INNOVATIVE TECHNOLOGY

Summary Report

DOE/EM-0592

Adaptive Sampling and Analysis Programs (ASAPs)

Characterization, Monitoring, and Sensor Technology Crosscutting Program and Subsurface Contaminants Focus Area

Prepared for

U.S. Department of Energy

Office of Environmental Management

Office of Science and Technology

August 2001

INNOVATIVE TECHNOLOGY
Summary Report

Adaptive Sampling and Analysis Programs (ASAPs)

OST/TMS ID 2946

Characterization, Monitoring, and Sensor Technology Crosscutting Program and Subsurface Contaminants Focus Area

Demonstrated at
Sandia National Laboratories, Albuquerque, NM
Argonne National Laboratory, Argonne, IL
Brookhaven National Laboratory, Upton, NY
FUSRAP sites in Painesville and Luckey, OH
and
USACE Ashland 2 FUSRAP Site, Tonawanda, NY
DoD sites at Kirtland Air Force Base, Albuquerque, NM and
Joliet Army Ammunition Plant, Joliet, IL
Private NORM contaminated site in Mt. Pleasant, MI

INNOVATIVE TECHNOLOGY

Summary Report

Purpose of this document

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

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

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

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

TABLE OF CONTENTS

APPENDICES

SECTION 1
SUMMARY

Technology Summary

Problem

Traditional site characterization methods rely on preplanned sampling programs and off-site analysis of samples to determine the extent and level of hazardous waste contamination. This process is costly and time-consuming. Static work plans specify the numbers and locations of samples to be collected, as well as the analyses to be performed on collected samples. Sampling crews are mobilized, samples are collected, and the crews are demobilized before final results become available. Additional sampling programs are often required to resolve uncertainties raised by the initial sampling and analysis results. The drawbacks of a traditional approach to sampling program design and execution are high costs per sample, pressure to over sample while at the site, and inevitable surprises in the analytical results that require additional sampling to resolve.

A key step in the characterization of hazardous wastes at U.S. Department of Energy (DOE) sites is determination of the extent of contamination. The proper number and placement of sampling locations is required to both minimize characterization costs and guarantee that contamination extent can be estimated with reasonable confidence. Because "soft" information (i.e., historical records, computer modeling results, past experience, etc.) for a site are usually just as important as "hard" laboratory results, the approach taken must include a quantitative way of accounting for both hard and soft site data.

Solution

An alternative to traditional sampling programs is Adaptive Sampling and Analysis Programs (ASAPs). ASAPs rely on field analytical methods to generate sample results quickly enough to have an impact on the course of the sampling program (Figure 1). Rather than a static work plan, ASAPs are based on dynamic work plans that specify the logic for how sampling numbers, locations, and analyses will be determined as the program proceeds. To ensure that the sampling stays on track, ASAPs also rely on rapid, field-level decision making. ASAPs require (1) field analytical methods that are appropriate for the types of expected contaminants and media present at the site, and (2) a way of supporting decision making in the field that is appropriate for the goals of the program.

Figure 1. Adaptive Sampling and Analysis Program design and execution.

How It Works

ASAPs utilize a dual approach to the sampling strategy problem. First, they use a Geographical Information System (GIS) specifically designed for site assessment work to integrate, manage, and display site characterization data as it is being generated, such as SitePlanner™, which was developed by ConSolve, Inc., is a graphical, object-oriented database designed to provide qualitative support of environmental site assessments. The purpose is to provide site characterization technical staff with as good an understanding of their site data as possible in near real time.

Coupled with the GIS is Plume™, an interactive software package developed at Argonne National Laboratory. Plume™ was developed as a separate technology with OST/TMS ID 733, and provides quantitative support for adaptive sampling and analysis programs. The software merges soft site data with hard sample results to form images of contamination location, provide quantitative measures of the potential benefits to be gained from additional sampling, and indicate the location of the best new sampling locations. Plume^{TM} uses advanced Bayesian and geostatistical procedures to complete these tasks. In this approach the analyst develops prior probabilities of threshold concentration level exceedences for constituents of concern using all available information such as site maps and so on. These prior probabilities are updated as often as daily; output generated includes: 1) graphics such as maps, fence diagrams, and boring logs that provide the characterization staff with a qualitative picture of the extent of contamination and its environmental context; 2) measures of contaminant extent and its uncertainty; 3) estimates of the benefits to be gained by obtaining additional samples; and 4) locations of the best new sampling locations. The most recent developments have focused on integrating these techniques into soil remedial actions to make those actions more precise.

The ASAP approach, supported through utilization of SitePlanner^{TM} and Plume^{TM}, is designed specifically for characterization of the presence and extent of contamination in groundwater, surface soils, and subsurface soils.

Advantages over the Baseline

The baseline method for characterizing the extent of contamination at a site includes rigid preplanned field sampling events with selective sampling based on best engineering judgment. Specimens are sent off-site for analysis and can require days to months for turnaround of sampling results depending on the sampling and analysis protocols (e.g., Contract Laboratory Program [CLP] analysis). Multiple sampling events are typically required to reach a high level of confidence that characterization is complete. Conversely, ASAPs provide optimization of sampling locations, on-site analysis utilizing lower cost field analytical methods, and single-stage sampling to arrive at the same levels of confidence (Johnson and Baecher 1997b). ASAPs provide several distinct advantages over the baseline method:

- ASAPs are better than traditional sampling approaches: Plume^{TM} can estimate the value that additional sampling data may provide, allowing stakeholders to weigh benefit/costs of collecting additional data. SitePlanner^{TM} allows rapid site data visualization as the data are generated. Both tools provide better characterization.

- ASAPs are faster than traditional sampling approaches: fewer samples are collected and additional field sampling events can be eliminated which results in expedited site characterization.

- ASAPs are safer than traditional sampling approaches: worker exposure to contaminants is reduced with fewer samples collected and fewer field-sampling events. Many field measurements can be performed *in situ*, which reduces or even eliminates wastes generated during the sampling process.

- ASAPs are cheaper than traditional sampling approaches: fewer samples are collected and overall project costs are reduced.

- When ASAPs are used to support soil remediation work, a more precise excavation plan can be developed. This reduces overall remediation costs by focusing the work on those soils that fail restoration goals.

Technology Status

Currently, deployment projects are underway at Fernald and at the U.S. Army Corps of Engineers (USACE) Formerly Utilized Sites Remedial Action Program (FUSRAP) Ashland 1 site (TMS Application ID: 1728). In addition, the USACE FUSRAP program is considering the use of these techniques for future work at the Linde and Colonie sites. All of these projects involve excavation of radionuclide-contaminated soils using a combination of real-time data collection techniques in an ASAP mode.

Demonstration Summary

This document covers several demonstrations and deployments of ASAPs that were conducted between 1992 and 1999. ASAPs have been used to delineate and quantify subsurface hazardous and mixed waste, and Naturally Occurring Radioactive Material (NORM) contamination, identify buried waste pits, and provide remediation support for precise excavations. The methodology has been applied at several sites that are summarized below.

- DOE facilities including Sandia National Laboratories, Chemical Waste Landfill (Albuquerque, NM), Argonne National Laboratory, 317 Area (Argonne, IL), and Brookhaven National Laboratory, Glass Holes Area (Upton, NY)
- DOE FUSRAP sites including Painesville (Painesville, OH) and Luckey (Luckey, OH)
- USACE Ashland 2 FUSRAP Site (Tonawanda, NY) in support of precision excavation, which is detailed in Sections 3 and 5 of this document
- Department of Defense (DoD) sites at Kirtland Air Force Base, RB-11 (Albuquerque, NM) and Joliet Army Ammunition Plant, TNT Production Area (Joliet, IL)
- Private NORM contaminated site in Mt. Pleasant, MI

The use of an ASAP approach at these sites has resulted in better site characterization and delineation of contamination with reduced sampling and analysis costs. This methodology has been used to develop defensible conceptual models of contaminated sites and generate estimates of extent and volume of contaminated soils. As a result of the significant cost savings and several successful demonstrations/ deployments, the use of a ASAPs approach is being evaluated for use at other FUSRAP sites for precise excavation.

