Sampler and then place a plastic screen through the outer extension for subsequent use as either a vent, landfill gas sampling point, or piezometer.

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APPENDIX A

**DATA SUMMARY TABLES AND STATISTICAL METHOD
DESCRIPTIONS**

for the

**AMS™
DUAL TUBE LINER SAMPLER**

APPENDIX A1

STATISTICAL METHOD DESCRIPTIONS

MANN-WHITNEY TEST AND SIGN TEST

MANN-WHITNEY TEST

A statistical evaluation of the volatile organic compound (VOC) concentration data was conducted based on the null hypothesis that there is no difference between the median contaminant concentrations obtained by the Dual Tube Liner Sampler and the reference sampling method. The two-tailed significance level for this null hypothesis was set at a probability of 5 percent ($p \# 0.05$) (2.5 percent for a one-tailed); that is, if a two-tailed statistical analysis indicates a probability of greater than 5 percent that there is no significant difference between data sets, then it will be concluded that there is no significant difference between the data sets. A two-tailed test was used because no information was available to indicate *a priori* that one method would result in greater concentrations than the other method. Because the F test for homogeneity of variances failed, a parametric analysis of variance could not be used to test the hypothesis. Therefore, a nonparametric method, the Mann-Whitney test, was used to test the statistical hypothesis for VOC concentrations. The Mann-Whitney statistic makes no assumptions regarding normality and assumes only that the differences between two values, in this case the reported chemical concentrations, can be determined. Other assumptions required for use of the Mann-Whitney test are that samples are independent of each other and that the populations from which the samples are taken differ only in location. The Mann-Whitney test was chosen because of its historical acceptability and ease of application to small data sets.

To use the Mann-Whitney test, all of the data within two data sets that are to be compared are ranked without regard to the population from which each sample was withdrawn. The cis-1,2-dichloroethene (DCE) data from the SBA site are provided as an example in Table A1. The combined data from both data sets are ranked from the lowest value to the highest. Next, the sum of ranks within a sample set is determined by adding the assigned rank values. In the example provided in Table A1, the sum of ranks is 52 for the Dual Tube Liner data and 53 for the reference sampling method.

A Mann-Whitney statistic is then calculated for each data set as follows:

$$\text{Mann-Whitney}_1 = N_1N_2 + \frac{N_1(N_1 + 1)}{2} - \text{sum of ranks value for the first data set}$$

and

$$\text{Mann-Whitney}_2 = N_1N_2 + \frac{N_2(N_2 + 1)}{2} - \text{sum of ranks value for the second data set}$$

Where

N_1 is the number of values in data set 1
N_2 is the number of values in data set 2

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Table A1. Mann-Whitney Test Rank of cis-1,2-DCE Data from the 9.5 Foot Depth of Grid 1 at the SBA Site

Sampler	Sample Location	cis-1,2-DCE Concentration (mg/kg)	cis-1,2-DCE Concentration Rank	Median Value Rank
Dual Tube Liner Sampler	A7	85.4	8	5
Dual Tube Liner Sampler	B3	75.3	6	3
Dual Tube Liner Sampler	C4	117	12	6
Dual Tube Liner Sampler	D1	156	14	7
Dual Tube Liner Sampler	E5	50.5	4	2
Dual Tube Liner Sampler	F7	80.2	7	4
Dual Tube Liner Sampler	G2	38.1	1	1
Reference	A3	49.7	2	1
Reference	B2	86.7	9	4
Reference	C2	109	11	6
Reference	D4	147	13	7
Reference	E4	67.1	5	3
Reference	F2	98.4	10	5
Reference	G7	50.2	3	2
Sum of Dual Tube Liner Sampler Ranks (8+ 6+ 12+ 14+ 4+ 7+ 1 = 52)			52	
Sum of Reference Sampler Ranks (2+ 9+ 11+ 13+ 5+ 10+ 3 = 53)			53	
Mann-Whitney$_1$ Statistic			25	
Mann-Whitney$_2$ Statistic			24	
Critical Mann-Whitney Value (for N_1= 7, N_2= 7, p= 0.05)			41	
Significance (Mann-Whitney Statistic > 41 ?)			no	

For the example provided in Table A1, the equations become:

$$\text{Mann-Whitney}_1 = (7)(7) + \frac{7(7+1)}{2} - 52$$

$$\text{Mann-Whitney}_1 = 49 + 28 - 52$$

$$\text{Mann-Whitney}_1 = 25$$

and

$$\text{Mann-Whitney}_2 = (7)(7) + \frac{7(7+1)}{2} - 53$$

$$\text{Mann-Whitney}_2 = 49 + 28 - 53$$

$$\text{Mann-Whitney}_2 = 24$$

To determine the significance of the calculated Mann-Whitney value, a table of critical values for the Mann-Whitney statistic is consulted. For the case of 7 samples in each data set, the Mann-Whitney statistic value for $N_1 = 7$ and $N_2 = 7$ is of interest. For a two-tailed test with a significance level of 0.05, the Mann-Whitney statistic value is 41 (Rohlf and Sokal, 1969). Therefore, when the Mann-Whitney statistic value is greater than 41, a significance level of $p < 0.05$ has been realized, and the null hypothesis is rejected; that is, the two data sets are statistically different. The example comparison provided in Table A1 yielded a maximum Mann-Whitney statistic of 25, which is less than 41; therefore, there is no statistically significant difference between the two data sets, and the null hypothesis is accepted.

The question of data points with equal values may be easily addressed with the Mann-Whitney statistic. When two values (contaminant concentrations in this instance) are equivalent, the median rank is assigned to each. For instance, if the initial two values in the rank series are equivalent (regardless of which data set they were derived from) they would be assigned a median rank of 1.5 ($[1+2]/2 = 1.5$). For three equivalent ranks, the assigned rank for each value would be 2 ($[1+2+3]/3 = 2$). This approach is also applied to data points where contaminant concentrations are reported as below the method detection limit.

For the demonstration data, certain VOCs were not detected in some, or all, of the samples for many data sets. There is no strict guidance regarding the appropriate number of values that must be reported within a data set to yield statistically valid results. Therefore, and for the purposes of this statistical analysis, the maximum number of nondetects allowed within any given data set has been set at three. That is, there must be at least four reported values above the method detection limit within each data set to perform the Mann-Whitney test.

SIGN TEST

The sign test was used to examine the potential for sampling and analytical bias between the Dual Tube Liner Sampler and the reference sampling method. The sign test is nonparametric and counts the number of positive and negative signs among the differences. The differences tested, in this instance, were the differences in the median concentrations of paired data sets (within a site, within a grid, within a depth, and within an analyte). From the data sets, counts were made of (1) the number of pairs in which the reference sampling method median concentrations were higher than the Dual Tube Liner Sampler median concentrations and (2) the number of pairs in which the Dual Tube Liner Sampler median concentrations were higher than the reference sampling method median concentrations. The total number of pairs in which the median concentrations were higher in Dual Tube Liner Sampler was then compared with the total number of pairs in which the median concentrations in the reference sampling method were higher. If no bias is present in the data sets, the probability that the total number of pairs for one or the other test method is higher is equivalent. That is, the probability of the number of pairs in which the median concentrations in the Dual Tube Liner Sampler are higher is equal to the probability of the number of pairs in which the median concentrations in the reference sampling method are higher. To determine the exact probability of the number of data sets in which the median concentrations in the Dual Tube Liner Sampler and reference sampling method were higher, a binomial expansion was used. If the calculated probability is less then 5 percent ($p < 0.05$), then a significant difference is present between the Dual Tube Liner Sampler and reference sampling method.

