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INNOVATIVE TECHNOLOGY
Summary Report

BetaScint™ Fiber-Optic Sensor for Detecting Strontium-90 and Uranium-238 in Soil

Characterization, Monitoring, and Sensor Technology Program and Deactivation and Decommissioning Focus Area

Prepared for
U.S. Department of Energy
Office of Environmental Management
Office of Science and Technology

December 1998

DISCLAIMER

INNOVATIVE TECHNOLOGY

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BetaScint™ Fiber-Optic Sensor for Detecting Strontium-90 and Uranium-238 in Soil

OST Reference #70

Characterization, Monitoring, and Sensor Technology Program and Deactivation and Decommissioning Focus Area

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Demonstrated at
Laboratory for Energy-Related Health Research
Davis, California

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

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

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

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

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

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SUMMARY

Technology Summary

Problem

Accurate measurements of radioactivity in soils contaminated with Strontium-90 (Sr-90) or Uranium-238 (U-238) are essential for many DOE site remediation programs. These crucial measurements determine if excavation and soil removal is necessary, where remediation efforts should be focused, and/or if a site has reached closure. Measuring soil contamination by standard EPA laboratory methods typically takes a week (accelerated analytical test turnaround) or a month (standard analytical test turnaround). The time delay extends to operations involving heavy excavation equipment and associated personnel which are the main costs of remediation. This report describes an application of the BetaScint™ fiber-optic sensor that measures Sr-90 or U-238 contamination in soil samples on site in about 20 minutes, at a much lower cost than time-consuming laboratory methods, to greatly facilitate remediation.

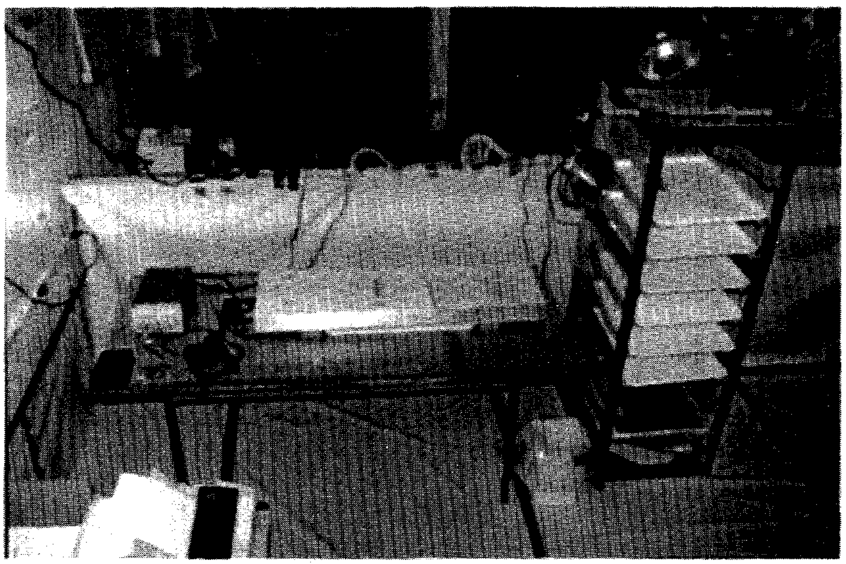

Figure 1A - At the LEHR site, samples were transferred to a nearby laboratory and placed in a standardized holder for rapid characterization. The surface/soil monitor can also be deployed in a dynamic conveyor configuration.

How it works

The BetaScint™ sensor shown in Figures 1A and 1B works as follows:

- Beta particles (electrons) emitted by radioactive soil contaminants excite electrons in plastic fiber doped with fluorescent compounds in the layers of the sensor.
- The plastic fibers give off light (scintillate) when the fluorescent molecules lose energy and return to their ground state.
- Scintillations in the plastic fibers are counted by photodetectors to determine beta radioactivity of the soil sample.

BetaScint™ sample processing for this application is limited to drying and sieving soil samples to remove rocks and excessive organic matter. The BetaScint™ system is easy to operate, and does not create secondary wastes.

The BetaScint™ sensor is commercially available and is optimized for obtaining measurements on contaminated soils, concrete, and other solid surfaces. Fluid medium versions are being developed for measurements on gases and groundwaters. BetaScint, Inc. provides a full range of services related to the use of the technology. This application utilized the characterization service. The technology has been used at the DOE Hanford Reservation by Bechtel Hanford, Inc., successfully deployed at the DOE Inhalation Toxicology Research Institute (Albuquerque, New Mexico), and demonstrated at Fernald Environmental Management Project (Cincinnati, Ohio). More information is available on the BetaScint web site at http://www.betascint.com.

Figure 1B - The BetaScint™ surface/soil monitor can also be placed directly on or above contaminated soil or surfaces to detect and quantify radiation associated with the decay of U-238 or Sr-90. The instrument is roughly 1.5 m by 35 cm by 8 cm and weighs approximately 20 kg (excluding power supply).

Advantages Over Laboratory Measurements (The Baseline Technology)

Laboratory measurements of Sr-90 and U-238 soil contamination are expensive (typically $150 standard to $275 accelerated per sample), time consuming delays (3-4 weeks/one week) are encountered before analytical test results are available, hazardous secondary wastes are often generated, and complex and expensive sample handling, packaging, shipping, and chain of custody procedures can be involved. In contrast, the BetaScint™ sensor measures Sr-90 and U-238 contamination in soil samples in about 20 minutes at a cost of $30 to $55 per sample. Eliminating delays in soil contamination data availability reduces remediation costs by reducing excavation delays and by allowing more efficient use of heavy excavation equipment and personnel. The BetaScint™ results are more representative of the contamination in the soil media measured because of the much larger sample volumes used. The overriding cost reduction is created in bringing the site remediation to closure in a significantly shortened time period with the amount of mixed and/or low-level waste minimized.

Application Summary

This report covers an application of the BetaScint™ sensor at the DOE Oakland Operations Office Laboratory for Energy-related Health Research (LEHR) at the University of California at Davis on Old Davis Road, in Davis, California, from July through September 1998.