Contacts

Technical

Robert Johnson, Principal Investigator, Argonne National Laboratory - Environmental Assessment Division, e-mail: rljohnson@anl.gov, telephone: (630) 252-7004

David J. Conboy, Ashland 2 Site Deployment Contact, USACE - Buffalo District, e-mail: david.j.conboy@usace.army.mil, telephone: (716) 879-4436

Management

Beth Moore, Characterization, Monitoring and Sensor Technology Crosscutting Program (CMST-CP), DOE-HQ Point of Contact, e-mail: beth.moore@em.doe.gov, telephone: (202) 586-6334

John Jones, CMST Field Technical Manager, e-mail: jonesjb@nv.doe.gov, telephone: (702) 295-0532

Web Site Locations

U.S. Department of Energy, Office of Science and Technology, http://www.em.doe.gov/ost

U.S. Department of Energy, CMST-CP Crosscutting Program, http://www.cmst.org

U.S. Department of Energy, Argonne National Laboratory, http://www.anl.gov

Other

All published Innovative Technology Summary Reports are available on the OST Web site at www.em.doe.gov/ost under “Publications.” The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for Adaptive Sampling and Analysis Programs (ASAPs) is 2946.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

ASAPs use real-time data collection techniques and in-field decision making to guide the progress of data collection at hazardous waste sites. An ASAP approach to site characterization/remediation is based on a dynamic work plan that specifies how data collection decisions will be made in the field; it does not, however, specify the exact locations and numbers of samples to be collected. In an ASAP data collection program, off-site analysis of soil samples using standard laboratory techniques is primarily used as a quality assurance/quality control (QA/QC) check for the real-time data; this analysis is not used as the principal data source for decision making. During ASAP data collection, the course of data collection work is driven by the results as they are obtained. In its extreme form, the next sampling location might be determined by all previous results. More commonly in an ASAP data collection effort, data planning and acquisition take place in sequential "chunks." For example, results from one day's work might be used to plan the data collection activities scheduled for the next day. Figure 1 graphically illustrates the ASAP process.

ASAP data collection programs require two key components to be effective: (1) real-time data collection techniques appropriate for the contaminants of concern and their cleanup guidelines, and (2) an in-field decision-making methodology for determining the course of data collection in response to real-time data streams.

Rapid in-field decision making (Figure 2) requires qualitative and quantitative decision support (Johnson et al. 1997). Qualitative decision support is defined as providing on-site technical staff with an accurate understanding of the progress concerning the sampling program as quickly as possible. Large ASAPs can produce hundreds of samples per day. Managing, integrating, and displaying the information associated with sampling pose a serious logistical problem that can interfere with program progress if not adequately addressed. A typical ASAP configuration includes some type of in-field database system along with some form of GIS for data display. Good qualitative support is the prerequisite for quantitative decision making. SitePlanner™ was developed for environmental management and display needs. Several other competitive software packages are available including ArcView® GIS and SiteView.

Quantitative decision support for ASAPs requires the ability to estimate contaminant extent based on sampling results, determine the uncertainty associated with those estimates, measure the utility expected from additional sampling (i.e., reductions in uncertainty), and find new sampling locations that provide the most value. Quantitative decision support for ASAPs must take into account two general characteristics of contamination at hazardous waste sites. The first characteristic is that while there may be initially few, if any, discrete sample results upon which to base a sampling program, there typically is a wealth of other pertinent information. The second characteristic is that spatial autocorrelation is usually present at hazardous waste sites and must be accounted for when drawing conclusions from discrete sample results. Plume™ provides quantitative support for adaptive sampling programs using a combination of Bayesian analysis with geostatistics to guide the program design and implementation.

Figure 2. ASAPs allow rapid field decisions.

Bayesian analysis is used to merge "soft" information about the probable location of contamination with "hard" data that might be available for the site. Hard data refers to results from the analysis of collected samples. Soft information refers to all other types of data that might be available for a site, including: site maps, aerial photographs, non-intrusive geophysical surveys, historical information concerning the nature and source of contamination, past experience with similar sites, fate and transport modeling, and other sources. This information, while not absolutely conclusive regarding the presence or absence of contamination above action levels at any particular location, contributes significantly to the technical staff's understanding about the probable location of contamination.

Geostatistics is used to interpolate sampling results from locations where hard data exist to other locations that lack sampling data. Geostatistics is grounded in the presence of spatial autocorrelation – the fact that two samples collected very close to each other will have results that are similar, but samples separated by a large distance may have results that are totally unrelated. When sample results are correlated and the level of correlation is a function of the distance separating the samples, spatial autocorrelation exists. For the purposes of contaminant extent delineation, the primary issue is not the absolute value of a contaminant observed but whether that value exceeds some action level or cleanup goal. In this context, sample results can be reduced to either 0 or 1. A value of 0 is assigned if contamination above action levels is not detected, and 1 if it is. A specialized form of geostatistics called indicator kriging can be used to interpolate these values and determine the spatial distribution of contamination above and below action levels.

Implementation

The ASAP design and implementation process for contamination delineation follows these steps:

1. A set of decision points forming a regular grid is laid across the site. Decision points are so named because at each point a decision will have to be made - based on the available information, will this point be considered clean (i.e., the probability of contamination above the prescribed action level is acceptably low) or contaminated (i.e., the probability of contamination being present at this point is unacceptably high). The acceptable level of uncertainty serves as the criterion for differentiating between decision points that can be considered clean and points that must be treated as contaminated. For example, the acceptable level of uncertainty may be set at 0.2 - a decision point with probability of contamination greater than 0.2 will be considered contaminated, while decision points with probability of contamination less than 0.2 will be considered clean. This value must be selected before the program begins with mutual agreement from the stakeholders and regulators involved. This treatment of uncertainty is consistent with the Type I and Type II error analysis advocated by the Environmental Protection Agency (EPA) Data Quality Objectives (DQOs) approach to environmental restoration decision making (U.S. EPA 1994).

2. Based on the soft information available for the site, a probability is assigned to each decision point that captures one's initial beliefs about the probability of contamination above action levels at that location. In some cases, one may be absolutely sure that soil contamination would be found. In other cases, one may be absolutely sure that soil contamination could not exist. Yet in other areas, one may not be able to draw any conclusion at all concerning the likely presence or absence of contamination (i.e., there is a 50-50 chance that contamination is present). The result is the initial conceptual model for the site.

3. If sample results are initially available, the probabilities at each of the decision points are updated with this hard data. Johnson (1996) provides a detailed description of how Bayesian analysis can be combined with indicator geostatistics to accomplish the required updating. The site is then broken into three regions: (1) regions where the probability of contamination associated with decision points is below the predefined acceptable level of uncertainty – these regions are accepted as clean with perhaps only minimal confirmatory sampling; (2) regions where the probability of contamination is so high that there is no need for sampling to confirm the presence of contamination; and (3) regions where the probability of contamination above action levels is neither very low nor very high - gray regions that represent areas of uncertainty in the context of the presence or absence of contamination above prescribed action levels.

4. The final step is actual sampling. There are several alternative decision rules that can be used to "drive" data collection. The most common is to focus on maximizing the area classified as clean, i.e., areas that have an acceptably low probability of contamination above requirements being present. This decision rule tends to produce an adaptive sampling program that starts at the fringe of known

contamination and works its way in. As data are collected, the underlying probability model is updated using Plume™, the value of collecting additional information evaluated, and additional sampling locations are selected that maximize the area classified as clean. Sampling stops when the additional value of sampling no longer warrants the investment. This becomes a simple cost calculation that weighs sampling and analysis costs with the expected volume of soil that might be reclaimed as "clean" and hence remediation costs avoided if sampling moves forward. Other decision rules that might be used include maximizing the area known to be contaminated, or minimizing the area categorized as uncertain.

Regardless of the decision rule used, the process is the same. Sampling locations are selected that provide the most benefit in the context of the selected decision rule. These would be sampled, their results analyzed, the probabilities of contamination associated with the decision point grid updated with the sample results, the extent of contamination determined again along with the number of "uncertain" decision points remaining, and a decision made whether additional sampling locations are justified. If so, the next best set of locations would be selected and the process carried through another iteration. When the expected gain in information from additional sampling no longer warrants the costs of collecting and analyzing additional samples, the program stops. SitePlanner™ and Plume™ are utilized to optimize sampling strategies (Figure 3).

The initial conceptual model is particularly important for three reasons.

1. The initial conceptual model takes qualitative information about a site and casts it into a quantitative format before sampling begins. By doing this, decisions can be made about whether any sampling is justified and, if so, what the potential value of that sampling might be. For example, based on existing soft and hard information, one might conclude that the volume of "uncertain" soils (i.e., soils that one cannot confidently classify as "contaminated" or "uncontaminated") is so small relative to the overall cleanup effort that investing in additional sampling to drive out that uncertainty is unwarranted. In this case, it might be cheaper to simply include the uncertain soils with the contaminated and remediate.

2. The initial conceptual model is the agreement point for all interested parties, including the responsible party, regulators, contractors, and the public. Since the evolution of the sampling program will be based on the initial conceptual model, it is important that all concerned parties are in agreement.