The sign test was chosen because it (1) reduces sensitivity to random analysis error and matrix variabilities by using the median VOC concentration across each grid depth, (2) enlarges the sample sizes as compared to the Mann-Whitney test, and (3) is easy to use.

For the demonstration data, certain VOCs were not detected in some, or all of the samples for many data sets. There is no strict guidance regarding the appropriate number of values that must be reported within a data set to yield statistically valid results. Therefore, and for the purposes of the statistical analysis, the maximum number of nondetects allowed within any given data set has been set at three. That is, there must be four reported values within each data set to perform the sign test.

APPENDIX A2

SAMPLE RECOVERY TEST DATA

TABLE A2a. DUAL TUBE LINER SAMPLER RECOVERY TEST DATA
SBA SITE

Sample Number	Sample Location	Soil Type	Reported Length Pushed (in.)	Reported Length Recovered (in.)	Sample Recovery (%)
AMSAG1A709.5	A7	Fine	24.0	24.0	100.0%
AMSAG1B309.5	B3	Fine	23.0	22.0	95.7%
AMSAG1C409.5	C4	Fine	23.0	24.0	100.0%[a]
AMSAG1D109.5	D1	Fine	23.0	19.0	82.6%
AMSAG1E509.5	E5	Fine	24.0	21.0	87.5%
AMSAG1F709.5	F7	Fine	22.0	19.5	88.6%
AMSAG1G209.5	G2	Fine	23.0	21.0	91.3%
AMSAG1A713.5	A7	Fine	27.0	27.0	100.0%
AMSAG1B313.5	B3	Fine	23.0	24.0	100.0%[a]
AMSAG1C413.5	C4	Fine	23.0	24.0	100.0%[a]
AMSAG1D113.5	D1	Fine	23.0	24.0	100.0%[a]
AMSAG1E513.5	E5	Fine	23.0	24.0	100.0%[a]
AMSAG1F713.5	F7	Fine	20.0	22.0	100.0%[a]
AMSAG1G213.5	G2	Fine	23.0	24.0	100.0%[a]
AMSAG2A303.5	A3	Fine	24.0	11.0	45.8%
AMSAG2B303.5	B3	Fine	24.0	12.0	50.0%
AMSAG2C403.5	C4	Fine	24.0	15.0	62.5%
AMSAG2D703.5	D7	Fine	24.0	19.0	79.2%
AMSAG2E403.5	E4	Fine	24.0	14.0	58.3%
AMSAG2F303.5	F3	Fine	24.0	17.0	70.8%
AMSAG2G603.5	G6	Fine	24.0	10.0	41.7%
AMSAG3A609.5	A6	Fine	24.0	24.0	100.0%
AMSAG3B209.5	B2	Fine	24.0	24.0	100.0%
AMSAG3C109.5	C1	Fine	24.0	24.0	100.0%
AMSAG3D29.5	D2	Fine	24.0	24.0	100.0%
AMSAG3E509.5	E5	Fine	24.0	24.0	100.0%
AMSAG3F409.5	F4	Fine	24.0	24.0	100.0%
AMSAG3G109.5	G1	Fine	24.0	24.0	100.0%
AMSAG4A409.5	A4	Fine	23.0	24.0	100.0%[a]
AMSAG4B109.5	B1	Fine	24.0	24.0	100.0%
AMSAG4C509.5	C5	Fine	24.0	23.0	95.8%
AMSAG4D309.5	D3	Fine	24.0	23.0	95.8%
AMSAG4E109.5	E1	Fine	24.0	24.0	100.0%
AMSAG4F109.5	F1	Fine	24.0	23.0	95.8%
AMSAG4G609.5	G6	Fine	24.0	21.5	89.6%
AMSAG3B213.5	B2	Fine	24.0	24.0	100.0%
AMSAG5C713.5	C7	Fine	24.0	24.0	100.0%
AMSAG5D513.5	D5	Fine	22.0	24.0	100.0%[a]
AMSAG5A713.5	A7	Fine	22.0	24.0	100.0%[a]
AMSAG5E113.5	E1	Fine	22.0	24.0	100.0%[a]
AMSAG5F213.5	F2	Fine	23.0	24.0	100.0%[a]
AMSAG5G313.5	G3	Fine	24.0	26.0	100.0%[a]

[a] Sample recovery is reported as 100 percent when length recovered is greater than length pushed.

Average: 91.2%
Range: 41.7 - 100.0%
Total # Samples: 42

TABLE A2b. DUAL TUBE LINER SAMPLER RECOVERY TEST DATA
CSC SITE

Sample Number	Sample Location	Soil Type	Reported Length Pushed (in.)	Reported Length Recovered (in.)	Sample Recovery (%)
AMSCG1A603.0	A6	Coarse	24.0	17.5	72.9%
AMSCG1B203.0	B2	Coarse	24.0	18.0	75.0%
AMSCG1C503.0	C5	Coarse	24.0	15.0	62.5%
AMSCG1D203.0	D2	Coarse	24.0	20.0	83.3%
AMSCG1E303.0	E3	Coarse	24.0	17.0	70.8%
AMSCG1F703.0	F7	Coarse	24.0	18.0	75.0%
AMSCG1G303.0	G3	Coarse	24.0	21.0	87.5%
AMSCG1A606.5	A6	Coarse	36.0	26.0	72.2%
AMSCG1B206.5	B2	Coarse	36.0	29.0	80.6%
AMSCG1C506.5	C5	Coarse	36.0	30.5	84.7%
AMSCG1D206.5	D2	Coarse	36.0	28.0	77.8%
AMSCG1E306.5	E3	Coarse	36.0	27.0	75.0%
AMSCG1F706.5	F7	Coarse	36.0	28.0	77.8%
AMSCG1G306.5	G3	Coarse	36.0	31.0	86.1%
AMSCG2A703.0	A7	Coarse	24.0	14.0	58.3%
AMSCG2B303.0	B3	Coarse	24.0	12.0	50.0%
AMSCG2C403.0	C4	Coarse	24.0	17.0	70.8%
AMSCG2D703.0	D7	Coarse	24.0	14.0	58.3%
AMSCGE403.0	E4	Coarse	24.0	12.0	50.0%
AMSCG2F303.0	F3	Coarse	24.0	14.0	58.3%
AMSCG2G703.0	G7	Coarse	24.0	16.5	68.8%
AMSCG3A403.0	A4	Coarse	24.0	16.0	66.7%
AMSCG3B203.0	B2	Coarse	24.0	16.5	68.8%
AMSCG3C403.0	C4	Coarse	24.0	13.5	56.3%
AMSCGD103.0	D1	Coarse	24.0	17.5	72.9%
AMSCG3E403.0	E4	Coarse	21.0	12.0	57.1%
AMSCG3F503.0	F5	Coarse	24.0	11.0	45.8%
AMSCG3G303.0	G3	Coarse	24.0	15.0	62.5%
AMSCG3A407.5	A4	Coarse	48.0	36.0	75.0%
AMSCG3B207.5	B2	Coarse	48.0	39.0	81.3%
AMSCG3C407.5	C4	Coarse	48.0	36.0	75.0%
AMSCG3D107.5	D1	Coarse	48.0	40.0	83.3%
AMSCG3E407.5	E4	Coarse	48.0	37.5	78.1%
AMSCG3F507.5	F5	Coarse	48.0	38.0	79.2%
AMSCG3G307.5	G3	Coarse	48.0	35.0	72.9%
AMSCG4A606.5	A6	Coarse	36.0	25.0	69.4%
AMSCG4B106.5	B1	Coarse	36.0	23.0	63.9%
AMSCG4C506.5	C5	Coarse	36.0	25.0	69.4%
AMSCG4D406.5	D4	Coarse	36.0	24.0	66.7%
AMSCG4E706.5	E7	Coarse	36.0	25.0	69.4%
AMSCG4F406.5	F4	Coarse	36.0	27.0	75.0%
AMSCG4G106.5	G1	Coarse	36.0	24.0	66.7%

