DEPLOYMENT OF SMART 3D SUBSURFACE CONTAMINANT CHARACTERIZATION AT THE BROOKHAVEN GRAPHITE RESEARCH REACTOR

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ABSTRACT

The Brookhaven Graphite Research Reactor (BGRR) Historical Site Assessment (BNL 1999) identified contamination inside the Below Grade Ducts (BGD) resulting from the deposition of fission and activation products from the pile on the inner carbon steel liner during reactor operations. Due to partial flooding of the BGD since shutdown, some of this contamination may have leaked out of the ducts into the surrounding soils. The baseline remediation plan for cleanup of contaminated soils beneath the BGD involves complete removal of the ducts, followed by surveying the underlying and surrounding soils, then removing soil that has been contaminated above cleanup goals. Alternatively, if soil contamination around and beneath the BGD is either non-existent/minimal (below cleanup goals) or is very localized and can be "surgically removed" at a reasonable cost, the BGD can be decontaminated and left in place. The focus of this Department of Energy Accelerated Site Technology Deployment (DOE ASTD) project was to determine the extent (location, type, and level) of soil contamination surrounding the BGD and to present this data to the stakeholders as part of the Engineering Evaluation/Cost Analysis (EE/CA) process. A suite of innovative characterization tools was used to complete the characterization of the soil surrounding the BGD in a cost-effective and timely fashion and in a manner acceptable to the stakeholders. The tools consisted of a tracer gas leak detection system that was used to define the gaseous leak paths out of the BGD and guide soil characterization studies, a small-footprint Geoprobe® to reach areas surrounding the BGD that were difficult to access, two novel, field-deployed, radiological analysis systems (ISOCS and BetaScint®) and a three-dimensional (3D) visualization system to facilitate data analysis/interpretation. All of the technologies performed as well or better than expected and the characterization could not have been completed in the same time or at the same cost without implementing this approach.

A total of 904 BGD soil samples were taken, evaluated, and modeled. Results indicated that contamination was primarily located in discrete areas near several expansion joints and underground structures (bustles), but that much of the soil beneath and surrounding the BGD was clean of any radiological contamination. One-year project cost savings are calculated to be \$1,254K. Life cycle cost savings, resulting from reduction in the number of samples and the cost of sample analysis, are estimated to be \$2,162K. When added to potential cost savings associated with decontamination and leaving the BGD in place (\$7.1 to 8.1M), even greater overall savings may be realized.

INTRODUCTION AND BACKGROUND

The Brookhaven Graphite Research Reactor (BGRR) was the world's first nuclear reactor dedicated to the peaceful exploration of atomic energy. The reactor pile consisted of a 700-ton, 25-foot cube of graphite fueled by uranium. A total of 1,369 fuel channels were available with roughly half in use at any given time. Insertion and removal of boron steel control rods controlled reactor power levels. One or more of five fans powered air-cooling. Air was brought in through two filtered plenums, flowed through and around the reactor core, through an exhaust duct containing filters, and finally out through the 320-foot high exhaust stack. Spent fuel was temporarily stored in the spent fuel canal, and then sent to the DOE's Savannah River Site (SRS).

The BGRR ceased operation in 1968 and was placed in a shutdown mode, in which all fuel was removed and sent to SRS. Penetrations in the biological shield around the graphite cube and fuel channels were sealed. The final decontamination and decommissioning (D&D) process was initiated in 1999 and is scheduled for completion in 2005. An accelerated schedule was developed that combines characterization with removal actions for the various systems and structures. Before D&D work on a section of the BGRR facility begins, contaminant characterization is conducted to determine the types and amounts of contaminants present. The data are then used for project planning, including decisions affecting the extent of removal, waste designation, and health and safety plans. Additional information on the D&D of the BGRR can be found at http://www.bnl.gov/bgrr/ and at http://www.dne.bnl.gov/ewtc/d_d.htm.