3. The initial conceptual model (updated with any existing hard sample data) will drive the selection of sampling locations in the beginning of the ASAP. The effectiveness and efficiency of the sampling program for delineating contamination will be directly related to the accuracy of this model.

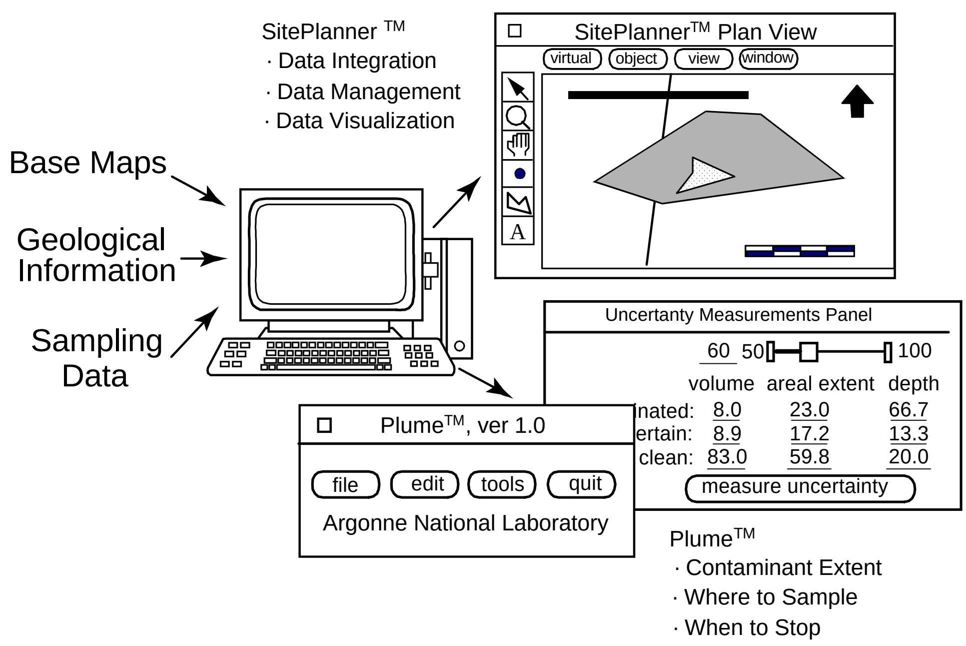

Figure 3. Optimization of sampling strategies.

SECTION 3
PERFORMANCE

Demonstration Plan

Ashland 2 Site Deployment

The Ashland 2 Site near Tonawanda, New York is the main focus of this document for performing cost assessment (DOE Technology Management System [TMS] Application ID: 1581). This FUSRAP site is the responsibility of the USACE Buffalo District. During the 1940s, the Manhattan Engineer District (MED) used facilities at a neighboring site to extract uranium from ore. The MED purchased property, currently known as the Ashland 1 Site, to use as a disposal location for ore refinery residues from the processing plant. Between 1974 and 1982 the Ashland Oil Company, who acquired the disposal site, excavated soil containing MED related low-level radioactive residues to the area known as the Ashland 2 Site. The Ashland 2 property includes about 115 acres of undeveloped land, although only a relatively small portion of the property was affected by soil disposal operations.

Over the last two decades a significant amount of characterization activities have taken place at the Ashland 2 Site, including 341 soil samples from 116 soil bores. Based on the Record of Decision for the Ashland 1 and Ashland 2 Sites, soils exceeding a site-specific guideline of 40 pCi/g thorium-230 (^{230}Th) were to be excavated followed by transportation to a licensed or permitted facility. Other contaminants of concern at the site included radium-226 (^{226}Ra) and uranium-238 (^{238}U).

An existing estimate based on data from the site Remedial Investigation (RI) placed soil volumes above the clean-up criteria at around 71,900 cubic yards (DOE 1997). Additional volumetric estimates of soil volumes above the clean-up criteria were derived for the Ashland 2 Site using Plume™. Based on this analysis, the required excavated volume was determined to be 48,400 cubic yards of soil (*in situ*). More importantly, however, the analysis indicated that the actual volume of soil above the clean-up criteria had a large degree of uncertainty despite the fact that the site had a relatively large amount of existing characterization data. This uncertainty clearly indicated that any remedial design based solely on the existing data would likely be incorrect for a significant volume of soil. Therefore, an ASAP approach was planned at the site in order to perform precise excavation of soils exceeding site-specific action levels, as discussed below.

- **Step 1 – Develop a conceptual model to bound the potential extent of contamination using existing data.** For this purpose, Plume™ (which combines indicator geostatistics and Bayesian analysis) was used. The products of this analysis were 2 and 3D probability maps that show the likelihood of any particular location exceeding clean-up guidelines. These probabilities ranged from 0, where sampling had determined that concentrations were consistently below clean-up goals, to 1, where samples had concentrations consistently above clean-up goals. The site was then divided into 3 regions:

    - The first region is where the probability of contamination above goals was sufficiently low that no excavation was deemed necessary.
    - The second region was where the probability of contamination above goals was so great that excavation was definitely required. The volume associated with this region represented the minimum amount of soil that would be remediated.
    - The third region is where the probability of contamination above goals was uncertain. The volume associated with this region combined with the volume of the second region represents the maximum amount of soil that would require excavation.

- **Step 2 - Select the most appropriate mix of data collection technologies for delineating excavation footprints as the excavation work proceeded.** Data collection technologies selected for the Ashland 2 precise excavation included gamma walkover surveys using a 2x2 Sodium Iodide (NaI) sensor combined with a Global Positioning System (GPS) for location control (Figure 4), and an on-site gamma spectroscopy lab for quick analyses of discrete samples. ^{230}Th posed special problems for the remediation since its gamma signature is extremely difficult to detect when ^{226}Ra and ^{238}U are present above background levels. In contrast, ^{226}Ra has a very clear gamma signature. A careful review of existing data indicated that by remediating areas to a ^{226}Ra concentration of 3 pCi/g, ^{230}Th could be reduced below its clean-up goals. This finding was substantiated by discrete sampling completed shortly before the excavation work began that attempted to establish the relationship between gross activity results and samples that exceed clean-up goals.

Figure 4. Gamma walkover equipment with GPS.

The advantage of gamma walkover scans is that one obtains a complete surficial picture of gross activity distribution at low cost. Another advantage of a walkover measurement program is that it is real time and decisions can be made quickly. The disadvantage is that these data are qualitative, and particularly for sites with multiple isotopes of concern, may only be weakly linked to the actual concentration-based clean-up criteria. The advantage of direct measurements/discrete samples is that one obtains concentration values directly comparable to clean-up guidelines. The disadvantages are that these data are relatively more expensive, provide only information for the specific locations where the data were collected, and there is a time lag until data are available.

The challenge for a precise excavation, using ASAP techniques in radionuclide-contaminated soil, is to develop a relationship between abundant screening data and clean-up goals using direct measurements/discrete samples. Figure 5 provides an example of this kind of relationship. In Figure 5, gross activity is along the x-axis, while the probability of samples encountering contamination above clean-up goals is shown on the y-axis. Discrete sampling is used to derive this relationship. With this relationship, one can select two gross activity trigger levels, the first below which one assumes soil can be left, and a second above which one assumes soil must come out. The range of gamma activities between these two triggers defines activities where definitive conclusions cannot be drawn regarding the presence or absence of soils above the cleanup requirements. For example, in Figure 5 the lower trigger level is 16,000 counts per minute (16K cpm), while the higher is 20K cpm.

- **Step 3 - Proceed with the excavation.** The excavation work proceeded in lifts ranging from 0.5 to 2 feet, with each lift face screened using gamma walkovers and characterized before excavation work continued. Combined gamma walkover/GPS data were logged and uploaded from the site daily to an Internet site. These data were converted into maps using ArcView® GIS and the exposed surfaces categorized as clean, uncertain or contaminated. The results of this analysis were made available to on-site staff and stakeholders via the Internet site. Turnaround times from collection to conclusions ranged from a few hours up to one day. Whether additional samples are collected is a cost/benefit judgement, with the cost of additional sampling (and an outcome of perhaps being able to label the soil as clean) balanced against the cost of simply lumping the soil with the rest of the contaminated area. Where disposal costs are low, additional discrete sampling may never be warranted. Where disposal costs are high, additional discrete sampling may always be beneficial. As excavation proceeded, additional discrete samples were collected periodically to verify that the relationship between gross activity and cleanup goals was not changing.