Average: 70.3%
Range: 45.8 - 87.5%
Total # Samples: 42

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TABLE A2c. REFERENCE SAMPLING METHOD RECOVERY TEST DATA
SBA SITE

Sample Number	Sample Location	Soil Type	Reported Length Pushed (in.)	Reported Length Recovered (in.)	Sample Recovery (%)
REFAG1A309.5	A3	Fine	18.0	13.5	75.0%
REFAG1A313.5	A3	Fine	19.0	17.0	89.5%
REFAG1B209.5	B2	Fine	18.0	17.0	94.4%
REFAG1B213.5	B2	Fine	18.0	19.0	100.0%[a]
REFAG1C209.5	C2	Fine	18.0	16.0	88.9%
REFAG1C213.5	C2	Fine	18.0	11.0	61.1%
REFAG1D409.5	D4	Fine	18.0	16.0	88.9%
REFAG1D413.5	D4	Fine	18.0	17.5	97.2%
REFAG1E409.5	E4	Fine	18.0	17.0	94.4%
REFAG1E413.5	E4	Fine	18.0	17.0	94.4%
REFAG1F209.5	F2	Fine	18.0	16.0	88.9%
REFAG1F213.5	F2	Fine	18.0	17.0	94.4%
REFAG1G709.5	G7	Fine	18.0	18.0	100.0%
REFAG1G713.5	G7	Fine	18.0	16.0	88.9%
REFAG2A203.5	A2	Fine	18.0	18.0	100.0%
REFAG2B403.5	B4	Fine	18.0	14.0	77.8%
REFAG2C103.5	C1	Fine	18.0	12.0	66.7%
REFAG2D603.5	D6	Fine	18.0	9.0	50.0%
REFAG2E503.5	E5	Fine	18.0	16.0	88.9%
REFAG2F103.5	F1	Fine	18.0	18.0	100.0%
REFAG2G403.5	G4	Fine	18.0	17.0	94.4%
REFAG3A209.5	A2	Fine	15.0	20.0	100.0%[a]
REFAG3B609.5	B6	Fine	15.0	18.0	100.0%[a]
REFAG3C409.5	C4	Fine	15.0	6.0	40.0%
REFAG3D609.5	D6	Fine	15.0	13.0	86.7%
REFAG3E109.5	E1	Fine	15.0	16.5	100.0%[a]
REFAG3F309.5	F3	Fine	15.0	21.0	100.0%[a]
REFAG3G609.5	G6	Fine	18.0	24.0	100.0%[a]
REFAG4A109.5	A1	Fine	18.0	16.5	91.7%
REFAG4B309.5	B3	Fine	18.0	18.0	100.0%
REFAG4C309.5	C3	Fine	18.0	16.0	88.9%
REFAG4D609.5	D6	Fine	18.0	17.0	94.4%
REFAG4E709.5	E7	Fine	18.0	17.0	94.4%
REFAG4F209.5	F2	Fine	18.0	15.0	83.3%
REFAG4G209.5	G2	Fine	18.0	17.5	97.2%
REFAG5A213.5	A2	Fine	18.0	18.0	100.0%
REFAG3B113.5	B1	Fine	18.0	18.0	100.0%
REFAG5C213.5	C2	Fine	18.0	15.5	86.1%
REFAG5D613.5	D6	Fine	18.0	17.0	94.4%
REFAG5E313.5	E3	Fine	18.0	11.0	61.1%
REFAG5F313.5	F3	Fine	18.0	12.0	66.7%
REFAG5G413.5	G4	Fine	18.0	17.0	94.4%

[a] Sample recovery is reported as 100 percent when length recovered is greater than length pushed.

Average:	88.4%
Range:	40.0-100.0%
Total # Samples:	42

TABLE A2d. REFERENCE SAMPLING METHOD RECOVERY TEST DATA
CSC SITE

Sample Number	Sample Location	Soil Type	Reported Length Pushed (in.)	Reported Length Recovered (in.)	Sample Recovery (%)
REFCG1A303.0	A3	Coarse	18.0	12.0	66.7%
REFCG1A306.5	A3	Coarse	18.0	16.0	88.9%
REFCG1B303.0	B3	Coarse	18.0	10.0	55.6%
REFCG1B306.5	B3	Coarse	18.0	14.0	77.8%
REFCG1C303.0	C3	Coarse	18.0	15.0	83.3%
REFCG1C306.5	C3	Coarse	18.0	13.0	72.2%
REFCG1D503.0	D5	Coarse	18.0	16.0	88.9%
REFCG1D506.5	D5	Coarse	18.0	14.0	77.8%
REFCG1E103.0	E1	Coarse	18.0	20.0	100.0%[a]
REFCG1E106.5	E1	Coarse	18.0	11.5	63.9%
REFCG1F103.0	F1	Coarse	18.0	14.5	80.6%
REFCG1F106.5	F1	Coarse	18.0	15.0	83.3%
REFCG1G703.0	G7	Coarse	18.0	14.0	77.8%
REFCG1G706.5	G7	Coarse	18.0	15.0	83.3%
REFCG2A103.0	A1	Coarse	18.0	13.0	72.2%
REFCG2B603.0	B6	Coarse	18.0	19.0	100.0%[a]
REFCG2C103.0	C1	Coarse	18.0	16.0	88.9%
REFCG2D603.0	D6	Coarse	18.0	18.0	100.0%
REFCG2E303.0	E3	Coarse	18.0	19.5	100.0%[a]
REFCG2F503.0	F5	Coarse	18.0	18.5	100.0%[a]
REFCG2G103.0	G1	Coarse	19.0	19.0	100.0%
REFCG3A203.0	A2	Coarse	18.0	17.5	97.2%
REFCG3A207.5	A2	Coarse	18.0	12.0	66.7%
REFCG3B103.0	B1	Coarse	18.0	17.0	94.4%
REFCG3B107.5	B1	Coarse	18.0	12.0	66.7%
REFCG3C203.0	C2	Coarse	18.0	18.0	100.0%
REFCG3C207.5	C2	Coarse	18.0	9.5	52.8%
REFCG3D603.0	D6	Coarse	19.0	18.0	94.7%
REFCG3D607.5	D6	Coarse	20.0	20.0	100.0%
REFCG3E603.0	E6	Coarse	18.0	18.0	100.0%
REFCG3E607.5	E6	Coarse	18.0	18.0	100.0%
REFCG3F603.0	F6	Coarse	18.0	18.0	100.0%
REFCG3F607.5	F6	Coarse	No data	No data	--
REFCG3G403.0	G4	Coarse	18.0	17.0	94.4%
REFCG3G407.5	G4	Coarse	18.0	18.0	100.0%
REFCG4A706.5	A7	Coarse	18.0	18.0	100.0%
REFCG4B606.5	B6	Coarse	18.0	13.0	72.2%
REFCG4C706.5	C7	Coarse	18.0	17.0	94.4%
REFCG4D306.5	D3	Coarse	18.0	17.0	94.4%
REFCG4E506.5	E5	Coarse	18.0	18.0	100.0%
REFCG4F306.5	F3	Coarse	18.0	18.0	100.0%
REFCG4G506.5	G5	Coarse	18.0	11.5	63.9%

[a] Sample recovery is reported as 100 percent when length recovered is greater than length pushed.