Experiments at LEHR during the 1960s through the 1980s exposed beagle dogs to Sr-90 and Radium-226 (Ra-226) in their diets to study the effects of radioactivity on mammals. During the 1960s and 1970s, low-level radioactive waste from the experiments was buried in disposal cells about 120 feet long, 2 feet wide and 8 to 10 feet deep in the Southwest Trenches Area, in the southwest corner of the LEHR site (see Figure 2). The BetaScint™ technology was used during excavation and removal of radioactive material in the Southwest Trenches Area. The BetaScint™ sensor was used to measure Sr-90 contamination, and a germanium detector was used to measure Ra-226 contamination.

As described in the Removal Action Work Plan (U. S. Weiss Associates 1998a) and Sampling and Analysis Plan (SAP, U. S. Weiss Associates 1998b), the BetaScint™ sensor was used for:

- Screening sampling to determine the extent of excavation needed to remove Sr-90 contamination.
- Confirmation sampling to verify that all Sr-90 contaminated wastes and adjacent Sr-90 contaminated soil has been removed.

The Required Detection Limit for the BetaScint™ sensor at LEHR is 10 pCi/g based on the LEHR Screening Criterion (SAP, Table 2-2). Without the BetaScint™ sensor, delays imposed by conventional laboratory methods for measuring Sr-90 contamination would have eliminated much of the benefit of using the germanium detector to determine Ra-226 levels. Combining the two technologies resulted in a practical methodology for expediting site remediation.

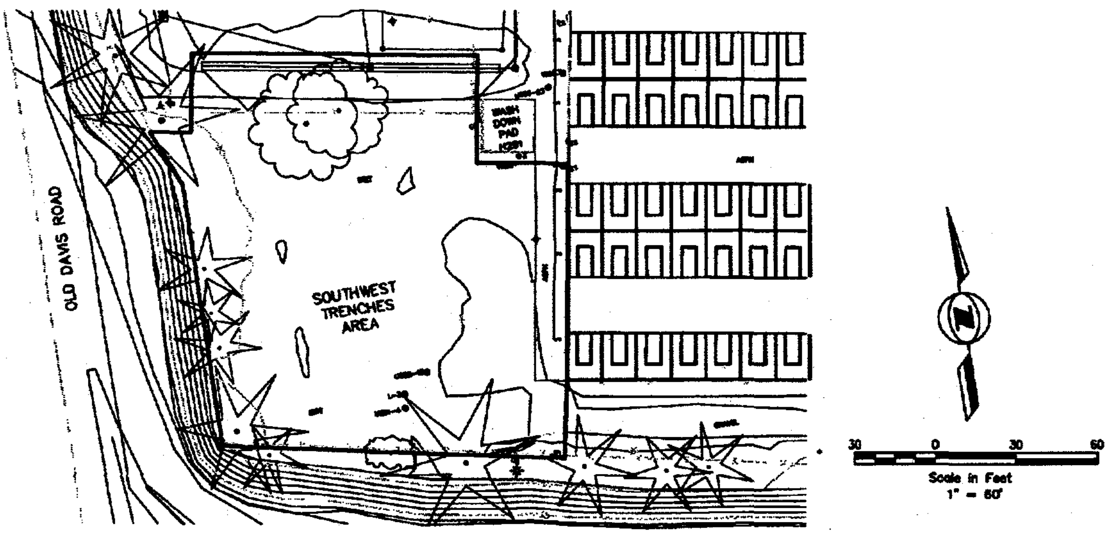

Figure 2 - Map of Southwest Trenches Area trenches taken from the Removal Action Work Plan

Parties involved in the application were:

- *DOE Oakland Operations Office*
- Pacific Northwest National Laboratory / BetaScint, Inc.
- Weiss Associates, the LEHR site Environmental Restoration/Waste Management contractor
- Environmental Management Services
- Special Technologies Laboratory

During the application, 283 soil samples were measured with the BetaScint™ sensor with an average turn-around time of about 20 minutes per sample. BetaScint™ performance was demonstrated by the success of the sensor in measuring known amounts of Sr-90 contamination added to 10 samples of LEHR soil (2 samples were blanks) when the concentration of the contamination was unknown to the measuring technician (see results plots in Figure 3).

<u>Detection Limit/Reproducibility:</u> The BetaScint™ sensor can measure contamination at approximately 1 pCi/g above background using a 5-minute count time, with a standard deviation error of 2.5%. The Required Detection Limit for the BetaScint™ sensor at LEHR is 10 pCi/g based on the LEHR Screening Criterion (SAP, Table 2-2). The 10 pCi/g LEHR Screening Criterion for Sr-90 comes from a Risk-Based Action Standard for excess cancer risk of 10^{-6} (SAP, Table 2-4). During the application, only one soil sample exceeded the Screening Criterion, necessitating additional excavation to remove the contaminated soil. Without these practical real-time measurements either delays or over-excavation (or both) would have been necessary - adding cost in terms of time delays and/or waste disposal. Background Sr-90 concentration at LEHR is 0.056 pCi/g (SAP), and the maximum Sr-90 concentration found when sampling the waste matrix in the Southwest Trenches in 1996 was 16,700 pCi/g (SAP, Table 2-1).

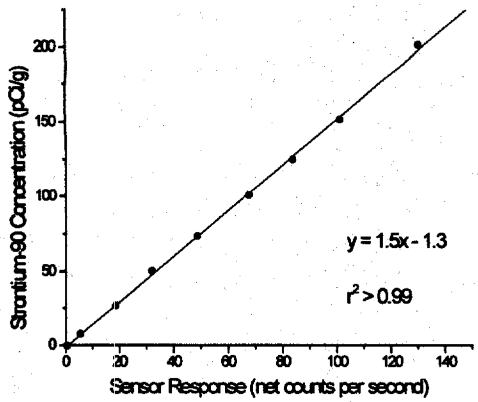

Figure 3 - Correlation plot of contaminant concentration versus sensor response with linear regression results

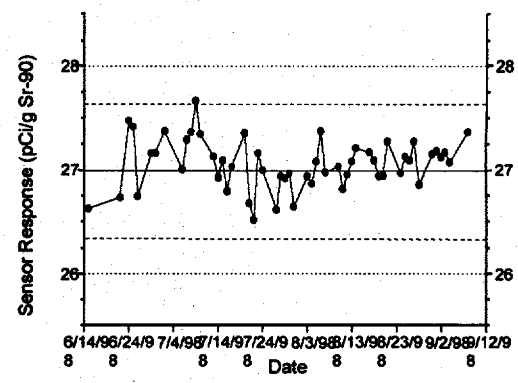

Figure 4 - Control chart associated with the 27-pCi/g secondary standard that indicates the long-term stability of the sensor.