The BGRR Historical Site Assessment (1) identified contamination inside the Below Grade Ducts (BGD) resulting from the deposition of fission and activation products from the pile on the inner carbon steel liner during reactor operations. The air plenums experienced water intrusion both during BGRR operation and in the 30 years since it has been shut down. The water intrusion was attributed to rainwater leaks into degraded parts of the system and to internal cooling water system leaks. Samples of the water and sludge deposited in the ducts were analyzed indicating the presence of Cs-137, Sr-90 (> 90% of the total activity), and other isotopes. It is believed that the contaminated water leaked out of the ducts, thus potentially contaminating large volumes of soil beneath the BGD. In that case, the BGD structure itself would require removal to remediate the contaminated soil beneath. If the subsurface contamination is limited to discrete locations however, the soil may be "surgically removed" so that the BGD structure could be decontaminated and left in place.

Figure 1 depicts the layout of the BGRR duct facilities and a side view of the ducts. The underground air ducts (plenums) are approximately 170 feet long, running from Building 701 (Reactor Building) to the above ground joint. Each of the north and south exhaust air-plenums are approximately ten feet wide and fourteen feet high. The bottom of the air-plenum concrete is at an approximate elevation of 75 feet, about 35 feet below the grade level, which is at an elevation of 110 feet. The ducts are constructed of one-foot thick reinforced concrete lined with two layers of carbon steel. The steel liners make up the primary and secondary ducts. The primary duct provided cooling air for the reactor; the secondary duct maintained counter-flow cooling to prevent overheating of the concrete. Both of the primary ducts are highly contaminated. However, most of the contamination is confined to the primary ducts, but corrosion of the primary ducts has lead to some contamination of the secondary ducts. Leakage of water from the ducts is likely to have resulted in contamination of the surrounding soil.

The main air duct has two expansion joints and three minor joints, which are considered to be potential points for the release of contamination from the ducts to the environment. In addition, the concrete ducts are over forty years old. There is no certainty that these old, large, casting concrete structures have not cracked, yielding new pathways for contamination release. Removal of the BGD will provide access for remediation of any contaminated soils below the plenum. If it can be demonstrated that the soils under the air plenum are not contaminated above the established regulatory criteria or require only a small amount of remediation, the air plenums will not have to be removed. This will result in substantial remediation cost savings (estimated at $7.1 to 8.1M) and reduction in the total duration of the project with associated administrative cost savings (estimated at $850K per year). In addition, waste volumes that require off-site disposal as low-level waste would be reduced.

STRATEGY TO DEFINE CONTAMINATION

The recent draft Engineering Evaluation/Cost Analysis (EE/CA) lists five alternative remediation options for the BGD. The options include:

1. No action,
2. Removal of the instrument house only,
3. Targeted removal of contaminated soils above the surface cleanup goals,
4. Partial removal of the BGD, and
5. Complete removal of the BGD.

The last option involves removal of the primary ducts followed by excavation and removal of the concrete ducts and secondary plenum, surveying the underlying and surrounding soils, and then removing soil that is contaminated above cleanup goals. Alternatives 2 and 3 call for leaving the BGD in place and either no soil removal from around the BGD (Alternative 2) or localized removal of contaminated soil that is above the surface remediation goals (Alternative 3). To leave the duct in place requires that soil contamination surrounding the BGD is either non-existent/minimal (below cleanup goals), is very localized and can be "surgically removed" at a reasonable cost, or poses little or no risk if left in place. It is estimated that Alternatives 2 and 3 would save $7.1 to 8.1M over Alternative 5.

Documented leakage of water into the ducts indicates that it is possible that contamination may have leaked out from the ducts. However, without detailed soil characterization, there is insufficient information for making cost-effective and risk-based decisions on further disposition of the BGD. To determine whether the BGD can be left in place and provide a scientific basis to the stakeholders that this is protective of public health, the contaminants and their location and concentration levels must be known. As can be seen in Figure 1, the ducts are very large and a huge volume of soil surrounds the BGD. To adequately define the extent of contamination without knowing where the contamination leaked from would require analysis of all the soil immediately surrounding the BGD. Based on soil characterization data for the Canal House soils (which are immediately adjacent to the BGD soils), core samples would be needed every three feet along the sides of the duct as well as below the duct. Cost for outside laboratory analysis of that many samples would be exorbitant and the time for turn around would force an unacceptable delay in the remediation. In addition, much of the soil surrounding the BGD is in hard-to-access areas (i.e., under the duct) so it would be difficult to obtain cores. Thus, to adequately define the contamination using conventional means would be cost prohibitive and would deplete much of the cost savings obtained by leaving the ducts in place.