Average: 86.7%
Range: 52.8-100.0%
Total # Samples: 41

APPENDIX A3

VOLATILE ORGANIC COMPOUND CONCENTRATIONS

**TABLE A3a. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 1 - 9.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (μg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSAG1A709.5	A7	Fine	High	85,397	100	82,561	100
AMSAG1B309.5	B3	Fine	High	75,310	100	177,127	1,283
AMSAG1C409.5	C4	Fine	High	117,344	100	167,242	965
AMSAG1D109.5	D1	Fine	High	156,305	100	177,633	1,709
AMSAG1E509.5	E5	Fine	High	50,524	100	238,218	1,727
AMSAG1F709.5	F7	Fine	High	80,152	100	139,783	990
AMSAG1G209.5	G2	Fine	High	38,060	100	64,826	473

Range: 38,100 - 156,000   100   64,800 - 238,000   100 - 1,730

Median: 80,200   NC   167,000   990

REFERENCE SAMPLING METHOD DATA							
REFAG1A309.5	A3	Fine	High	49,671	100	52,846	100
REFAG1B209.5	B2	Fine	High	86,749	100	70,217	669
REFAG1C209.5	C2	Fine	High	108,582	100	251,269	2,012
REFAG1D409.5	D4	Fine	High	147,042	100	418,733	4,511
REFAG1E409.5	E4	Fine	High	67,126	100	290,739	1,534
REFAG1F209.5	F2	Fine	High	98,437	100	276,149	1,720
REFAG1G709.5	G7	Fine	High	50,237	100	289,330	1,625

Range: 49,700 - 147,000   100   52,800 - 419,000   100 - 4,510

Median: 86,700   NC   276,000   1,630

Note: Values reported as "100" are nondetects with a detection limit of 100.

NC =   No medians calculated because at least half the reported values were below the method detection limit.

μg/kg =   Micrograms per kilogram.

TABLE A3b. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 1 - 13.5 FEET

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSAG1A713.5	A7	Fine	High	42,547	100	332,266	1,665
AMSAG1B313.5	B3	Fine	High	4,283	100	24,798	100
AMSAG1C413.5	C4	Fine	High	27,949	100	56,539	100
AMSAG1D113.5	D1	Fine	High	25,986	100	31,665	100
AMSAG1E513.5	E5	Fine	High	5,164	100	41,365	100
AMSAG1F713.5	F7	Fine	High	1,098	100	62,659	100
AMSAG1G213.5	G2	Fine	High	9,900	100	47,536	100

Range: 1,100 - 42,500   100   24,800 - 332,000   100 - 1,670

Median: 9,900   NC   47,500   NC

REFERENCE SAMPLING METHOD DATA							
REFAG1A313.5	A3	Fine	High	6,762	100	33,736	100
REFAG1B213.5	B2	Fine	High	14,453	100	40,511	100
REFAG1C213.5	C2	Fine	High	20,362	100	48,730	100
REFAG1D413.5	D4	Fine	High	44,929	100	432,508	2,405
REFAG1E413.5	E4	Fine	High	12,343	100	40,984	100
REFAG1F213.5	F2	Fine	High	15,415	100	26,652	100
REFAG1G713.5	G7	Fine	High	1,356	100	39,138	100

Range: 1,360 - 44,900   100   26,700 - 433,000   100 - 2,410

Median: 14,500   NC   40,500   NC

Note: Values reported as "100" are nondetects with a detection limit of 100.
NC = No medians calculated because at least half the reported values were below the method detection limit.
µg/kg = Micrograms per kilogram.

TABLE A3c. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 2 - 3.5 FEET

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (μg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSAG2A303.5	A3	Fine	Low	1	1	40.0	1
AMSAG2B303.5	B3	Fine	Low	1	1	33.6	1
AMSAG2C403.5	C4	Fine	Low	1	1	95.1	1
AMSAG2D703.5	D7	Fine	Low	1	1	86.9	1
AMSAG2E403.5	E4	Fine	Low	1	1	95.5	1
AMSAG2F303.5	F3	Fine	Low	4.24	1	90.5	1
AMSAG2G603.5	G6	Fine	Low	1	1	73.8	1

Range: 1 - 4.24   1   33.6 - 95.5   1

Median: NC   NC   86.9   NC

REFERENCE SAMPLING METHOD DATA							
REFAG2A203.5	A2	Fine	Low	1	1	22.6	1
REFAG2B403.5	B4	Fine	Low	1	1	58.2	1
REFAG2C103.5	C1	Fine	Low	1	1	29.3	1
REFAG2D603.5	D6	Fine	Low	1	1	43.5	1
REFAG2E503.5	E5	Fine	Low	1	1	56.9	1
REFAG2F103.5	F1	Fine	Low	1	1	78.6	1
REFAG2G403.5	G4	Fine	Low	2.18	1	88.8	1

Range: 1 - 2.18   1   22.6 - 88.8   1

Median: NC   NC   56.9   NC

Note: Values reported as "1" are nondetects with a detection limit of 1.
NC =   No medians calculated because at least half the reported values were below
          the method detection limit.
μg/kg =   Micrograms per kilogram.

**TABLE A3d. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 3 - 9.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSAG3A609.5	A6	Fine	High	591	100	19,831	100
AMSAG3B209.5	B2	Fine	High	370	100	16,143	100
AMSAG3C109.5	C1	Fine	High	601	100	48,027	100
AMSAG3D209.5	D2	Fine	High	557	100	13,632	100
AMSAG3E509.5	E5	Fine	High	537	100	22,150	100
AMSAG3F409.5	F4	Fine	High	100	100	12,027	100
AMSAG3G109.5	G1	Fine	High	425	100	23,326	100

		Range:	100 - 601	100	12,000 - 48,000	100
		Median:	537	NC	19,800	NC

Sample Name	Sample Location	Soil Type	Concentration Zone	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
REFERENCE SAMPLING METHOD DATA							
REFAG3A209.5	A2	Fine	High	796	100	34,069	100
REFAG3B609.5	B6	Fine	High	1,007	100	34,420	100
REFAG3C409.5	C4	Fine	High	1,455	100	63,740	100
REFAG3D609.5	D6	Fine	High	799	100	42,502	100

		Range:	796 - 1,460	100	34,100 - 63,700	100
		Median:	903	NC	38,500	NC

Note: Values reported as "100" are nondetects with a detection limit of 100.

NC =   No medians calculated because at least half the reported values were below
            the method detection limit.

µg/kg =   Micrograms per kilogram.