<u>Sensor stability:</u> During the application, sensor stability was monitored by checking day to day variation of the BetaScint™ sensor reading in response to a standard soil sample containing 27 pCi/g of Sr-90. From 6/14/98 to 9/12/98, all but one of the readings were within the 95% confidence interval (see Figure 4) indicating sensor response is stable and consistent over time.

<u>Cost</u>: The BetaScint™ alternative cost about half ($175 versus $325 per sample) of an approach using conventional laboratory testing. Also, actual BetaScint™ sensor test costs were less than 20% ($54 dollars compared with $274 per sample) of accelerated (one week turnaround) analytical laboratory test cost. The BetaScint™ sensor costing ($54 per sample) is also less expensive than non-accelerated (standard 30-day turnaround) analytical lab test costs ($149 per sample). Finally, the LEHR project involved analysis of only 283 samples, although the BetaScint™ sensor set-up could have accommodated up to 2,088 sample tests. Under ideal conditions, BetaScint™ analytical costs could have gone from $54 per sample to around $31 per sample (based on actual test times and fixed price contract costs).

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Web Site location

All published Innovative Technology Summary Reports are available on-line at http://em-50.em.doe.gov under publications. The Technology Management System, also available through the EM50 web site, provides information about OST programs, technologies, and problems. The OST Reference Number for the BetaScint™ sensor is **70**.

ACKNOWLEDGEMENT

The work of Dr. Thomas R. Mongan, P.E., and Richard N. Fallejo in the preparation of this report is gratefully acknowledged.

SECTION 2

TECHNOLOGY DESCRIPTION

Overall Process Definition

The BetaScint™ sensor technology was selected for screening sampling to determine the extent of excavation needed to remove Sr-90 contamination as work progressed, and confirmation sampling to verify that all Sr-90 contaminated wastes and adjacent Sr-90 contaminated soil was removed at the end of excavation.

The basic principles of the BetaScint™ technology are:

- 2.3 MeV beta particles (electrons) are emitted by radioactive decay of Yttrium-90 or Protactinium-234m (the equilibrium radioactive decay daughters of Sr-90 and U-238, respectively) on soil surfaces contaminated with Sr-90 or U-238.
- The beta particles excite electrons in the two 1-mm thick ribbons and one 0.5-mm thick ribbon of plastic scintillation fibers that make up the sensor.
- The excited fluorophores in the plastic fibers give off light (scintillate) when they lose energy and return to their ground state.
- The scintillations from the plastic fibers are counted by photodetectors.
- When background counts are eliminated (as explained below), the number of scintillations counted in a given time is proportional to the average beta radioactivity of the soil sample in pCi/g.

Figure 5 is a schematic cross-section of the BetaScint™ sensor, indicating the top 1-mm layer of anti-coincidence scintillation fibers, the 6-mm-thick layer of acrylic absorbing material, the two layers of 1-mm scintillation fibers below the absorption layer, and the bottom layer of 0.5-mm scintillation fibers. White tracks in the diagram indicate regions where scintillation is induced by a charged particle (e.g., a beta particle). Background radiation events are eliminated by counting only those events producing scintillations in all three of the lower layers of plastic scintillation fibers, but not in the top anti-coincidence scintillation layer above the absorber layer. Two types of background events are eliminated as follows:

- Cosmic ray events are not counted because they produce scintillation in the top anti-coincidence layer above the absorber as well as in the bottom scintillation layers.
- Low energy beta particles from naturally occurring background radioactivity are not counted because they do not produce scintillation in all three of the lower scintillation layers.

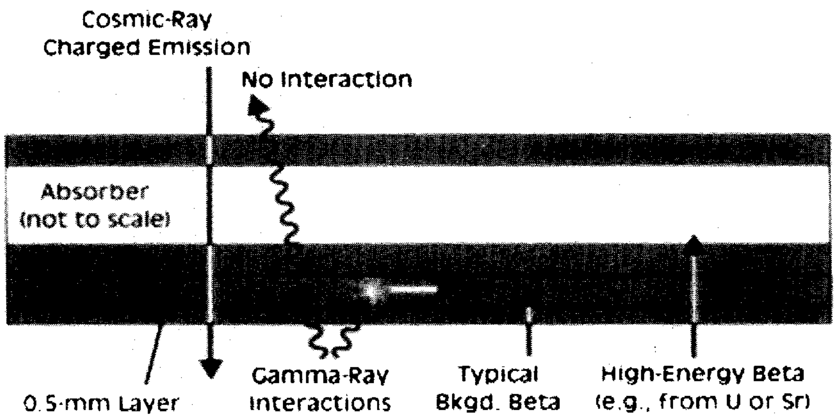

Figure 5 - Schematic cross-section of Strontium-90 sensor showing discrimination capabilities for (1) high- vs. low-energy beta particles, and (2) beta particles vs. gamma rays and cosmic-induced species. Note: The white areas within the layers indicate the particle tracks that lead to ionizations or excitations and subsequent scintillations.

The number of events producing scintillations in all three of the lowest layers of plastic fibers, but not in the top anti-coincidence layer above the absorber layer, in a given measurement time is proportional to the surface beta radioactivity of the soil sample. Therefore, there is a linear relation between scintillation counts in a given measuring period and average beta activity in pCi/g of the soil sample. The linear relation between scintillation counts and average beta activity in the soil sample is identified during system calibration by determining the number of scintillation counts produced in a given measuring period by the surface beta activity of calibration soil samples with known values of average beta activity in pCi/g evenly distributed throughout the soil sample. Calibration samples, called spiked soil samples, are prepared by adding known amounts of radioactivity to site soil samples. The calibration curve relating Sr-90 activity in pCi/g to sensor counts per second from surface radioactivity of spiked LEHR soil samples in the BetaScint™ detector is shown in Figure 6.