Results

Remediation of the Ashland 2 Site began on July 10, 1998. The boundary between soil above the clean-up criteria and soil below the clean-up criteria turned out to be very distinct. Precise excavation was essentially completed in December 1998. By the time the work was completed, approximately 45,500 cubic yards of soil (*ex situ*) were identified as being above the clean-up criteria. Status surveys were conducted and post-remediation testing and verification documentation were completed by August 1999. Backfill of the excavation and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site closure were completed in September 1999.

The effectiveness of the precise excavation approach can be measured by answering the following questions (Durham et al. 1999): (1) How "precise" was the excavation? (2) What difference was there between the footprint of the precise excavation and one defined solely on pre-existing RI data? (3) What additional cost or scheduling burdens did this approach place on the remediation process?

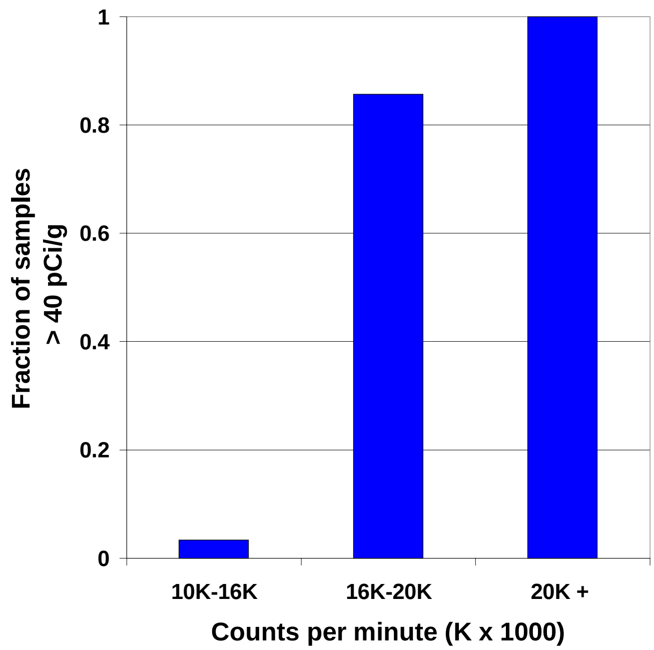

Figure 5. Relationship between gamma walkover data and cleanup requirements.

- Soil excavated above the clean-up criteria was stockpiled awaiting shipment by rail via intermodals. Of the 146 composite samples that were collected to characterize the material for shipment, 97 percent exceeded the clean-up criteria. Of the 4 composite intermodal samples that were below the clean-up criteria, 2 were collected from soil excavated within the first two weeks of the remediation when the precise excavation process was still being refined.

- Soils left in place underwent a final status survey process. Of 430 samples collected in the primary excavation area, only 5 exceeded the Record of Decision requirements. If excavation of surficial soil had been a conservative excavation based solely on pre-existing RI data, a total of 10,000 cubic yards would have been removed in the surface lift, compared to the 14,000 that were actually excavated. These 10,000 cubic yards would have included 4,000 cubic yards of soil below the clean-up criteria unnecessarily, and would have missed 8,000 cubic yards of soil actually above the clean-up criteria. These soils would have either been caught by the final status survey, in which case they would have represented an additional excavated volume, or they would have been missed, left behind and represented an unacceptable residual health risk. This large discrepancy was for surface soil where there was the greatest density of existing soil samples. The volume of soil above the clean-up criteria missed and the volume of soil unnecessarily excavated would have been even larger for deeper lifts where less data existed.

- The use of a precise excavation approach does place additional scheduling demands on the excavation process. Since excavation in a particular area cannot proceed until after screening has been completed, there is the possibility of expensive downtime for excavation crews. In the case of Ashland 2, however, this did not occur. In fact the bottleneck for the remediation process turned out to be the off-site shipment of soil and not the excavation work itself.

- Precise excavation also places an additional data collection/analysis burden on the remediation process. At Ashland 2, this took the form of gamma walkover surveys conducted after each lift plus data interpretation at Argonne National Laboratory. Preliminary cost estimation work indicates that the additional cost was approximately $208,000 over 6 months of excavation. Over $1.5 million in cost savings was achieved by avoiding unnecessary off-site disposal costs for just the first 2-foot lift (Durham et al. 1999). As the analysis for the surface lift indicates, the additional investment was more than compensated for by the precise nature of the excavation work, and the resulting minimization of off-site soil disposal.

Precise excavation also provided several benefits to the Ashland 2 remediation that are harder to quantify. First, by producing quantifiable and recordable data for each and every lift, USACE had a documented and defensible record of what was excavated and why. Second, USACE also had an independent means for evaluating estimates of volumes of contaminated soil being shipped off site, which was one measure for reimbursement for the prime remediation contractor. Finally, by making remediation support data immediately available over the Internet, USACE provided a means to distribute site information to the project team, including the New York Department of Environmental Conservation, which improved coordination and confidence in the remediation work conducted.

Other Demonstrations/Deployments

Sandia National Laboratories, Chemical Waste Landfill, Albuquerque, NM (retrospective analysis, 1992 and 1993 – TMS Application ID: 2076): The problem area was subsurface soil contaminated with chromium beneath the unlined chromic acid pit and the 60s pits. SitePlanner™ and Plume™ were used in a retrospective study to determine ASAP advantages. Field analytical techniques included x-ray fluorescence (XRF).

Benefits:
- The study suggested savings greater than 60% compared to conventional techniques.
- ASAPs could provide a reduction in the number of soil bores, samples collected, and overall analytical costs.

Kirtland Air Force Base, RB-11, Albuquerque, NM (deployment, 1994 – TMS Application ID: 2077): The ASAP approach was applied to subsurface mixed waste contamination associated with burial pits at Kirtland Air Force Base. SitePlanner™ and Plume™ were used in a demonstration that was coordinated with actual characterization activities at the site. Field analytical techniques included XRF for metals, a photo ionization detector (PID) for volatile organic compound (VOC) monitoring, and a Geiger-Mueller sensor for detection of radionuclides.

Benefits:
- Cost savings included a 22% reduction for soil borings and a significant reduction in per sample analytical costs.
- The number of samples collected was reduced by 50%.

Argonne National Laboratory, 317 Area, Argonne, IL (deployment, 1995 - TMS Application ID: 2078): An ASAP approach was used to delineate surface and near surface VOC soil contamination in the 317 area at Argonne National Laboratory. The purpose of the investigation was to delineate contamination and locate a French drain. The contractor proposed 200 borings and collection of 600 samples from a regular grid. SitePlanner™ and Plume™ were employed in conjunction with field headspace analysis for organics (Figure 6).

Figure 6. Field screening for organics.

Benefits:
- The ASAP reduced the number of borings by 60% and the number of samples by 66%.
- The investigation was completed in less than half the time originally specified.

Joliet Army Ammunition Plant, TNT Production Area, Joliet, IL (deployment, 1995 - TMS Application ID: 2079): An ASAP approach was used for delineation of surface and near-surface trinitrotoluene (TNT), dinitrotoluene (DNT) and nitrotoluene (NT) soil contamination. The ASAP purpose was to delineate contamination in support of a feasibility study. SitePlanner™ and Plume™ were utilized in combination with immunoassay kits and a field gas chromatograph/mass spectrometer (GC/MS) system customized for explosives.

Benefits:

- The ASAP reduced analytical costs by 75%.
- The ASAP yielded a much more accurate volume estimate for contaminated soils as compared to the capabilities of the gridded approach, which was proposed by the contractor.

Brookhaven National Laboratory, Glass Holes Area, Upton, NY (deployment, 1995 - TMS Application ID: 2080): An ASAP approach was used for delineation of subsurface mixed waste contamination including VOCs, metals and radionuclides. The ASAP purpose was to identify buried waste pits and quantify associated contamination. Field analytical techniques included a suite of non-intrusive geophysics, use of a Geoprobe® for sample collection, and on-site GC/MS for detection of VOCs/semi-volatile organic compounds (SVOCs). SitePlanner™ was used for data display.

Benefits:

- The ASAP provided a much more exact enumeration and delineation of pits.
- The estimated reduction in projected cost of pit excavation was in the order of millions of dollars.

DOE FUSRAP, Painesville Site, Painesville, OH (deployment, 1996 - TMS Application ID: 2081): An ASAP approach was used for delineation of surface and near surface mixed waste contamination, including VOCs and radionuclides. The ASAP purpose was to identify and delineate near surface contamination in support of the Engineering Evaluation/Cost Analysis (EE/CA). SitePlanner™ and Plume™ were used to display data and estimate the extent of contamination. Real-time data collection included gamma walkover combined with a GPS and on-site gamma spectroscopy.