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**TABLE A3e. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 4 - 9.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSAG4A409.5	A4	Fine	Low	31.4	1	1,910	1
AMSAG4B109.5	B1	Fine	Low	7.55	1	1,017	1
AMSAG4C509.5	C5	Fine	Low	32.1	1	2,441	1
AMSAG4D309.5	D3	Fine	Low	20.8	1	1,299	1
AMSAG4E109.5	E1	Fine	Low	25.2	1	2,436	1
AMSAG4F109.5	F1	Fine	Low	47.7	1	3,182	1
AMSAG4G609.5	G6	Fine	Low	11.0	1	1,410	1

		Range:	7.55 - 47.7	1	1,020 - 3,180	1
		Median:	25.2	NC	1,910	NC

Sample Name	Sample Location	Soil Type	Concentration Zone	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
REFERENCE SAMPLING METHOD DATA							
REFAG4A109.5	A1	Fine	Low	7.15	1	847	1
REFAG4B309.5	B3	Fine	Low	6.68	1	966	1
REFAG4C309.5	C3	Fine	Low	21.2	1	1,709	1
REFAG4D609.5	D6	Fine	Low	13.2	1	1,834	1
REFAG4E709.5	E7	Fine	Low	12.1	1	1,306	1
REFAG4F209.5	F2	Fine	Low	22.1	1	2,084	1
REFAG4G209.5	G2	Fine	Low	19.2	1	1,870	1

		Range:	6.68 - 22.1	1	847 - 2,080	1
		Median:	13.2	NC	1,710	NC

Note: Values reported as "1" are nondetects with a detection limit of 1.

NC =   No medians calculated because at least half the reported values were below
              the method detection limit.

µg/kg =   Micrograms per kilogram.

TABLE A3f. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE - GRID 5 - 13.5 FEET

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSAG5A713.5	A7	Fine	Low	374	1	252	1
AMSAG5B213.5	B2	Fine	Low	166	1	106	1
AMSAG5C713.5	C7	Fine	Low	304	1	167	1
AMSAG5D513.5	D5	Fine	Low	310	1	250	1
AMSAG5E113.5	E1	Fine	Low	86.1	1	15.7	1
AMSAG5F213.5	F2	Fine	Low	81.8	1	27.4	1
AMSAG5G313.5	G3	Fine	Low	69.2	1	12.0	1

Range: 69.2 - 374   1   12.0 - 252   1

Median: 166   NC   106   NC

REFERENCE SAMPLING METHOD DATA							
REFAG5A213.5	A2	Fine	Low	81.2	1	23.3	1
REFAG5C213.5	C2	Fine	Low	118	1	58.0	1
REFAG5D613.5	D6	Fine	Low	147	1	138	1
REFAG5E313.5	E3	Fine	Low	106	1	18.7	1
REFAG5F313.5	F3	Fine	Low	59.5	1	3.23	1
REFAG5G413.5	G4	Fine	Low	33.7	1	1	1

Range: 33.7 - 147   1   1 - 138   1

Median: 93.6   NC   21.0   NC

Note: Values reported as "1" are nondetects with a detection limit of 1.
NC =   No medians calculated because at least half the reported values were below
                      the method detection limit.
µg/kg =   Micrograms per kilogram.

**TABLE A3g. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 1 - 3.0 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSCG1A603.0	A6	Coarse	High	100	197	100	3,149
AMSCG1B203.0	B2	Coarse	High	100	100	100	1,219
AMSCG1C503.0	C5	Coarse	High	100	100	100	903
AMSCG1D203.0	D2	Coarse	High	100	100	100	737
AMSCG1E303.0	E3	Coarse	High	100	100	100	445
AMSCG1F703.0	F7	Coarse	High	100	100	100	1,639
AMSCG1G303.0	G3	Coarse	High	100	100	100	550

			Range:	100	100 - 197	100	445 - 3,150
			Median:	NC	NC	NC	903

Sample Name	Sample Location	Soil Type	Concentration Zone	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
REFERENCE SAMPLING METHOD DATA							
REFCG1B303.0	B3	Coarse	High	100	256	100	5,742
REFCG1C303.0	C3	Coarse	High	100	659	100	1,881
REFCG1D503.0	D5	Coarse	High	100	100	100	6,217
REFCG1E303.0	E3	Coarse	High	100	644	100	2,166
REFCG1F103.0	F1	Coarse	High	100	100	100	2,895
REFCG1G703.0	G7	Coarse	High	100	100	100	1,887

			Range:	100	100 - 659	100	1,880 - 6,220
			Median:	NC	NC	NC	2,530

Note: Values reported as "100" are nondetects with a detection limit of 100.
NC =   No medians calculated because at least half the reported values were below
             the method detection limit.
µg/kg =   Micrograms per kilogram.

TABLE A3h. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 1 - 6.5 FEET

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (μg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSCG1A606.5	A6	Coarse	Low	11.8	1	2.67	68.8
AMSCG1B206.5	B2	Coarse	Low	7.01	75.5	12.1	106
AMSCG1C506.5	C5	Coarse	Low	1	15.5	1	29.2
AMSCG1D206.5	D2	Coarse	Low	2.86	38.4	5.80	109
AMSCG1F706.5	F7	Coarse	Low	1	1.78	1	11.4
AMSCG1G306.5	G3	Coarse	Low	4.65	72.1	6.44	74.0

			Range:	1 - 11.8	1 - 75.5	1 - 12.1	11.4 - 109
			Median:	3.76	26.9	4.23	71.4

Sample Name	Sample Location	Soil Type	Concentration Zone	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
REFERENCE SAMPLING METHOD DATA							
REFCG1A306.5	A3	Coarse	Low	2.03	32.1	6.46	107
REFCG1B306.5	B3	Coarse	Low	1	14.0	3.47	58.5
REFCG1C306.5	C3	Coarse	Low	2.36	54.6	22.4	848
REFCG1D506.5	D5	Coarse	Low	1	13.1	4.18	109
REFCG1F106.5	F1	Coarse	Low	5.81	19.8	8.39	114
REFCG1G706.5	G7	Coarse	Low	3.08	36.3	6.44	256

			Range:	1 - 5.81	13.1 - 54.6	3.47 - 22.4	58.5 - 848
			Median:	2.20	26.0	6.45	112

Note: Values reported as "1" are nondetects with a detection limit of 1.
NC =   No medians calculated because at least half the reported values were below
               the method detection limit.
μg/kg =   Micrograms per kilogram.

TABLE A3i. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 2 - 3.0 FEET

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (μg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSCG2A703.0	A7	Coarse	High	100	100	100	704
AMSCG2B303.0	B3	Coarse	High	100	100	100	483
AMSCG2C403.0	C4	Coarse	High	100	100	100	499
AMSCG2D703.0	D7	Coarse	High	100	100	100	719
AMSCG2E403.0	E4	Coarse	High	100	100	100	1,788
AMSCG2F303.0	F3	Coarse	High	100	100	100	643
AMSCG2G703.0	G7	Coarse	High	100	100	100	676
			Range:	100	100	100	483 - 1,790
			Median:	NC	NC	NC	676

REFERENCE SAMPLING METHOD DATA							
REFCG2A103.0	A1	Coarse	High	100	100	126	1,830
REFCG2B603.0	B6	Coarse	High	100	100	100	1,615
REFCG2C103.0	C1	Coarse	High	100	100	100	2,003
REFCG2D603.0	D6	Coarse	High	100	100	100	1,556
REFCG2E303.0	E3	Coarse	High	100	984	435	2,905
REFCG2F503.0	F5	Coarse	High	100	320	375	2,149
REFCG2G103.0	G1	Coarse	High	100	273	355	2,282
			Range:	100	100 - 984	100 - 435	1,560 - 2,910
			Median:	NC	NC	126	2,000

Note: Values reported as "100" are nondetects with a detection limit of 100.