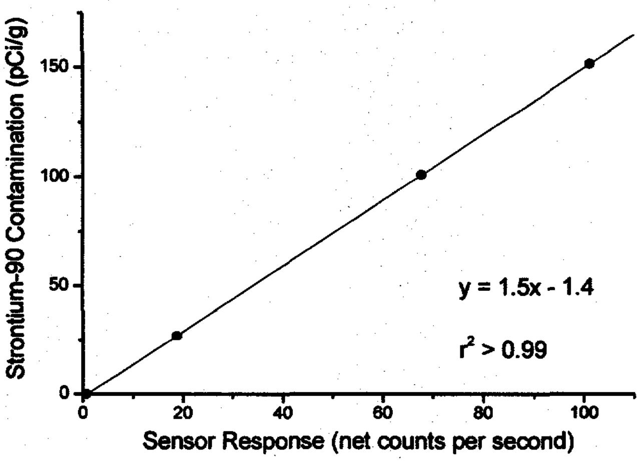

Figure 6 - Site-specific calibration plot for LEHR soils with linear regression results.

For calibration and operation, a 1 to 2 pound soil sample is dried, sieved to remove rocks (over 0.25 inches in size) and excessive organic matter, spread on a sampling tray and placed beneath the 30-cm by 60-cm face of the BetaScint™ sensor. Measuring the average radioactivity of these relatively large soil samples gives readings more representative of average soil conditions at the site than the 20 g soil samples used in laboratory measurements with standard EPA Method 905.0.

The sample extends over the entire active window of the sensor (as do the calibration sources). Since beta particles are readily attenuated by the sample media, and the beta sensor observes particles originating only from the near surface of a well homogenized sample, the minimum sample size should provide at least an "infinite thickness" of material with respect to the betas (i.e., roughly 1 to 2 mm). For a 30-cm by 60-cm tray, and a sample density of roughly 1.5 g/cc, this leads to a minimum sample size on the order of 700 g. It is not unreasonable to expect that a minimum sample size be specified along with the detection limit. The sample homogeneity is verified by performing replicate analyses on samples that are re-homogenized between measurements. The LEHR results bear evidence of sensor reproducibility.

System Operation

To begin operations, the BetaScint™ sensor is calibrated by spiking representative dry soil samples from the site with known concentrations of Sr-90. The calibration curve, like the curve developed at LEHR (see Figure 6), relates sensor counts per second caused by surface beta radiation from a dried soil sample in the sample tray to the average beta radiation in pCi/g for the soil sample. Each day, the stability of the BetaScint™ sensor is tested by measuring the radioactivity in a soil sample with known contamination (see Figure 4).

Operation of the BetaScint™ system is straightforward. Soil samples are dried, sieved, spread on the sample tray, placed under the BetaScint™ sensor and counted for 5 minutes to achieve a detection limit of approximately 1 pCi/g above background. The larger samples, which are more representative than smaller samples in an environment of heterogeneous contamination, also serve to enhance data precision, increasing the probability of locating elevated levels of activity (which is the intent of remedial characterization surveys). Materials and energy requirements for the measurement system are minimal, there are no secondary wastes from the measurement process, and the only expendable items used are disposable protective clothing and sample containers.

Technicians operating the BetaScint™ sensor at a remediation site will be exposed to radioactive material in the samples, so they must have radiation worker training acceptable to site management. In addition, BetaScint, Inc. requires classroom and practical training to qualify a technician to use the BetaScint™ sensor.

SECTION 3

PERFORMANCE

Demonstration Plan

The BetaScint™ technology was deployed at the LEHR Southwest Trenches, a waste disposal site used during DOE-funded and UCD-operated research that exposed beagles to Sr-90 and Ra-226. The waste disposal cells in the Southwest Trenches Area are in the southwest corner of the LEHR site. Each waste disposal cell is about 120 feet long, 2 feet wide, and 8 to 10 feet deep. The Western Dog Pens at LEHR define the eastern boundary of the application area, the Institute of Toxicology and Environmental Health facility fenceline defines the southern and western boundaries of the application area, and two UCD research facilities (Building H215, Clinical Pathology, and Building H216, Specimen Storage) define the northern boundary of the application area.

The background Sr-90 concentration at LEHR is 0.056 pCi/g (SAP); the maximum Sr-90 concentration found when sampling the waste matrix in the Southwest Trenches in 1996 was 16,700 pCi/g (SAP, Table 2-1). Waste disposal cells were located by excavating 2-foot-wide trenches along grid lines spaced 10 feet apart in the north-south and east-west directions. During the application, all contaminated wastes from the Southwest Trenches Areas were excavated and removed. A six-inch layer of soil surrounding the waste material was also removed to ensure that contaminated soil adjacent to the wastes was completely removed.

As described in the Removal Action Work Plan (U. S. Weiss Associates 1998a) and Sampling and Analysis Plan (SAP, U. S. Weiss Associates 1998b) the BetaScint™ sensor was used for

- Screening Sampling to determine the extent of excavation needed to remove Sr-90 contamination as work progressed.
- *Confirmation Sampling to verify that all Sr-90 contaminated wastes and adjacent Sr-90 contaminated* soil was removed at the end of excavation.

Screening samples were taken every 20 feet along the excavations. Sidewall samples were taken near the top and bottom of the excavation, penetrating the sidewall by about 6 inches. Samples from the bottom of the excavation were collected about 12 inches below the bottom of the excavation. As provided by the SAP, 5% of screening samples, and 10% of confirmation samples were duplicated. One sample from each duplicate was measured with the BetaScint™ sensor and the other sample from the duplicate was sent off-site for laboratory quality assurance/quality control verification.

Accuracy of the BetaScint™ sensor was demonstrated by its performance in measuring known amounts of Sr-90 contamination added to 10 samples of LEHR soil (Figure 3) and by duplicate BetaScint™ measurements of 10% of soil samples taken during the remediation. This allowed backfilling of excavated areas at LEHR prior to return of confirmation results from the laboratory.