Benefits:

- Bechtel estimated overall project savings on the order of $10 million (Bechtel National was prime contractor).
- Work received a DOE Pollution Prevention Award.

DOE FUSRAP, Luckey Site, Luckey, OH (deployment, 1997 - TMS Application ID: 2082): An ASAP approach was used for delineation of surface and near-surface mixed waste contamination, including beryllium and radionuclides. The ASAP purpose was to identify and delineate near surface contamination in support of the EE/CA. Real-time data collection included gamma walkover combined with a GPS, laser-induced breakdown spectroscopy (LIBS) backpack and trailer systems for beryllium, *in situ* high purity germanium (HPGe) gamma spectroscopy, and on-site gamma spectroscopy.

Benefits:

- There was a reduction in per sample characterization costs.
- The use of an ASAP approach resulted in a much more detailed delineation of surficial beryllium and radionuclide contamination.

Private NORM Contaminated Site, Mt. Pleasant, Michigan (deployment, 1998 - TMS Application ID: 2083): An ASAP approach was used to delineate surface and near-surface NORM contamination (^{226}Ra). The ASAP was built into the characterization and excavation process. Real-time data collection included gamma walkover combined with GPS, *in situ* HPGe gamma spectroscopy and the RadInSoil, a NaI-based *in situ* system for ^{226}Ra.

Benefits:

- Greatly reduced per sample analytical costs.
- A reduced reliance on soil sampling and *ex situ* gamma spectroscopy analyses.
- Characterization and remediation activities were combined in one field work cycle
- The remediation effort was more effective with a much more precise excavation footprint.

Currently, projects are underway at Fernald and several other USACE FUSRAP sites including Colonie, Ashland 1 (TMS Application ID: 1728), and Linde. All of these projects involve precise excavation (Figure 7) of radionuclide-contaminated soils using a combination of real-time data collection techniques in an ASAP mode.

Figure 7. ASAP mode used for precise excavation of soils.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Related Technologies

The baseline method for characterizing the extent of contamination at a site includes rigid preplanned field sampling events with selective sampling based on best engineering judgment. A phased approach is typically used for data collection using a statistical basis or regular grid to develop a site conceptual model. Samples are sent off site for analysis and can require days to months for turnaround of sampling results depending on the sampling and analysis protocols (e.g., CLP analysis). Multiple sampling events are typically required to reach a high level of confidence that characterization is complete. Other competing approaches for site characterization of soils and groundwater include:

- **The Observational Method** - This is an investigative process developed and used in the 1920's to 1950's for geotechnical characterization of soils and geotechnical engineering design. Characterization, design, and construction proceed hand-in-hand. As construction proceeds, observed changes in the soil system are used to modify the design. A critical element of the method is an early assessment of most probable conditions. Application to RI work or characterization stage focuses on determination of general site conditions and identification of the most probable conditions and reasonable deviations as the basis for a flexible approach to remediation design. The Observational Method does not provide explicit sampling design guidance.

- **Expedited Site Characterization (ESC)** - This method (U.S. DOE 1998a) was developed as a time saving, cost-effective approach for hazardous waste site investigations. ESC is an alternative approach that effectively shortens the length of the assessment period and may significantly reduce costs at many sites. It is not a specific technology or system but is a methodology for most effectively conducting a site characterization. The principal elements of ESC include: a field investigation conducted by an integrated team of experienced professionals working in the field at the same time; analysis, integration and initial validation of the characterization data as they are obtained in the field; and, a dynamic work plan that enables the team to take advantage of new insights from recent data to adjust the work plan in the field. The ESC methodology emphasizes the delineation of the hydrogeologic framework of the potentially contaminated site, followed by the delineation of the contaminant pathways and contaminant distribution, and the selection of the most effective measurement technologies. ASAPs can be integrated into the ESC approach for site characterization.

- **Superfund Accelerated Cleanup Model (SACM) and the Streamlined Approach for Environmental Restoration (SAFER)** - SACM was developed by U.S. EPA and SAFER was developed by the DOE. These are complimentary approaches for speeding up CERCLA Remedial Investigation/Feasibility Study (RI/FS) projects. SAFER integrates DQOs with the observational method. An ASAP approach can be easily incorporated into the characterization portion of SAFER to provide a conceptual model of the site in reduced time. The use of ASAPs in SAFER and SACM would lessen the emphasis on contingency planning due to the development of a robust and accurate site conceptual model during characterization.

The ASAPs approach, supported through utilization of SitePlanner™ (or other relational database management systems with GIS capabilities) and Plume™, is designed specifically for characterization of the presence and extent of contamination in groundwater, surface soils and subsurface soils. This approach allows real-time adjustment of the site conceptual model and allows rapid, 3D visualization of the results in the field. Unlike the baseline and competing technologies, ASAPs are adjusted "on the fly" as new data is generated in the field. ASAPs provide several key advantages over standard characterization approaches that rely on static work plans and off-site analysis:

- Data collection programs rely on real-time data collection techniques that typically incorporate screening and field analytical technologies. Per sample analytical costs can be significantly less than the costs for off-site laboratory analyses.

- ASAPs can determine which new sampling locations provide the most beneficial information, eliminating unnecessary sampling.

- Data collection programs can be adjusted in the field, “on the fly” as results are encountered, thereby producing much more focused and efficient data collection programs.

- Data collection proceeds until the characterization goals have been met. Consequently, the need for additional site characterization efforts is greatly reduced. In contrast, traditional characterization programs that rely on off-site laboratory analyses for information often require repeated mobilizations to clarify sample results.

- Finally, because ASAPs provide data on site in an expedient fashion using Bayesian analysis and geostatistics, characterization and remediation activities can be merged effectively, which shortens project schedules and facilitates the use of more precise remediation technologies. This is particularly true when remediating contaminated soils where ASAP data collection can be effectively used as an *in situ* soil segregation or sorting technique.

Technology Applicability

The ASAPs approach can be most effectively utilized for the following situations:

- Contaminants of concern are well understood

- Field screening or analytic methods are available that are appropriate for the contaminants of concern and their action levels

- The purpose of sampling is to identify contamination location and delineate its extent

The ASAPs approach may not be appropriate where contaminants of concern are not known, where there are no field analytical methods appropriate for the contaminants of concern and their action levels, or for sampling objectives other than to identify and delineate contamination extent

Patents/Commercialization/Sponsor

The ASAPs technology was initially comprised of two primary components: SitePlanner™ and Plume™. Intellectual property rights for these components are controlled through copyrights and trademarks. ConSolve, Inc. (now defunct) in Lexington, MA owns the copyright and trademark for SitePlanner™. The copyright and trademark for Plume™ are owned by Argonne National Laboratory in Argonne, IL.

Funding for this work originally came from the DOE Office of Technology Development (OTD) [now known as Office of Science and Technology (OST)] through the Mixed Waste Landfill Integrated Demonstration Project. The work began in FY 1992 and continued with OTD support through FY 1994. After FY 1994, there was considerable additional work with support from the Strategic Environmental Research and Development Program and through various DOE offices and DoD Installation Restoration Programs. Most recently, there has been DOE OST support through the Accelerated Site Technology Deployment program for work at the Fernald site, which is focused on integrating ASAP techniques into soil remedial actions. The DOE Office of Fossil Energy is currently sponsoring a technology transfer project for making ASAP techniques more widely available to oil and gas industry NORM problems.

SECTION 5
COST

Methodology

This section summarizes cost information for applying an ASAPs approach at the Ashland 2 FUSRAP site near Tonawanda, New York. The estimates reflect actual field costs incurred during site remediation using an ASAPs methodology to refine boundaries during remediation and allow a precise excavation of contaminated soils exceeding site action levels. Original data from the site RI was used to develop a baseline for the site. Gamma walkover data combined with GPS was used in conjunction with samples collected and analyzed using an on-site mobile laboratory to perform gamma spectroscopy, and samples collected and analyzed using alpha spectroscopy at an off-site laboratory. These data were used to refine the footprint for excavation as remediation progressed.

The challenge is to provide a defensible cost analysis when comparing the innovative ASAPs approach to the baseline technology of applying traditional sampling and analysis results from the RI to perform site remediation. Three alternatives will be examined: (1) performance of remediation using block excavation techniques based on the original RI data, (2) performance of remediation using block excavation techniques when applying Plume™ to the original RI data, and (3) performance of remediation using precise excavation techniques based on using an ASAPs approach that fuses RI data with data obtained from gamma walkover surveys, on-site gamma spectroscopy, and off-site alpha spectroscopy of discrete samples.