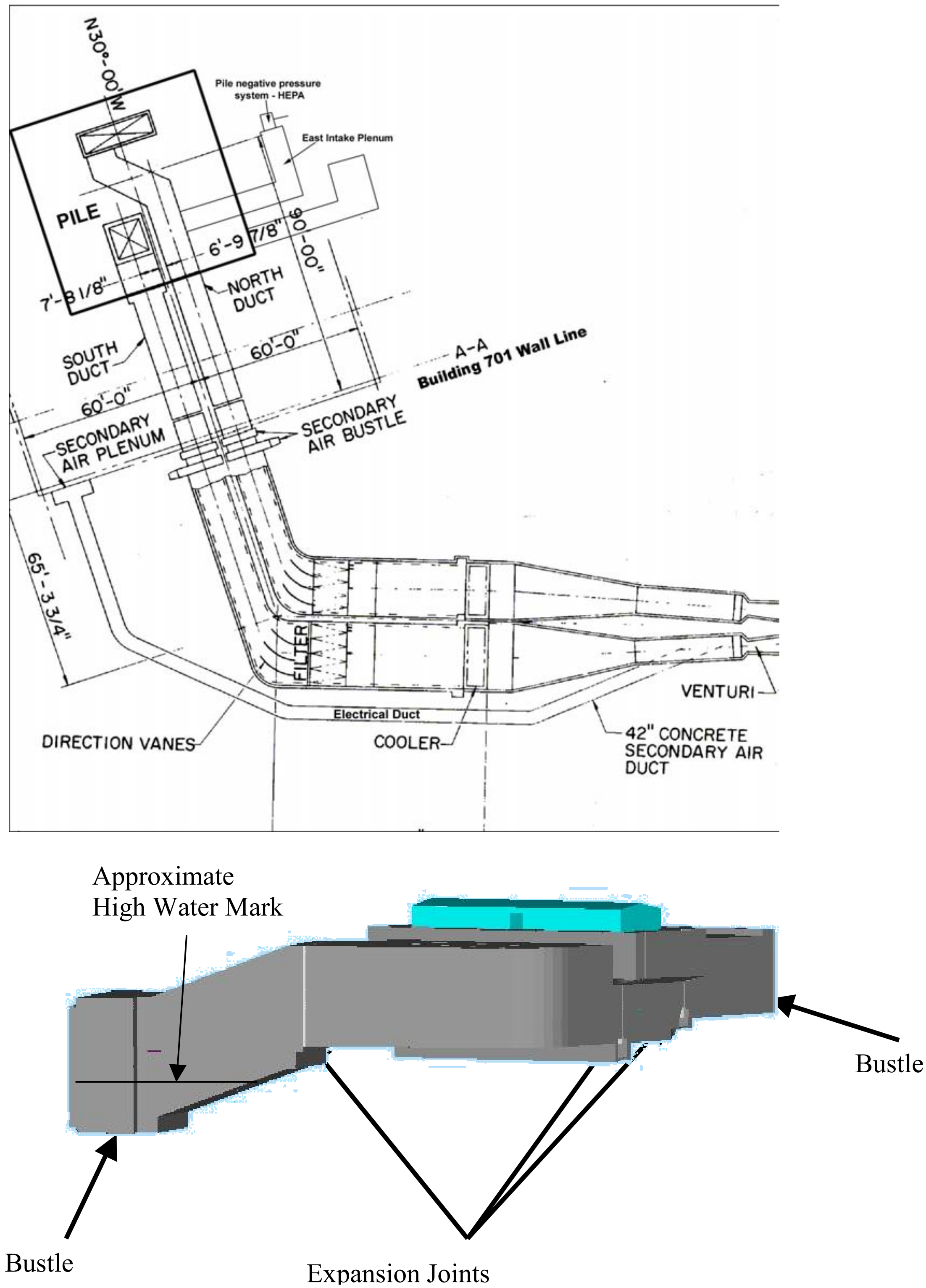


Fig. 1. Top and side view of BGRR ducts

OBJECTIVE

The focus of this project was to determine the extent (location, type, and level) of soil contamination surrounding the Below Grade Ducts (BGD) and to present this data to the stakeholders as part of the Engineering Evaluation/Cost Analysis (EE/CA) process.