Mechanized equipment used in the application included front-end loaders, backhoes, a sheepsfoot roller, a water trailer, a shaker screen, a forklift, a dump truck, and pickup trucks (U.S.Weiss Associates 1998a). In addition to laborers and equipment operators, eight supervisory personnel were involved throughout the application (U.S.Weiss Associates 1998a). If the BetaScint™ technology were not available, it would have been necessary to cover the excavation and wait for laboratory results before proceeding with back-filling or further excavation. This would require additional cycles of equipment mobilization and demobilization, and possibly the need to train replacement personnel. As detailed in Section 5, reduced soil sample analysis costs and reduced excavation equipment and personnel mobilization/demobilization costs are the primary cost savings realized by using the BetaScint™ sensor.

Results

During the application, 283 soil samples were measured with the BetaScint™ sensor. The average turn-around time was about 20 minutes. BetaScint™ performance is demonstrated by the success of the sensor in measuring known amounts of Sr-90 contamination added to 10 samples of LEHR soil (2 samples were blanks) when the contamination was unknown to the measuring technician as shown in Figure 3.

Detection Limit/Reproducibility: BetaScint, Inc. specifies the BetaScint™ sensor to measure contamination at approximately 1 pCi/g above background using a 5-minute count time, with a standard deviation error of 2.5%. The Required Detection Limit for the BetaScint™ sensor at LEHR is 10 pCi/g, based on the LEHR Screening Criterion (SAP, Table 2-2). The 10 pCi/g LEHR Screening Criterion for Sr-90 comes from a Risk-Based Action Standard for excess cancer risk of 10^{-6} (SAP, Table 2-4). During the application, only one soil sample exceeded the Screening Criterion, necessitating additional excavation to remove the contaminated soil.

Sensor stability: During the application, sensor stability was monitored by checking day to day variation of the BetaScint™ sensor reading in response to a standard soil sample containing 27 pCi/g of Sr-90. From 6/14/98 to 9/12/98, all but one of the readings were within the 95% confidence interval (Figure 4) indicating sensor response is stable and consistent over time.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Technology Applicability

The BetaScint™ technology is ideally suited to measure Sr-90 contamination in soil--the focus of its application at LEHR. It can also be used to measure U-238 contamination. BetaScint™ soil samples taken in different ways provide different types of information. A surface soil sample from a large planar area in an excavation measures average radioactivity at that surface of the soil. Soil core measurements determine average soil radioactivity between the surface and the core depth.

The main limitations of the BetaScint™ technology are:

- It is specifically designed to measure beta radiation from Sr-90 and U-238. If other radionuclides are known (or suspected) to be present, the BetaScint™ sensor must be supplemented with other measurement techniques such as the germanium detector used to measure Ra-226 contamination at LEHR.
- The BetaScint™ sensor cannot distinguish between beta radiation from Sr-90 and U-238, so it actually measures total (Sr-90 + U-238) contamination. However, except in rare cases such as the contamination found at the Chernobyl site in Ukraine Sr-90 and U-238 usually do not occur together in contaminated soils because Sr-90 is a fission product and U-238 is a raw material for nuclear processes.

Competing Technology

The competing technology, and the baseline technology for cost and operational comparisons, is laboratory measurement of beta radiation from Sr-90 in soil samples using standard EPA Method 905.0. Advantages of the BetaScint™ sensor over laboratory soil contamination measurements include:

- BetaScint™ soil contamination measurements can be made in about 20 minutes, as compared to a week or more for laboratory methods, reducing equipment and personnel mobilization/ demobilization costs during remediation efforts.
- BetaScint™ measurements cost on the order of $30 to $55 per sample, compared to laboratory costs of $150 per sample or more.
- After a brief training period, the BetaScint™ sensor is simple to operate.
- BetaScint™ measurements have high reproducibility, typically showing less than 3% variation between measurements on duplicate samples.
- Sample handling, packaging, shipping, and chain of custody procedures can be simplified by using the BetaScint™ sensor.
- The BetaScint™ technology does not generate secondary waste.

Note that gamma-ray detectors can measure U-238 concentrations, but not Sr-90 concentrations.

While the BetaScint™ sensor's Lower Limit of Detection (LLD) is not as low as some traditional laboratory techniques, the extremely low LLDs provided by these techniques (e.g., much less than 1 pCi/g) offer no added value in a site remediation scheme, particularly when one considers the high cost and level of effort associated with such methods. The BetaScint™ sensor provides significant sensitivity coupled with low cost, ease of use, and rapid throughput, which is unmatched by traditional laboratory techniques.

Commercial Status

The BetaScint™ technology (U.S. patent # 5,442,180, August 1995) is commercially available from BetaScint, Inc. through equipment lease or purchase. BetaScint, Inc. offers a range of site characterization and project support service including consultation, training, maintenance and calibration. In addition to the LEHR application, BetaScint™ sensors have been used:

- By Bechtel Hanford, Inc., one of the primary remediation contractors at DOE's Hanford Reservation.
- In the Fernald Environmental Management Project near Cincinnati, Ohio.
- At DOE's Inhalation Toxicology Research Institute in Albuquerque, New Mexico.

SECTION 5

COST

Methodology

This section compares the BetaScint™ sensor technology application with the conventional baseline method of analytical laboratory tests for Sr-90. Four primary assumptions applied to both alternatives:

1. Preparation for and initial excavation prior to the first Sr-90 test was identical.
2. Comparison of 214 sample tests.
3. Analytical results and waste disposition paths were identical.
4. Excavation/closure activities were the same.

If the BetaScint™ technology were not available, it would have been necessary to excavate adjoining contaminated areas, and reallocate staff/equipment while awaiting laboratory results before proceeding with backfilling or further excavation. The primary savings realized by using the BetaScint™ sensor includes reduced soil sample analysis costs, reduced excavation equipment/personnel mobilization/demobilization costs, and time.

The detailed activities comprising the two methods were identified, and the associated activity-based cost estimate was developed by DOE Oakland Operations' Cost Estimating Group (see Appendix B). Costs compiled for the BetaScint™ sensor application were obtained from actual data from the LEHR site remediation project completed in September 1998. These costs primarily involved the BetaScint, Inc. fixed price contract with related support from a separate Weiss Associates contract, and other associated subcontract costs. Due to the ease of use and timely results of the BetaScint™ sensor during the project, additional samples (totaling 283 tests) were taken to ensure contamination removal. However, to provide a reasonable actual cost comparison with the conventional method, the BetaScint™ sensor estimate is based on the actual cost for 214 sample tests, the identical number of analyses for the baseline method. Note that the BetaScint, Inc. fixed price contract also included a majority of work for gamma spectroscopic analysis. Also note that equipment costs were not passed onto the LEHR customer since BetaScint, Inc. provided the use of the technology as a characterization service.