This study will develop the overall cost of applying each alternative to remediation of the Ashland 2 site and develop the benefit-to-cost ratio for applying the ASAPs approach. To determine present value, actual costs for the excavation were escalated from the excavation end date (December 1998) to March 2000 using values from the Engineering News Record (ENR) Construction Cost Index (CCI). This remediation involved excavation of contaminated soils above the prescribed action level of 40 picocuries per gram (pCi/g) ^{230}Th, followed by transportation to the approved disposal facility at International Uranium Corporation (IUC) White Mesa Uranium Mill near Blanding, Utah. Data used in the cost analysis is summarized in Table 1.

Table 1. Data utilized to perform cost analysis for Ashland 2 site

Parameter	Units	Value
In situ soil excavated in block excavation based on RI data	yd^3	71,900
In situ soil excavated in block excavation, applying geostatistics to RI data	yd^3	48,400
In situ soil excavated in precise excavation based on ASAPs	yd^3	36,400
Actual excavation time using ASAPs approach	months	6
Soil volume expansion factor (*ex situ*)	percent	25
Off-site alpha spectroscopy for uranium, radium, and thorium (discrete)	$/sample	350
On-site gamma spectroscopy for uranium, radium, and thorium	$/sample	100
Intermodal container rental fee	$/container	189
Intermodal container capacity	yd^3	18.5
Intermodal container full-suite analysis (chemical, radiological, TCLP)	$/sample	2,500
Soil excavation (block excavation technique)	$/yd^3	4.94
Soil excavation (precise excavation technique)	$/yd^3	6.70
Soil transportation fee	$/yd^3	173
Soil disposal fee (International Uranium Corporation)	$/yd^3	90
Backfill/compact and grade site with borrow soil (ECHOS 1998)	$/yd^3	7.70

Note: Cost basis is December 1998.

Assumptions in this analysis were derived from discussions with personnel involved in the excavation operations, values used by the USACE in preliminary estimates, and a value engineering study (USACE 1998) conducted jointly by the USACE and other parties involved in the site remediation activities. General and administrative (G&A) costs are 8 percent and fees are 6.75 percent. Other cost factors include site engineering/design/permitting at 10 percent of the project cost, and project management at 10 percent.

At Ashland 2 there was no evidence that the precise excavation delayed scheduled excavation work. A simplifying assumption is made that both block and precise excavation would require the same amount of time. Therefore, the primary areas for cost savings are associated with excavation, transportation and disposal fees. A description of assumptions for costing each alternative is listed below. Table 1 includes data used to perform the cost analysis for the Ashland 2 site.

Block Excavation Based on RI Data

Block excavation involves identifying a rough excavation footprint and determining the required depth of excavation before removing soil within that footprint. In this cost scenario, the footprint is defined by the original RI characterization data. Excavation is completed without intermediate checking of the contaminant levels before the attainment of remediation levels is verified. Block excavation occurs without interruption, which usually results in over excavation of soils. This method is generally easier to implement. It requires less logistical effort and coordination of activities and therefore results in fewer delays. As a result of excavating beyond the bounds of contamination, in some cases to background levels, verification is simpler and less subject to failures. Using a more conservative block excavation approach for remediation based on utilizing information from the site RI would require the excavation and disposal of 55,000 m^3 (71,900 cubic yards *in situ*) of soils from the Ashland 2 property at depths up to 8 feet.

Block Excavation Based on Applying Plume™ to the RI Data

This scenario involves identifying a detailed excavation footprint based on applying geostatistics to the original RI data. The volume of soil at the Ashland 2 property that would be remediated was initially estimated using joint Bayesian/indicator geostatistics, prior to site remediation. Plume™ was used to perform this analysis, utilizing never-to-exceed cleanup guidelines. Successive two-foot lifts were defined to approximate potential approaches to soil excavation. The lateral extent of contamination was then estimated on a lift-by-lift basis. At the Ashland 2 property, five (5) lifts were defined and volumes of contaminated soil were estimated for each lift. Based on the analysis, it was concluded that a conservative estimate of *in situ* contaminated soil at the Ashland 2 site was 37,000 m^3 (48,400 cubic yards *in situ*).

Precise Excavation based on ASAPs Approach

Although precise excavation does not require special excavation equipment, methods are typically different than those used in block excavation. Precise excavation is more difficult to implement because of the coordination required, and verification may be subject to more failures as a result of final concentrations being closer to restoration action levels.

Precise excavation based on the ASAPs approach involves identifying a detailed initial excavation footprint, redefining this footprint after shallow lifts (for example, 2 ft depth) are removed, and repeating this process until the entire area has attained remediation goals. Precise excavation requires some combination of screening, direct measurement, and/or sampling techniques to determine excavation footprints for subsequent lifts. The techniques utilized at the Ashland 2 site included gamma walkover surveys combined with GPS, on-site gamma spectroscopy and off-site alpha spectroscopy. Plume™ was utilized with the original RI data to identify likely contamination footprints for each of the layers prior to excavation. Gamma walkover data was used to refine these likely contamination footprints and determine soil excavation requirements as remediation proceeded. The actual amount of soil excavated at the Ashland 2 site (*ex situ*) was 45,500 cubic yards.

Cost Analysis

Additional investment costs for applying an ASAPs approach to designing and implementing the precise excavation technique include the following: the use of additional workers to perform gamma walkover surveys and mark the precision lifts; creation of an Internet page to allow communication from the site to off-site analysts; and, the cost of daily data analysis required to make real-time decisions regarding subsequent soil lifts. These costs include the use of two laborers to perform gamma walkover surveys and mark lifts in the field, and a supervisor to oversee the laborers. All three of these personnel charged half of their time to the precise excavation. Table 2 summarizes the investment cost to implement an ASAPs approach at the Ashland 2 site.

Table 2. Investment Cost to implement ASAPs approach at Ashland 2 site

Item	Units	Unit Cost ($)	Quantity	Cost ($)
Creation of Internet page	lump sum	30,000	1	30,000
Laborers to mark lifts and perform gamma walkover survey	hour	19	1,733	32,900
Supervisor	hour	30	867	26,000
Off-site analyst	month	10,000	6	60,000
Subtotal				148,900
Engineering/design/permitting (10 %)				14,900
G&A and Fees (14.75 percent)				22,000
Project Management (10 percent)				14,900
Total Cost (December 1998)				200,700
Total Escalated Cost (March 2000) [1]				**207,700**

[1] Total includes escalation using ENR CCI (12/98 = 5991 and 3/00 = 6201).

Table 3 summarizes the escalated cost of each remediation alternative when applied to the Ashland 2 site. It is important to note that costs for soil excavation and borrow soil replacement are based on *in situ* volumes. All other cost line items in the table are based on *ex situ* volumes as measurement for intermodals sent to IUC was based on cubic yards of soil shipped. *Ex situ* soil volumes in the table reflect an expansion factor of 25 percent from the *in situ* volume. This value is based on-site experience. No operation and maintenance costs are included in this cost analysis for out years due to the short duration of remediation (6 months). Stewardship of the site after closure would be essentially the same cost for each of the three alternatives and is not included in the estimate.

Benefits attributable to the reduced volume of soils for excavation, transportation and disposal costs are indicated directly in the analysis. These benefits are a direct function of the reduction in the quantity of soil excavated and shipped from the Ashland 2 Site to IUC. A lower volume of soils shipped also results in a lower quantity of intermodal containers rented for shipping soils via rail to IUC. Additionally, cost savings attributable to different sampling techniques used in the ASAPs approach are factored into the total costs.

During the precise excavation using an ASAPs approach, approximately 600 samples were analyzed on-site using gamma spectroscopy and approximately 150 discrete samples were collected and analyzed off-site using alpha spectroscopy. It was assumed that 750 discrete samples would be collected and analyzed using off-site alpha spectroscopy for both of the block excavation alternatives based on RI data. This assumption is based on the premise that all alternatives would require the same level of confirmation sampling prior backfill of the excavation.

Confirmation sampling of the soils, prior to receipt and processing by IUC, includes analysis for metals, radionuclides, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and Toxicity Characteristic Leaching Procedure (TCLP). One sample was collected and analyzed for each 500 cubic yards of soil shipped to IUC.