NC = No medians calculated because at least half the reported values were below the method detection limit.

μg/kg = Micrograms per kilogram.

TABLE A3j. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 3 - 3.0 FEET

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSCG3C403.0	C4	Coarse	High	100	100	100	1,621
AMSCG3D103.0	D1	Coarse	High	100	100	100	1,499
AMSCG3E403.0	E4	Coarse	High	100	100	100	1,558
AMSCG3F503.0	F5	Coarse	High	100	100	100	2,209
AMSCG3G303.0	G3	Coarse	High	100	100	100	1,674

Range:	100	100	100	1,500 - 2,210
Median:	NC	NC	NC	1,620

Sample Name	Sample Location	Soil Type	Concentration Zone	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
REFERENCE SAMPLING METHOD DATA							
REFCG3A203.0	A2	Coarse	High	100	313	100	2,105
REFCG3B103.0	B1	Coarse	High	100	100	100	1,597
REFCG3C203.0	C2	Coarse	High	100	100	100	2,067
REFCG3D603.0	D6	Coarse	High	100	100	100	1,372
REFCG3E603.0	E6	Coarse	High	100	100	100	1,027
REFCG3F603.0	F6	Coarse	High	100	100	100	1,056

Range:	100	100 - 313	100	1,030 - 2,110
Median:	NC	NC	NC	1,480

Note: Values reported as "100" are nondetects with a detection limit of 100.
NC =   No medians calculated because at least half the reported values were below
               the method detection limit.
µg/kg =   Micrograms per kilogram.

TABLE A3k. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE - GRID 3 - 7.5 FEET

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (μg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSCG3A407.5	A4	Coarse	Low	1	19.4	8.04	35.7
AMSCG3B207.5	B2	Coarse	Low	1	18.6	7.15	22.2
AMSCG3C407.5	C4	Coarse	Low	1	20.3	6.95	29.7
AMSCG3D107.5	D1	Coarse	Low	3.77	35.1	13.7	55.7
AMSCG3E407.5	E4	Coarse	Low	1	45.1	14.6	98.8
AMSCG3F507.5	F5	Coarse	Low	1	19.0	5.18	17.0
AMSCG3G307.5	G3	Coarse	Low	1	26.3	8.69	35.0

Range:				1 - 3.77	18.6 - 45.1	5.18 - 14.6	17.0 - 98.8
Median:				NC	20.3	8.04	35.0

Sample Name	Sample Location	Soil Type	Concentration Zone	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
REFERENCE SAMPLING METHOD DATA							
REFCG3A207.5	A2	Coarse	Low	1	3.81	2.48	21.1
REFCG3D607.5	D6	Coarse	Low	7.35	21.9	31.7	177
REFCG3E607.5	E6	Coarse	Low	5.69	13.5	19.6	98.7
REFCG3G407.5	G4	Coarse	Low	2.55	14.3	10.2	47.3

Range:				1 - 7.35	3.81 - 21.9	2.48 - 31.7	21.1 - 177
Median:				4.12	13.9	14.9	73.0

Note: Values reported as "1" are nondetects with a detection limit of 1.
NC =   No medians calculated because at least half the reported values were below
              the method detection limit.
μg/kg =   Micrograms per kilogram.

**TABLE A3l. VOLATILE ORGANIC COMPOUND CONCENTRATIONS
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOND
CSC SITE - GRID 4 - 6.5 FEET**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (μg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSCG4A606.5	A6	Coarse	Low	1	18.5	3.84	31.9
AMSCG4C506.5	C5	Coarse	Low	1	10.8	2.56	46.5
AMSCG4D406.5	D4	Coarse	Low	1	1	1	11.2
AMSCG4E706.5	E7	Coarse	Low	1	22.0	3.79	47.3
AMSCG4F406.5	F4	Coarse	Low	1	11.8	2.84	65.7
AMSCG4G106.5	G1	Coarse	Low	1	3.66	1	29.2

			Range:	1	1 - 22.0	1 - 3.84	11.2 - 65.7
			Median:	NC	11.3	2.70	39.2

REFERENCE SAMPLING METHOD DATA							
REFCG4B606.5	B6	Coarse	Low	5.72	51.4	43.3	749
REFCG4C706.5	C7	Coarse	Low	1	8.09	2.37	24.8
REFCG4D306.5	D3	Coarse	Low	1	3.54	1	50.3
REFCG4F306.5	F3	Coarse	Low	2.10	12.9	4.39	59.7
REFCG4G506.5	G5	Coarse	Low	1	1	1	5.55

			Range:	1 - 5.72	1 - 51.4	1 - 43.3	5.55 - 749
			Median:	NC	8.09	2.37	50.3

Note: Values reported as "1" are nondetects with a detection limit of 1.
NC =   No medians calculated because at least half the reported values were below
             the method detection limit.
μg/kg =   Micrograms per kilogram.

TABLE A3m. VOLATILE ORGANIC COMPOUND CONCENTRATIONS IN INTEGRITY SAMPLES
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
SBA SITE

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (μg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSAG1A70INT	A7	Fine	Low	1	1	1	1
AMSAG1B30INT	B3	Fine	Low	1	1	1	1
AMSAG1E50INT	E5	Fine	Low	1	1	1	1
AMSAG1F70INT	F7	Fine	Low	1	1	1	1
AMSAG1G20INT	G2	Fine	Low	1	1	1	1

Range: 1   1   1   1

Median: NC   NC   NC   NC

REFERENCE SAMPLING METHOD DATA							
REFAG1A30INT	A3	Fine	Low	1	1	1	1
REFAG1B20INT	B2	Fine	Low	1	1	1	1
REFAG1C20INT	C2	Fine	Low	1	1	1	1
REFAG1D40INT	D4	Fine	Low	1	1	1	1
REFAG1E40INT	E4	Fine	Low	1	1	1	1
REFAG1F20INT	F2	Fine	Low	1	1	1	1
REFAG1G70INT	G7	Fine	Low	1	1	1	1

Range: 1   1   1   1

Median: NC   NC   NC   NC

Note: Values reported as "1" are nondetects with a detection limit of 1.
NC =   No medians calculated because at least half the reported values were below
         the method detection limit.
μg/kg =   Micrograms per kilogram.

**TABLE A3n. VOLATILE ORGANIC COMPOUND CONCENTRATIONS IN INTEGRITY SAMPLES
FOR DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD
CSC SITE**

Sample Name	Sample Location	Soil Type	Concentration Zone	Contaminant Concentration (µg/kg)			
				cis-1,2-DCE	1,1,1-TCA	TCE	PCE
DUAL TUBE LINER SAMPLER DATA							
AMSCG1A60INT	A6	Coarse	Low	1	1	1	1
AMSCG1B20INT	B2	Coarse	Low	1	1	1	1
AMSCG1C50INT	C5	Coarse	Low	6.07	1	1	1
AMSCG1D20INT	D2	Coarse	Low	1	1	1	1
AMSCG1E30INT	E3	Coarse	Low	1	1	1	1
AMSCG1F70INT	F7	Coarse	Low	1	1	1	1
AMSCG1G30INT	G3	Coarse	Low	1	1	1	1

Range:				1 - 6.07	1	1	1
Median:				NC	NC	NC	NC

REFERENCE SAMPLING METHOD DATA							
REFCG1A30INT	A3	Coarse	Low	1	1	1	1
REFCG1B30INT	B3	Coarse	Low	1	1	1	1
REFCG1D50INT	D5	Coarse	Low	1	1	1	1
REFCG1E10INT	E1	Coarse	Low	1	1	1	1
REFCG1G70INT	G7	Coarse	Low	1	1	1	1

Range:				1	1	1	1
Median:				NC	NC	NC	NC

Note: Values reported as "1" are nondetects with a detection limit of 1.