The conventional Baseline Sr-90 Laboratory Test Method reflects how the work would have been accomplished without the BetaScint™ sensor. Weiss Associates developed an alternative strategy that minimized staff/equipment standby time, kept costs low, and provided an acceptable option to local regulators/stakeholders. The primary elements of this alternative were an accelerated analytical test turnaround time of one week (to partially reduce the BetaScint™ sensor's "real time" results advantage), and slight "over excavation" to increase chances of removing all contaminated soil. All costs for associated activities were based on past historical, or present contractual cost data.

Cost Analysis

The Standard Life-Cycle Cost Savings Analysis Methodology for the Deployment of Innovative Technologies document was consulted while developing these cost estimates and the subsequent cost comparison. The graded approach methodology was used. Since the BetaScint™ application took place within one fiscal year, the cash-flow and net present value calculation/comparison were identical for the cost estimate developed.

Table 1 compares the cost estimates for the two alternatives. Detailed activity based cost estimates with related assumptions are also included as Appendix A. The BetaScint™ sensor application estimate identifies capital and operating items/costs required during the LEHR site remediation project. These items along with approximate costs shown in parenthesis are:

- Sensor calibration/response pre-deployment ($1,800).
- Staff/equipment mobilization, demobilization and site specific safety training ($5,400).
- Other direct costs, such as personal protective equipment, supplies, technician per diem, and the BetaScint, Inc. equipment transportation charges ($9,800).

Table 1

Activity Description	(Baseline) Sr-90 Lab Test Method ($)	BetaScint™ Sensor Technology ($)
BetaScint™ sensor Calibration/Response	0	1,790
Sitework (Mobilization/Demobilization)	0	5,394
Analyze 214 Samples	58,628	11,618
Verification Sampling (21 Samples)	3,613	3,613
Program Management	6,600	5,208
Other Direct Costs	650	9,784
TOTAL	69,491	37,407
Overall Cost per Sample	325	175
Analysis Cost per Sample	274	54

Cost Conclusions

There are a number of benefits from the use of the BetaScint™ sensor besides the timely results and reduced costs. Security needs, liability and stakeholder concerns are minimized by reducing the duration of the open excavation. The BetaScint™ application also did not generate any secondary wastes, or require any soil "over excavation." Although it was not possible to quantify these additional benefits, these factors should be considered during any remediation method selection process.

From Table 1, the main cost difference (about $47,000) between the two alternatives is the "Analyze 214 Samples" cost. The BetaScint™ sensor technology alternative cost about roughly half ($175 versus $325 per sample) of conventional laboratory testing. Also, the actual BetaScint™ sensor analytical "real time" (about twenty minutes) test results were less than 20% ($54 compared with $274 per sample) of the accelerated (one week turnaround) analytical laboratory test cost. The BetaScint™ sensor cost ($54 per sample) is also more cost effective than the non-accelerated (standard 30-day turnaround) analytical laboratory test cost ($149 per sample).

In addition to the cost, time saving, and other benefits provided by the BetaScint™ sensor, opportunities exist to further reduce costs. Recall that the LEHR project involved analysis of 283 samples (which also slightly lowers the applicable unit cost shown because of the further fixed cost distribution). The BetaScint™ sensor set-up at the LEHR site could have accommodated up to 2,088 sample tests. Thus, under ideal conditions, the BetaScint™ sensor analytical costs could have gone from $54 per sample to around $31 per sample (based on actual test times and fixed price contract costs).

SECTION 6

REGULATORY AND POLICY ISSUES

Regulatory Considerations

The BetaScint™ technology may reduce regulatory complexity of remediation projects because:

- Complications associated with sample handling, packaging, shipping, and off-site chain of custody procedures for laboratory testing of soil samples may be reduced.
- The measurement process generates no secondary wastes.

BetaScint, Inc. plans to certify the sensor under the California EPA certification program and the EPA Environmental Technology Verification program.

Safety, Risks, Benefits, and Community Reaction

Worker Safety

The BetaScint™ sensor is simple to operate and can be safely used by properly trained technicians. Quick determination of soil contamination levels also helps prevent overexposure of workers to radiation during remediation work.

Community Safety

Rapid measurements of Sr-90 and U-238 soil contamination may reduce radiation exposure of the public. Only 5 - 10% of soil samples need to be sent to off-site laboratories for quality assurance/quality control measurement verification. The reduced need to ship soil samples to off-site laboratories reduces the potential for community exposure from radiation in soil samples transported off-site.

Environmental Impacts

Rapid measurements of Sr-90 and U-238 soil contamination should reduce the time when excavation faces are left open, reducing possible environmental impacts from wind or water erosion of exposed radiation-contaminated soils.

Socioeconomic Impacts and Community Perceptions

Use of BetaScint™ technology is not expected to have large impacts on the regional work force or the regional economy. If the community is aware of the use of this improved technology, it may improve perceptions of the safety, efficiency, and cost-effectiveness of remediation efforts.

SECTION 7

LESSONS LEARNED

Implementation Considerations

Technology Selection

BetaScint™ should be considered in any situation where laboratory measurement of contamination with Sr-90 or U-238 could delay remediation or health protection procedures.

Implementation Considerations

The BetaScint™ technology must be supplemented by technologies suitable for measuring other types of radioactive contamination if radionuclides other than Sr-90 or U-238 are known, or suspected, to be present in the material sampled.

High levels of Cs-137 in the soil may produce an interference. Experience to date has been that Cs-137 interference will not become an issue of concern unless its concentration exceeds that of Sr-90 by many orders of magnitude. This is an unlikely situation in real-world remediation conditions. When Cs and Sr levels are comparable and less than 100 pCi/g (i.e., typical soil remediation conditions), the Cs contribution to the sensor background is negligible.