Table 3. Comparison of costs based on remediation approach at the Ashland 2 site

	Block Excavation Based on RI Data	Block Excavation Based on RI Data using Geostatistics	Precise Excavation Based on ASAPs Approach
Total excavated soil (yd^3) *in situ*	71,900	48,400	36,000
Total soil (yd^3) *ex situ*	89,900	60,500	45,500
Item	Cost ($)	Cost ($)	Cost ($)
Excavate soils/load intermodals	355,200	239,100	241,200
On-site gamma spectroscopy	0	0	60,000
Off-site alpha spectroscopy	262,500	262,500	52,500
Intermodal container rental	918,400	618,100	464,800
Transportation fees	15,552,700	10,466,500	7,871,500
Disposal fees	8,091,000	5,445,000	4,095,000
Sampling and analysis of intermodals	449,500	302,500	227,500
Backfill/compact and grade site with borrow soil	553,600	372,700	277,200
Subtotal	26,182,900	17,706,400	13,289,700
Engineering/design (10 %)	2,618,300	1,770,600	1,329,000
G&A and fees (14.75 %)	3,862,000	2,611,700	1,960,200
Project management (10 %)	2,618,300	1,770,600	1,329,000
Total Cost (December 1998)	35,281,500	23,859,300	17,907,900
Total Escalated Cost (March 2000) [1]	**36,518,200**	**24,695,600**	**18,535,600**

[1] Total includes escalation using ENR CCI (12/98 = 5991 and 3/00 = 6201).

Cost Conclusions

The cost analysis indicates that utilization of an ASAPs approach to perform a precise excavation at the Ashland 2 site results in a cost savings of $18 million when compared to performance of remediation using block excavation techniques based on the original RI data. This reflects a benefit to cost ratio of 87 to 1 (based on the investment cost to apply an ASAPs approach at the Ashland 2 site, Table 2). Likewise, savings of $6.2 million could be realized when comparing use of an ASAPs approach for precise excavation to performance of remediation using block excavation techniques based on applying geostatistics to the original RI data. The resulting benefit to cost ratio is 30 to 1. Based on this analysis, the following conclusions are presented:

- Significant cost savings are indicated when comparing the utilization of an ASAPs approach to perform a precise excavation at the Ashland 2 site versus alternatives of: (1) performance of remediation using block excavation techniques based on the original RI data, and (2) performance of remediation using block excavation techniques when applying Plume™ to the original RI data.

- Although the precise excavation using an ASAPs approach may require more time, the reduced volume of soils to excavate offsets this time. The Ashland 2 site experience has shown that precision excavation techniques can be deployed without compromising remediation schedules or productivity.

- With respect to the Ashland 2 Site, the additional costs of data collection were more than offset by the savings realized from minimizing off-site disposal volumes.

- Cost savings when comparing the alternatives for excavation is linked heavily to transportation and disposal fees for the subject waste.

- Significant cost savings could be realized when applying an ASAPs approach for precise excavation at other FUSRAP and similar sites.
- As a result of the significant cost savings and successful deployment, the use of an ASAPs approach is being evaluated for use at other FUSRAP sites for precise excavation.
- Cost savings realized can be greatly affected by regulatory interpretations of remediation action levels for contaminants of concern, resulting in an increase or decrease in project costs.
- When suitable “real-time” data collection technologies exist for the contaminants of concern at a site, precision excavation is a very attractive alternative to traditional methods for designing and implementing soil remedial actions.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

The EPA has substantial interest in decision-making tools and methodologies similar to those utilized by SitePlanner^{TM} and Plume^{TM}. The EPA recognizes the need for better environmental data management and display tools similar to SitePlanner^{TM} and embraces the DQO framework for site characterization decision-making. The EPA has used SitePlanner^{TM} in several of its programmatic offices. Plume^{TM} fits neatly into this framework.

- The ASAPs methodology includes regulatory interaction at the initiation of a project, which is critical to ensuring regulatory approval.

- Typical sampling activities require the handling of investigation-derived wastes (IDWs) such as drill cuttings and equipment decontamination fluids. An emphasis on the use of non-intrusive sampling methods along with a reduction in the total number of samples collected reduces IDWs.

- By making remediation support data immediately available over the Internet, the customer has a method of distributing information to stakeholders and regulators, which improves coordination and confidence in remediation work being performed.

The nine evaluation criteria imposed by CERCLA were developed to assess remedial alternatives and to develop remedy selections. Evaluation using these criteria does not apply since the ASAPs methodology is a characterization tool. Some of the criteria such as protection of human health (worker exposure) are discussed below. Cost effectiveness was discussed in Section 5.

Safety, Risks, Benefits, and Community Reaction

Worker Safety

- Use of ASAPs for characterization reduces worker exposure to IDWs as fewer samples are collected and many sampling techniques utilized are not intrusive.

- The risk to workers is minimized due to the reduced time required for site characterization activities.

Community Safety

- Using ASAPs for characterization reduces the number of samples collected and IDWs produced. This results in less potential community exposure to radionuclides and other contaminants.

- Using ASAPs for precise excavation reduces contaminated soil shipped off site and potential hazards involved in transportation and disposal at an off-site facility.

Environmental Impact

- The use of an ASAPs approach provides ultimately better remediation, as measured by being more precise in delineating soils that are not in compliance with requirements. This ensures a cleaner closure at sites with no missed contamination.

Socioeconomic Impacts and Community Perception

- The emphasis on development of a strong conceptual model of the site should improve community understanding of site characterization and plans for site restoration.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The utilization of SitePlanner™, ArcView® GIS or SiteView along with Plume™ requires at least a personal computer with a Pentium II processor, 24 megabytes (MB) of random access memory (RAM) and 400 MB of disk space using Windows 95/98 or NT, or a personal computer with the Unix Operating System and 32 MB of RAM. Color monitors are recommended. For hardcopy output, a PostScript printer is required. Computer hardware used requires a reliable power supply. Software and hardware can be purchased for about $5,000. Some practical considerations for implementation of an ASAPs approach (Johnson and Baecher 1997b) are listed below:

- Adaptive sampling programs rely on field analytical methods and their ability to produce numerical results in real time. The field analytical method selected must be appropriate for the needs of the characterization program.

- Sample production rates must be closely matched with field laboratory analysis capabilities. If the sample production rate is significantly greater than the laboratory can analyze, there will be significant pressure to continue sampling without the benefit of results from the previous round of sampling, and the value of adaptive sampling will be lost. If the laboratory can analyze significantly more samples than field crews can produce, then per sample analytical costs will be driven up, since field laboratories are billed on a daily basis.

- The coordination of data including sample location, chain-of-custody records, sample results, and subsequent analyses can become a problem. Data management logistics are not an issue in traditional, preplanned programs. However, if the logistics of ASAPs data management have not been laid out and tested beforehand, problems can result that prevent field staff from making timely decisions. The use of Web sites for data integration and dissemination has proven to be a particularly effective enabler of ASAP-based characterization and remediation programs.

- Adaptive sampling requires a higher degree of coordination and control of field level decision-making than traditional programs where sampling points are predetermined. The ability to make decisions in the field in response to sampling results is what makes adaptive sampling efficient. If timely decisions cannot be made, the value of adaptive sampling is lost. The inclusion of practice sessions involving sample collection teams, field chemists, and key decision-makers before the actual work begins is helpful in identifying potential problems.

- A careful, spatially correct initial model has a positive effect on the efficiency of adaptive sampling. While the ability to visually identify contaminated soils is peculiar to certain types of contamination, every contaminated site will include information that - if explicitly included in an initial conceptual model - leads to better sampling programs. These data may be aerial photographs, stressed vegetation, the physical layout of facilities, results from contaminant fate and transport modeling, data from non-intrusive geophysical work, or past experience with similar sites.

- Appropriate experience and qualifications of the team members is essential to success when implementing an ASAPs approach to characterization. In particular, the proper use of Plume™ requires an understanding of geostatistical techniques applied to environmental data sets.

- ASAPs impose contractual requirements different from standard sampling and analysis programs. Because the level of data collection is unknown prior to the outset of work, fixed price contracting without sufficient flexibility for contingencies is an impediment to the implementation of ASAPs. One approach to contracting for an ASAP is to establish a base level of work that can be guaranteed for contractors, as well as an estimate of the likely overall project scope, with contingencies built into the contract to allow significant deviations from this overall estimate. Additional performance-based language can also be included in contingencies that specify allowable maximum per sample collection and analytical costs to ensure cost-effective contractor performance.

- Not all data collection program requirements are amenable to an ASAP approach. For example, in some instances the use of CLP-derived data sets may be required from the standpoint of potential litigation. Data collection to support baseline risk assessments, and data collection to support final closure of sites are the most difficult to address with an ASAP approach. In contrast, ASAPs are readily applicable to data collection that supports Engineering Evaluation/Cost Analysis (EE/CA) studies, Feasibility Studies, pre-design remedial activities, and remedial actions themselves. The need for some level of CLP-derived data can be at least partially addressed through selective split sampling during ASAP data collection, ensuring that a portion of samples collected are submitted also for a more traditional analysis.