NC = No medians calculated because at least half the reported values were below the method detection limit.

µg/kg = Micrograms per kilogram.

APPENDIX A4

STATISTICAL SUMMARY OF MANN-WHITNEY TEST

TABLE A4a. COMPARATIVE SUMMARY OF MANN-WHITNEY STATISTICS FOR THE DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD

Site Description	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
Site: **SBA** Grid: **1** Depth: **9.5 feet** Soil Type: **Fine** Concentration: **High**	NO	NC (ALL ND)	NO	NO
Site: **SBA** Grid: **1** Depth: **13.5 feet** Soil Type: **Fine** Concentration: **High**	NO	NC (ALL ND)	NO	NC (2)
Site: **SBA** Grid: **2** Depth: **3.5 feet** Soil Type: **Fine** Concentration: **Low**	NC (2)	NC (ALL ND)	NO	NC (ALL ND)
Site: **SBA** Grid: **3** Depth: **9.5 feet** Soil Type: **Fine** Concentration: **High**	**YES**	NC (ALL ND)	NO	NC (ALL ND)
Site: **SBA** Grid: **4** Depth: **9.5 feet** Soil Type: **Fine** Concentration: **Low**	NO	NC (ALL ND)	NO	NC (ALL ND)
Site: **SBA** Grid: **5** Depth: **13.5 feet** Soil Type: **Fine** Concentration: **Low**	NO	NC (ALL ND)	NO	NC (ALL ND)
Site: **CSC** Grid: **1** Depth: **3.0 feet** Soil Type: **Coarse** Concentration: **High**	NC (ALL ND)	NC (4)	NC (ALL ND)	**YES**

TABLE A4a. COMPARATIVE SUMMARY OF MANN-WHITNEY STATISTICS FOR THE DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD (Continued)

Site Description	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
Site: **CSC** Grid: **1** Depth: **6.5 feet** Soil Type: **Coarse** Concentration: **Low**	NO	NO	NO	NO
Site: **CSC** Grid: **2** Depth: **3.0 feet** Soil Type: **Coarse** Concentration: **High**	NC (ALL ND)	NC (3)	NC (4)	**YES**
Site: **CSC** Grid: **3** Depth: **3.0 feet** Soil Type: **Coarse** Concentration: **High**	NC (ALL ND)	NC (1)	NC (ALL ND)	NO
Site: **CSC** Grid: **3** Depth: **7.5 feet** Soil Type: **Coarse** Concentration: **Low**	NC (4)	**YES**	NO	NO
Site: **CSC** Grid: **4** Depth: **6.5 feet** Soil Type: **Coarse** Concentration: **Low**	NC (2)	NO	NO	NO

Note:

NC — No medians calculated because at least half the reported values were below the method detection limit.

(ALL ND) — Level of contaminants in all samples tested were below the method detection limits.

(X) — Number of samples in which some level of contamination was detected. The number of samples containing some contaminants in the referenced test series was deemed too low for statistical analysis (that is, there were too many "0" values).

NO — Level of difference between tested populations was not statistically significant.

YES — Level of significance between tested populations was $p \leq 0.10$.

TABLE A4b. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD SBA SITE

Site: **SBA**
Grid: **1**
Depth: **9.5 feet**
Soil Type: **Fine**
Concentration: **High**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7	52		41	45.5
Reference (2)	7	53		64	59.5
N1N2+ [N1(N1+1)]/2		77		77	77
N1N2+ [N2(N2+1)]/2		77		77	77
Mann-Whitney 1		25		36	31.5
Mann-Whitney 2		24		13	17.5
Mann-Whitney > 41?		NO		NO	NO

Site: **SBA**
Grid: **1**
Depth: **13.5 feet**
Soil Type: **Fine**
Concentration: **High**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7	50		57	
Reference (2)	7	55		48	
N1N2+ [N1(N1+1)]/2		77		77	
N1N2+ [N2(N2+1)]/2		77		77	
Mann-Whitney 1		27		20	
Mann-Whitney 2		22		29	
Mann-Whitney > 36?		NO		NO	

Site: **SBA**
Grid: **2**
Depth: **3.5 feet**
Soil Type: **Fine**
Concentration: **Low**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7			64	
Reference (2)	7			41	
N1N2+ [N1(N1+ 1)]/2				77	
N1N2+ [N2(N2+ 1)]/2				77	
Mann-Whitney 1				13	
Mann-Whitney 2				36	
Mann-Whitney > 41?				NO	

Site: **SBA**
Grid: **3**
Depth: **9.5 feet**
Soil Type: **Fine**
Concentration: **High**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7	28		31	
Reference (2)	4	38		35	
N1N2+ [N1(N1+ 1)]/2		56		56	
N1N2+ [N2(N2+ 1)]/2		38		38	
Mann-Whitney 1		28		25	
Mann-Whitney 2		0		3	
Mann-Whitney > 25?		**YES**		NO	

TABLE A4b. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD SBA SITE (Continued)

Site: **SBA**
Grid: **4**
Depth: **9.5 feet**
Soil Type: **Fine**
Concentration: **Low**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7	65		62	
Reference (2)	7	40		43	
N1N2+ [N1(N1+1)]/2		77		77	
N1N2+ [N2(N2+1)]/2		77		77	
Mann-Whitney 1		12		15	
Mann-Whitney 2		37		34	
Mann-Whitney > 41?		NO		NO	

Site: **SBA**
Grid: **5**
Depth: **13.5 feet**
Soil Type: **Fine**
Concentration: **Low**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7	60		59	
Reference (2)	6	31		32	
N1N2+ [N1(N1+1)]/2		70		70	
N1N2+ [N2(N2+1)]/2		63		63	
Mann-Whitney 1		10		11	
Mann-Whitney 2		32		31	
Mann-Whitney > 36?		NO		NO	

TABLE A4c. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD CSC SITE

Site: **CSC**
Grid: **1**
Depth: **3.0 feet**
Soil Type: **Coarse**
Concentration: **High**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7				32
Reference (2)	6				59
N1N2+ [N1(N1+ 1)]/2					70
N1N2+ [N2(N2+ 1)]/2					63
Mann-Whitney 1					38
Mann-Whitney 2					4
Mann-Whitney > 36?					**YES**

Site: **CSC**
Grid: **1**
Depth: **6.5 feet**
Soil Type: **Coarse**
Concentration: **Low**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	6	42.5	40	30.5	26.5
Reference (2)	6	32.5	38	47.5	51.5
N1N2+ [N1(N1+ 1)]/2		57	57	57	57
N1N2+ [N2(N2+ 1)]/2		57	57	57	57
Mann-Whitney 1		14.5	17	26.5	30.5
Mann-Whitney 2		24.5	19	9.5	5.5
Mann-Whitney > 31?		NO	NO	NO	NO