Technology Limitations

As presently configured, the BetaScint™ sensor can only measure contamination from Sr-90 or U-238.

APPENDIX A

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APPENDIX B

DETAILED ACTIVITY-BASED COST ESTIMATES

Betascint Sensor Cost Estimate
Revision 7.1, 10-Nov-98

Scope: This activity based cost estimate focuses on the process to obtain, analyze and verify sample results using the Betascint Sensor. The resource allocations are based on actual field data from the LEHR project completed in September 1998.

			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
												Fully loaded labor rates								
Item #	Activity description		Material	Qty		Labor			Sub-contract				Proj engr/	Env engr/				Admin/		
		%	Unit cost $	Each	Amount $	Hours	Avg rate $	Amount $	Unit cost $	Amount $	Total $	Proj mgr	Ind hyg	Beta tech	Tech supv	Equip op	Field tech	Clerical	La-borer	Total hours
												145.00	105.00	93.00	60.00	55.00	40.00	37.50	35.00	
1.0	Sensor calibration and response (predeployment)																			
1.1	Shipment of 30 kg of clean soil from target site to an independent lab																			
1.1.1	Locate, excavate and package clean soil sample at LEHR.				-	4	40.00	160		-	160	-	-	-	-	-	4	-	-	4
1.1.2	Ship soil from LEHR site to PNNL Lab at Richland, WA (FedEx)		100	1	100	1	40.00	40		-	140	-	-	-	-	-	1	-	-	1
1.1.3	PNNL Lab: Provide analytical tests (and chart) for 10 samples			10	-	-		-	149	1,490	1,490	-	-	-	-	-	-	-	-	-
2.0	Sitework																			
2.1	Mobilization (Betascint staff and equipment)				-	40	93.00	3,720		-	3,720	-	-	40	-	-	-	-	-	40
2.2	On-site safety training				-	8	93.00	744		-	744	-	-	8	-	-	-	-	-	8
2.3	Demobilization				-	10	93.00	930		-	930	-	-	10	-	-	-	-	-	10
3.0	Field sampling																			
3.1	Analyze 214 samples for Sr-90 concentration (as applicable, 75% [=214/283 samples] of actuals was used below)																			
3.1.1	Gather 2-3 kg soil samples, sieve in situ to remove excessive organic material, large rocks, double-bag in plastic, and transport to on-site facility characterization (0.33 hr/sample and place in two large "ziploc" bags; 22 set PPE @ $10)				220	71	40.00	2,840		-	3,060	-	-	-	-	-	71	-	-	71
3.1.2	Homogenize field samples by hand and situate under infrared lamps in trays to remove excess moisture (48 hr for 283 samples; 48 * 75% = 36 hr)				-	36	93.00	3,348		-	3,348	-	-	36	-	-	-	-	-	36
3.1.3	Perform 300-second analysis. Also includes generation/ documentation of common control charts using daily measurements (additional 54 measurements) (75% of 24 hr)				-	18	93.00	1,674		-	1,674	-	-	18	-	-	-	-	-	18
3.2	Record data values on daily log sheets (75% of 24 hr)				-	18	93.00	1,674		-	1,674	-	-	18	-	-	-	-	-	18
3.3	Perform random quality control (test QA on site) on samples previously characterized (after rehomogenizing and reanalyzing) to demonstrate efficacy of sample preparation and sensor reproducibility (75% of 18 hr)				-	14	93.00	1,302		-	1,302	-	-	14	-	-	-	-	-	14
3.4	Lab equipment maintenance (75% of 18 hr)				-	14	40.00	560		-	560	-	-	14	-	-	-	-	-	14
3.5	Verification sampling (QA/QC 10% of tests) (10% of 214 = 21 samples)																			
3.5.1	Obtain/prep 21 samples, includes collecting, packaging, and chain of custody paperwork. For 28 samples, pack coolers (2.25 hr) and airbill paperwork, perform radcon surveys 1.25 hr/3 coolers = 0.42 hr/cooler and document results; plus 3 hr)				-	6	40.00	240		-	240	-	-	-	-	-	6	-	-	6
3.5.2	Ship (FedEx) 21 samples in 2 coolers totaling 165 lb and associated paperwork (ship 2 coolers @ $122/ea and 20 samples per cooler)		122	2	244	-	-	-		-	244	-	-	-	-	-	-	-	-	-
3.5.3	Analytical lab tests which includes summary report ($149/sample for 30-day turnaround)			21	-	-		-	149	3,129	3,129	-	-	-	-	-	-	-	-	-
4.0	Program management																			
4.1	Predeployment: Training specific to LEHR site needs/requirements				-	20	93.00	1,860		-	1,860	-	-	20	-	-	-	-	-	20

4.2	Postdeployment																			
4.2.1	Procurement of supplies				-	10	93.00	930		-	930	-	-	10	-	-	-	-	-	10
4.2.2	Site coordination meetings				-	18	93.00	1,674		-	1,674	-	-	18	-	-	-	-	-	18
4.2.3	Report preparation				-	8	93.00	744		-	744	-	-	8	-	-	-	-	-	8
	Direct labor (unburdened)											-	-	214	-	-	82	-	-	296
	Fringe benefits	Incl																		
	Overhead	Incl																		
	Labor contingency	Incl																		
	DIRECT LABOR COST					296					27,623									
	OTHER DIRECT COST										9,784									
	PPE: Additional suits, gloves, boots				100															
	Other supplies: Coolers, labels (Weiss $100, Betascint $50)				150															
	Air freight: Betascint equipment (WA to CA and return)				1,200															
	Travel: 1 Betascint person 87 days, car 1600 mi @ 0.315 cents/mi (= $504) round trip from Kennewick, WA to LEHR, CA; per diem @ $90/day for 87 days (=$7,830)				8,334															
	ODC Contingency	Incl			-															
	General and administrative	Incl									-									
	SUBTOTAL										37,407									
	Fee	Incl									-									
	TOTAL										37,407									