APPROACH

A suite of innovative characterization tools was used to complete the characterization of the soil surrounding the BGD in a cost-effective and timely fashion and in manner acceptable to the stakeholders. The tools consisted of a tracer gas leak detection system that was used to define the gaseous leak paths out of the BGD and guide soil characterization studies, a small-footprint Geoprobe® to reach areas surrounding the BGD that were difficult to access, two novel, field-deployed, radiological analysis systems (ISOCS and BetaScint®) and a three-dimensional (3D) visualization system to facilitate data analysis/interpretation for the stakeholders. Support for this Accelerated Site Technology Deployment project was provided by the DOE Office of Science and Technology D&D Focus Area. The remainder of this paper discusses the performance and costs associated with implementation of each innovative technology. Costs are compared to baseline costs, where applicable, and estimates of life cycle cost savings are provided. Additional detailed information is available in the Cost and Performance Report (2).

DETERMINING POTENTIAL LEAK PATHWAYS USING PFTs

A state-of-the-art gaseous perfluorocarbon tracer (PFT) technology developed at BNL was utilized to characterize gas leak pathways from the ducts. These tracers were originally used in atmospheric and oceanographic studies and have since been applied to a great variety of problems, including detecting leaks in buried natural gas pipelines and locating radon leak pathways into residential basements (3,4). PFTs have regulatory acceptance and are used commercially (e.g. detecting leaks in underground power cable systems). PFTs allow locating and sizing of leaks at depth, have a resolution of fractions of an inch, and have been used in a variety of soils. The BNL Environmental Research and Technology Division has developed the tracer technology for use as a leak detection system for subsurface structures such as containment barriers and cap/cover systems on waste sites (2,3,5). The BGD can be viewed as a large underground containment structure (containing air). The use of PFTs to check for leaks in the BGD is a natural extension to previous environmental applications (e.g., integrity verification in subsurface barriers) (5,6,7).

Leaks in the BGRR underground ducts were located by injecting the PFT(s) inside of the duct and monitoring for that tracer(s) outside of the duct. The location and concentration of the tracer detected on the monitoring side of the duct defined the location and size of the leaks. Larger openings in the duct permit greater amounts of tracer to be transported to the monitored area. Inlet and outlet flexible ducting was installed to provide separate circulation loops for the North and South Ducts (Figure 1) to allow different tracers to be circulated in each duct. This yielded data that was specific for each duct and helped to more accurately define leak pathways. The injection continued for seven to ten days and the concentration of tracer was monitored at regular sampling intervals. The tracers employed are listed in Table I.

Table I. Chemical Acronym, Name, and Formula for PFT Tracers Used in This Study

Chemical Acronym	**Chemical Name**	**Chemical Formula**
PDCB	Perfluorodimethylcyclobutane	C_6F_{12}
PMCP	Perfluoromethylcyclopentane	C_6F_{12}
PMCH	Perfluoromethylcyclohexane	C_7F_{14}
o-PDCH	Orthocisperfluorodimethylcyclohexane	C_8F_{16}

The injected PFTs were monitored outside the ducts through a series of multi-level gas sample ports in close proximity to the ducts. Monitoring locations were installed every ten feet along the ducts (Figure 2). A total of 131 monitoring ports were installed. This diagram depicts the underground ducts from the secondary bustle to the coolers (to see how this fits into the reactor layout and overall air-ducts see Figure 1).

The PFT data were analyzed to determine gas leak locations. This, in turn, allowed determination of what soil regions under or adjacent to the ductwork were to be emphasized in the soil characterization process. Knowledge of where gaseous tracers leaked from the ducts yielded a conservative picture of where water may have moved out of or into the BGD. Although every leakage location may not result in soil contamination (for example at the side or top of the duct), the likelihood of contamination occurring is higher at these areas. The regions with the highest chance of releasing contamination to the surrounding soils are the locations determined by the PFT tests that are along the bottom or below the high water mark in the ducts.