TABLE A4c. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD CSC SITE (Continued)

Site: **CSC**
Grid: **2**
Depth: **3.0 feet**
Soil Type: **Coarse**
Concentration: **High**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7				30
Reference (2)	7				75
N1N2+ [N1(N1+ 1)]/2					77
N1N2+ [N2(N2+ 1)]/2					77
Mann-Whitney 1					47
Mann-Whitney 2					2
Mann-Whitney > 41?					**YES**

Site: **CSC**
Grid: **3**
Depth: **3.0 feet**
Soil Type: **Coarse**
Concentration: **High**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	5				35
Reference (2)	6				31
N1N2+ [N1(N1+ 1)]/2					45
N1N2+ [N2(N2+ 1)]/2					51
Mann-Whitney 1					10
Mann-Whitney 2					20
Mann-Whitney > 27?					NO

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TABLE A4c. COMPARATIVE MANN-WHITNEY STATISTICS FOR THE DUAL TUBE LINER SAMPLER AND REFERENCE SAMPLING METHOD CSC SITE (Continued)

Site: **CSC**
Grid: **3**
Depth: **7.5 feet**
Soil Type: **Coarse**
Concentration: **Low**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	7		52	37	37
Reference (2)	4		14	29	29
N1N2+ [N1(N1+1)]/2			56	56	56
N1N2+ [N2(N2+1)]/2			38	38	38
Mann-Whitney 1			4	19	19
Mann-Whitney 2			24	9	9
Mann-Whitney > 25?			**YES**	NO	NO

Site: **CSC**
Grid: **4**
Depth: **6.5 feet**
Soil Type: **Coarse**
Concentration: **Low**

Sum of Rank Statistics

	N	cis-1,2-DCE	1,1,1-TCA	TCE	PCE
AMS (1)	6		37.5	33.5	34
Reference (2)	5		28.5	29.5	32
N1N2+ [N1(N1+1)]/2			51	51	51
N1N2+ [N2(N2+1)]/2			45	45	45
Mann-Whitney 1			13.5	17.5	17
Mann-Whitney 2			16.5	15.5	13
Mann-Whitney > 27?			NO	NO	NO

Note: (N> xx) *Mann-Whitney* value must be greater than the given value to be significant at the 0.05 level of statistical significance. This is a two-tailed test.

Statistical Source:

Rohlf, F. James and Robert R. Sokal. 1969. Statistical Tables. W. H. Freeman and Company. Table CC. Critical values of the Mann-Whitney statistic, page 241.

US EPA ARCHIVE DOCUMENT

APPENDIX A5

STATISTICAL SUMMARY OF SIGN TEST

TABLE A5a. SIGN TEST SUMMARY
COMPARISON OF MEDIAN VOC CONCENTRATIONS FOR DUAL TUBE LINER SAMPLER
AND REFERENCE SAMPLING METHOD
SBA SITE

Site Description	Technology	Median cis-1,2-DCE	Median 1,1,1-TCA	Median TCE	Median PCE
Site: **SBA** Grid: **1**	Reference Sampling Method	86,700	ALL ND	276,000	1,630
Depth: **9.5 feet** Concentration: **High**	Dual Tube Liner Sampler	80,200	ALL ND	167,000	990
Site: **SBA** Grid: **1**	Reference Sampling Method	14,500	ALL ND	40,500	NC(1)
Depth: **13.5 feet** Concentration: **High**	Dual Tube Liner Sampler	9,900	ALL ND	47,500	NC(1)
Site: **SBA** Grid: **2**	Reference Sampling Method	NC(1)	ALL ND	56.9	ALL ND
Depth: **3.5 feet** Concentration: **Low**	Dual Tube Liner Sampler	NC(1)	ALL ND	86.9	ALL ND
Site: **SBA** Grid: **3**	Reference Sampling Method	903	ALL ND	38,500	ALL ND
Depth: **9.5 feet** Concentration: **High**	Dual Tube Liner Sampler	537	ALL ND	19,800	ALL ND
Site: **SBA** Grid: **4**	Reference Sampling Method	13.2	ALL ND	1,710	ALL ND
Depth: **9.5 feet** Concentration: **Low**	Dual Tube Liner Sampler	25.2	ALL ND	1,910	ALL ND
Site: **SBA** Grid: **5**	Reference Sampling Method	93.6	ALL ND	21.0	ALL ND
Depth**: 13.5 feet** Concentration: **Low**	Dual Tube Liner Sampler	166	ALL ND	106	ALL ND
Number of pairs in which Reference Sampling Method median is higher		3	0	2	1
Number of pairs in which Dual Tube Liner Sampler median is higher		2	0	4	0

Notes:

NC   No medians calculated because at least half the reported values were below the method detection limit.

ALL ND   Level of contaminants in all samples tested were below the method detection limits.

(X)   Number of samples in which some level of contamination was detected. The number of samples containing some contaminants in the referenced test series was deemed too low for statistical analysis (that is, there were too many "0" values).

**TABLE A5b. SIGN TEST SUMMARY
COMPARISON OF MEDIAN VOC CONCENTRATIONS FOR DUAL TUBE LINER SAMPLER
AND REFERENCE SAMPLING METHOD
CSC SITE**

Site Description	Technology	Median cis-1,2-DCE	Median 1,1,1-TCA	Median TCE	Median PCE
Site: **CSC** Grid: **1** Depth: **3.0** Concentration: **High**	Reference Sampling Method	ALL ND	NC(3)	ALL ND	2,530
	Dual Tube Liner Sampler	ALL ND	NC(1)	ALL ND	903
Site: **CSC** Grid: **1** Depth: **6.5 feet** Concentration: **Low**	Reference Sampling Method	2.20	26.0	6.45	112
	Dual Tube Liner Sampler	3.76	26.9	4.23	71.4
Site: **CSC** Grid: **2** Depth: **3.0 feet** Concentration: **High**	Reference Sampling Method	ALL ND	NC(3)	126	2,000
	Dual Tube Liner Sampler	ALL ND	ALL ND	ALL ND	676
Site: **CSC** Grid: **3** Depth: **3.0 feet** Concentration: **High**	Reference Sampling Method	ALL ND	NC(1)	ALL ND	1,480
	Dual Tube Liner Sampler	ALL ND	ALL ND	ALL ND	1,620
Site: **CSC** Grid: **3** Depth: **7.5 feet** Concentration: **Low**	Reference Sampling Method	4.12	13.9	14.9	73.0
	Dual Tube Liner Sampler	NC(1)	20.3	8.04	35.0
Site: **CSC** Grid: **4** Depth: **6.5 feet** Concentration: **Low**	Reference Sampling Method	NC(2)	8.09	2.37	50.3
	Dual Tube Liner Sampler	ALL ND	11.3	2.70	39.2
Number of pairs in which Reference Sampling Method median is higher		0	0	2	5
Number of pairs in which Dual Tube Liner Sampler median is higher		1	3	1	1

Notes:

NC   No medians calculated because at least half the reported values were below the method detection limit.

ALL ND   Level of contaminants in all samples tested were below the method detection limits.

(X)   Number of samples in which some level of contamination was detected. The number of samples containing some contaminants in the referenced test series was deemed too low for statistical analysis (that is, there were too many "0" values).