Technology Limitations and Needs for Future Development

ASAPs utilize a dual approach to the sampling strategy problem. First, they use a state-of-the-art object-oriented database system that is specifically designed for site assessment work to integrate, manage, and display site characterization data as it is being generated. Packages such as SitePlanner™, ArcView® GIS and SiteView are graphical, object-oriented databases designed to provide qualitative support of environmental site assessments. Plume™ provides quantitative support for adaptive sampling programs. The software merges soft site data with hard sample results to form images of contamination location, provide quantitative measures of the potential benefits to be gained from additional sampling, and indicate the location of the best new sampling locations. Plume™ uses advanced Bayesian and geostatistical procedures to complete these tasks. These software packages have been developed and tested in several field demonstrations with promising results.

A factor that greatly influences the outcome of characterization using an ASAPs approach is the ability of field analytical methods to support the program. In the example of the Ashland 2 Site, gamma walkover data in conjunction with laboratory analysis of soil samples was used to indirectly correlate ^{230}Th concentrations. This was due to the inability of the gamma walkover to accurately detect ^{230}Th at the cleanup criteria of 40 pCi/g. This points to the need for developing better field analytical techniques that can support an ASAPs approach.

Technology Selection Considerations

- Characterization utilizing an ASAPs approach may be applied at candidate sites with groundwater, surface-soil or subsurface-soil contamination, provided that the characterization costs are not excessive when compared to restoration costs.

- ASAPs should be utilized at sites where data collection techniques can be matched to the contaminants of concern. The ASAPs approach may not be cost effective if appropriate field analytical techniques are not available.

- Utilization of the ASAPs approach to perform precise excavation provides a greater level of confidence in the remediation effectiveness when compared to traditional block excavation techniques, based on existing characterization data, which may result in contaminated soils being left at a site.

- The ASAPs approach has been successfully deployed at the Ashland 2 Site for closure of a FUSRAP site under the regulation of CERCLA. Based on this success, the probability of selling this characterization methodology to regulators for other CERCLA sites is enhanced.

APPENDIX A
REFERENCES

Argonne National Laboratory. 1997. *Supplemental Characterization Report for the Animal/Chemical Pits and Glass Holes Areas at Brookhaven National Laboratory*, Upton, New York, Argonne, IL: Argonne National Laboratory.

Bujewski, G. E., and R. L. Johnson. 1996. *Adaptive Sampling Approach to Environmental Site Characterization at Joliet Army Ammunition Plant: Phase II Demonstration.* SAND96-0840 • UC-600. Albuquerque, NM: Sandia National Laboratories.

Durham, L. A., D. J. Conboy, R. Johnson, and T. Sydelko. 1999. Precise Excavation – An Alternative Approach to Soil Remediation, pp. 93-98 in *Proceedings of National Defense Industrial Association, 25th Environmental Symposium & Exhibition*, March 29 – April 1, Denver, CO.

ECHOS. 1998. *Environmental Remediation Cost Data - Unit Price*. 4th Annual Edition. Kingston, MA: R. S. Means Company, Inc.

Engineering News-Record [online]. 2000. *Construction Cost Index History (1908-1999)*. Retrieved March 14, 2000 from the World Wide Web: http://www.enr.com/cost/costcci.asp (last updated March 14).

Floran, R. J., G. E. Bujewski, and R. L. Johnson. *Adaptive Sampling Approach to Environmental Site Characterization: Phase I Demonstration*. SAND95-0070. Albuquerque, NM: Sandia National Laboratories.

Formerly Utilized Sites Remedial Action Program, U.S. Army Corps of Engineers, Buffalo District. 2000. *Ashland 2 Site Status*. Retrieved September 7, 2000 from the World Wide Web: http://www.lrb.usace.army.mil/fusrap/ash2/ash2stat.htm (last updated June 5).

Humphreys, K. K., and P. Wellman. 1996. *Basic Cost Engineering*. Third Edition, Revised and Expanded. New York: Marcel Dekker, Inc.

Johnson, R. L. 1993. *Adaptive Sampling Strategy Support for the Unlined Chromic Acid Pit, Chemical Waste Landfill, Sandia National Laboratories, Albuquerque, New Mexico*. ANL/EAD/TM-2. Argonne, IL: Environmental Assessment Division, Argonne National Laboratory.

Johnson, R. L. 1996. A Bayesian/Geostatistical Approach to the Design of Adaptive Sampling Programs. *Geostatistics for Environmental and Geotechnical Application, ASTM STP 1283*. R. M. Srivastava, S. Rouhani, M. V. Cromer, and A. I. Johnson (Eds.). Philadelphia: American Society for Testing and Materials.

Johnson, R. L., and G. B. Baecher. 1997a. *Adaptive Site Characterization: Applications*. Retrieved January 18, 2000 from the World Wide Web: http://www.ence.umd.edu/~gbaecher/papers.d/j&b-02.d/paper-02.htm.

Johnson, R. L., and G. B. Baecher. 1997b. *Adaptive Site Characterization: Theory*. Retrieved January 18, 2000 from the World Wide Web: http://www.ence.umd.edu/~gbaecher/papers.d/j&b-01.d/paper-01.htm.

Johnson, R., J. Quinn, L. Durham, G. Williams, and A. Robbat, Jr. 1997. Adaptive Sampling and Analysis Programs for Contaminated Soils. *Remediation* (Summer): 81-96.

Johnson, R., K.P. Smith, and J. Quinn. 1999. *The Application of Adaptive Sampling and analysis Program (ASAP) Techniques to NORM Sites*. Argonne, IL: Environmental Assessment Division, Argonne National Laboratory.

Pacific Northwest National Laboratory. 1997. *Optimization of Sampling Strategies for Contaminant, Delineation and Risk Assessment*. Retrieved January 18, 2000 from the World Wide Web: http://www.pnl.gov/WEBTECH/mwlid/sampstra.html.

U.S. Army Corps of Engineers. 1998. *Value Engineering Team Study Report, Formerly Utilized Sites Remedial Action Program, Ashland 1 & 2 Sites, Tonawanda, New York*. Draft. U.S. Army Engineer District, Buffalo.

U.S. Department of Energy, Formerly Utilized Sites Remedial Action Program. 1997. *Soil Cleanup Studies for Ashland 1 and 2 Properties, Town of Tonawanda, New York*. Argonne, IL: Environmental Assessment Division, Argonne National Laboratory.

U.S. Department of Energy, Office of Environmental Management, Office of Science and Technology. 1998a. Innovative Technology Summary Report: *Expedited Site Characterization*. DOE/EM-0420. Characterization, Monitoring, and Sensors Technology Crosscut Program and Subsurface Contaminants Focus Area.

U.S. Department of Energy, Office of Environmental Management. 1998b. *Standard Life-Cycle Cost-Savings Analysis Methodology for Deployment of Innovative Technologies*. Draft dated October 30. Morgantown, WV: Federal Energy Technology Center.

U.S. Environmental Protection Agency (EPA). 1994*. Guidance for the Data Quality Objectives Process, EPA QA/G-4*. EPA/600/R-96/055. Washington, D.C.: U. S. EPA, Office of Research and Development.

APPENDIX B
ACRONYMS AND ABBREVIATIONS

ASAPs	Adaptive Sampling and Analysis Programs
CCI	Construction Cost Index
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
CMS	Corrective Measures Study
DNT	Dinitrotoluene
DOE	Department of Energy
DQOs	Data Quality Objectives
EE/CA	Engineering Evaluation/Cost Analysis
ENR	Engineering News Record
EPA	Environmental Protection Agency
ESC	Expedited Site Characterization
FS	Feasibility Study
FUSRAP	Formerly Utilized Sites Remedial Action Program
G&A	General and Administrative
GC/MS	Gas Chromatograph/Mass Spectrometer
GIS	Geographical Information System
GPS	Global Positioning System
HPGe	High Purity Germanium
IUC	International Uranium Corporation
LIBS	Laser Induced Breakdown Spectroscopy
MED	Manhattan Engineering District
NaI	Sodium Iodide
NORM	Naturally Occurring Radioactive Materials
NT	Nitrotoluene
OST	Office of Science and Technology
OTD	Office of Technology Development
PID	Photoionization Detector
QA/QC	Quality Assurance/Quality Control
RAM	Random Access Memory
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RI	Remedial Investigation
SACM	Superfund Accelerated Cleanup Program
SAFER	Streamlined Approach for Environmental Restoration
SVOC	Semi-volatile Organic Compound
TCLP	Toxicity Characteristic Leaching Procedure
TMS	Technology Management System
TNT	Trinitrotoluene
USACE	U.S. Army Corps of Engineers
VOC	Volatile Organic Compound
XRF	X-ray Fluorescence