Assumptions:
1. Modified PPE safety level D used. Reduced unit price derived from a large volume purchase.
2. LEHR did not have Betascint equipment already on-site. Mobilization costs can be reduced if site owned equipment, or if already on the premises. Insufficient information to perform lease versus purchase (of equipment) analysis.
3. Insufficient information to perform lease versus purchase (of equipment) analysis.
4. Initial clearing and grubbing would be the same as the lab test (baseline) method scenario, and not addressed here.
5. Due to convenience/ease of test results, the actual number of samples taken was 283. However, to fairly compare this method with the baseline method, the value 214 was used. For "Item 3" activities, 75% (=214/283 samples) of actual costs was used.
6. Volume and type of waste would be less than the lab test (baseline) method (requiring slight soil over excavation) scenario. This amount was unquantifiable and not addressed here.
7. Clean-up of the D&D equipment area would be the same as the lab test (baseline) method scenario, and not addressed here.
8. Site utilities provided at no cost by LEHR.
9. PNNL owned Betascint equipment which is leased to Betascint, Inc. However, Betascint, Inc did not pass any charges onto the LEHR contract/customer.
10. Anticipated capacity of contract work was to address a continuous heavy inflow potentially up to 2,088 samples; however, the inflow was sporadic and was less than expected.

Sr-90 Lab Test (Baseline) Method Cost Estimate
Revision 5.1

10-Nov-98

Scope: This activity based cost estimate focuses on the process to obtain, analyze and verify sample results using the lab testing (baseline) method for Sr-90. Represents the alternative remediation strategy had the Betascint Sensor not been available.

			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
			Material	Qty		Labor			Subcontract			Fully Loaded Labor Rates								
Item#	Activity Description	%	Unit Cost$	Each	Amount $	Hours	Avg Rate$	Amount $	Unit Cost$	Amount $	Total$	Proj Mgr	Proj Engr/ Ind Hyg	Env Engr/ Beta Tech	Tech Supv	Equip Op	Tech	Admin/ Clerical	Laborer	Total Hours
												145.00	105.00	93.00	60.00	55.00	40.00	37.50	35.00	
1.0	Field Sampling																			
1.1	Analyzed 214 samples for Sr-90 concentration.																			
1.1.1	Gather/collect 5-7 pounds (2-3 Kg) soil samples. (0.17 hrs/sample = 10mins/sample for Tech to collect/package. No sifting & limited sample prep. Each sample double bagged in gallon size ziploc bags & labeled. 10 samples/zone, or 22 set PPE@$10.)				220	36	40.00	1,440		-	1,660	-	-	-	-	-	36	-	-	36

1.1.2	Package/document samples including Chain of Custody forms. (Includes air bill paperwork, and packinging (11) coolers. 10mins/sample = 0.17 hours/sample. Also, perform radcon survey and document results 1.25 hours/3 coolers = 0.42 hours/cooler.)				-	41	40.00	1,640		-	1,640	-	-	-	-	-	41	-	-	41
1.1.3	Shipping (Federal Express). (20 samples in each cooler totaling 165 pounds and shipped for a $122 dollars. Thus, need 11 coolers.)		122	11	1,342	-	-	-	122	1,342	2,684	-	-	-	-	-	-	-	-	-
1.1.4	Analytical lab tests which includes summary report. ($246/sample for one week (I.e. 5 working days) result turnaround time)			214	-	-		-	246	52,644	52,644									
1.2	Verification/duplication sampling (QA/QC 10% of tests).																			
1.2.1	Obtain/prepare 21 samples. (0.17 hours/sample. Also include perform radcon sample at 0.42 hours/cooler.)				-	6	40.00	240		-	240	-	-	-	-	-	6	-	-	6
1.2.2	Ship (Federal Express) 21 samples in 2 coolers totaling 165 pounds and associated paperwork, perform radiological survey and document results.		122	2	244	-	-	-		-	244	-	-	-	-	-	-	-	-	-
1.2.3	Analytical lab tests which includes summary report. ($149/sample for standard 30 day turnaround time.)			21	-	-		-	149	3,129	3,129	-	-	-	-	-	-	-	-	-
2.0	Program Management																			
2.1	Project coordination.				-	8	105.00	840		-	840	-	8	-	-	-	-	-	-	8
2.2	Safety.				-	8	105.00	840		-	840	-	8	-	-	-	-	-	-	8
2.3	Report preparation and record keeping.				-	28	85.71	2,400		-	2,400	-	20	-	-	-	-	8	-	28
2.4	Procurement of supplies.				-	8	105.00	840		-	840	-	8	-	-	-	-	-	-	8
2.5	Site coordination meetings.				-	16	105.00	1,680		-	1,680	-	16	-	-	-	-	-	-	16
	Direct Labor (Unburdened)											-	60	-	-	-	83	8	-	151
	Fringe Benefits	Incl																		
	Overhead	Incl																		
	Labor Contingency	Incl																		
	DIRECT LABOR COST					151					68,841									
	OTHER DIRECT COST										650									
	PPE: Additional suits, gloves, boots,...		100																	
	Other: 13 Coolers @$25/ea=$325, other miscellaneous: ice, phone...=$125		450																	
	Travel: Minimal local.		100																	
	ODC Contingency	Incl	-																	
	General and Administrative	Incl									-									
	SUB-TOTAL										69,491									
	Fee	Incl									-									
	TOTAL										69,491									

ASSUMPTIONS

1 Modified PPE safety level D used. Reduced unit price derived from a large volume purchase.

2 (Original) mobilization covered under initial project mobilization.
3 Initial clearing and grubbing would be the same as the Betascint Sensor application scenario, and not addressed here.

4 This method relies on an unquantifiable amount of soil "over excavation" to increase chances of removing all contaminated soil and possibly some clean soil..

5 All sample results yield a negative result (i.e. no additional excavation is required which would require re-mobilization of operator/equipment.)

6 Clean-up of the D&D equipment area would be the same as the Betascint Sensor application scenario, and not addressed here.

7 Site utilities provided at no cost by LEHR.
8 To mitigate equipment/operator standby time, an accelerated sample Sr-90 turnaround time of one week (I.e. 5 calendar days as opposed to the standard 30 days) was used at increased cost to accommodate regulator and scheduling concerns.

9 Excavate maximum amount of probable contaminated soil before taking samples. After shipping off these samples, operator/backhoe continues work in other work areas. Operator/backhoe are reassigned to avoid standby time while awaiting lab results.