Equally as important, the PFT data showed which areas of the duct were not leaking and, therefore, required only a limited number of confirmatory soil explorations. Figure 3 presents representative data for the tracer PMCH at the South Duct and PDCB at the North Duct on February 6, 2001. These are fully developed profiles as they represent the concentrations at the end of the injection period. Evidence of the tracers in the surrounding soils indicates a leak pathway from the internal duct. The diagram shows only the underground ducts and the sample locations. Sample concentrations are color-coded with red denoting the highest concentration and blue the lowest. The red to orange areas near the bustle (left-hand side) indicate that a substantial hole exists in the duct at this area. Regions of minimal or no leakage are depicted in blue. Viewing the figure, it is clear that the larger leaks all occur along expansion joints and the largest leak occurs at the first bustle. The data also clearly indicate that there are substantial areas where leakage is minimal. This would suggest soil characterization should be focused on the areas with the highest leak rates. If a region is not susceptible to gas leakage, it is not susceptible to water leakage.

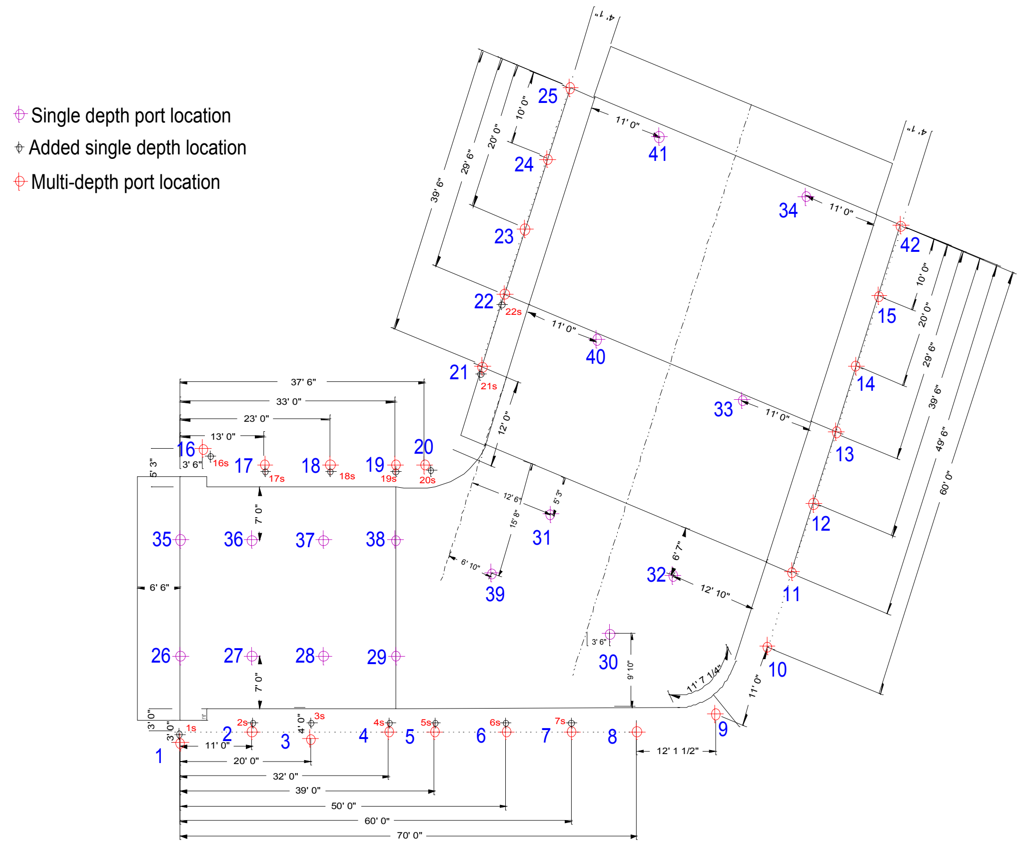
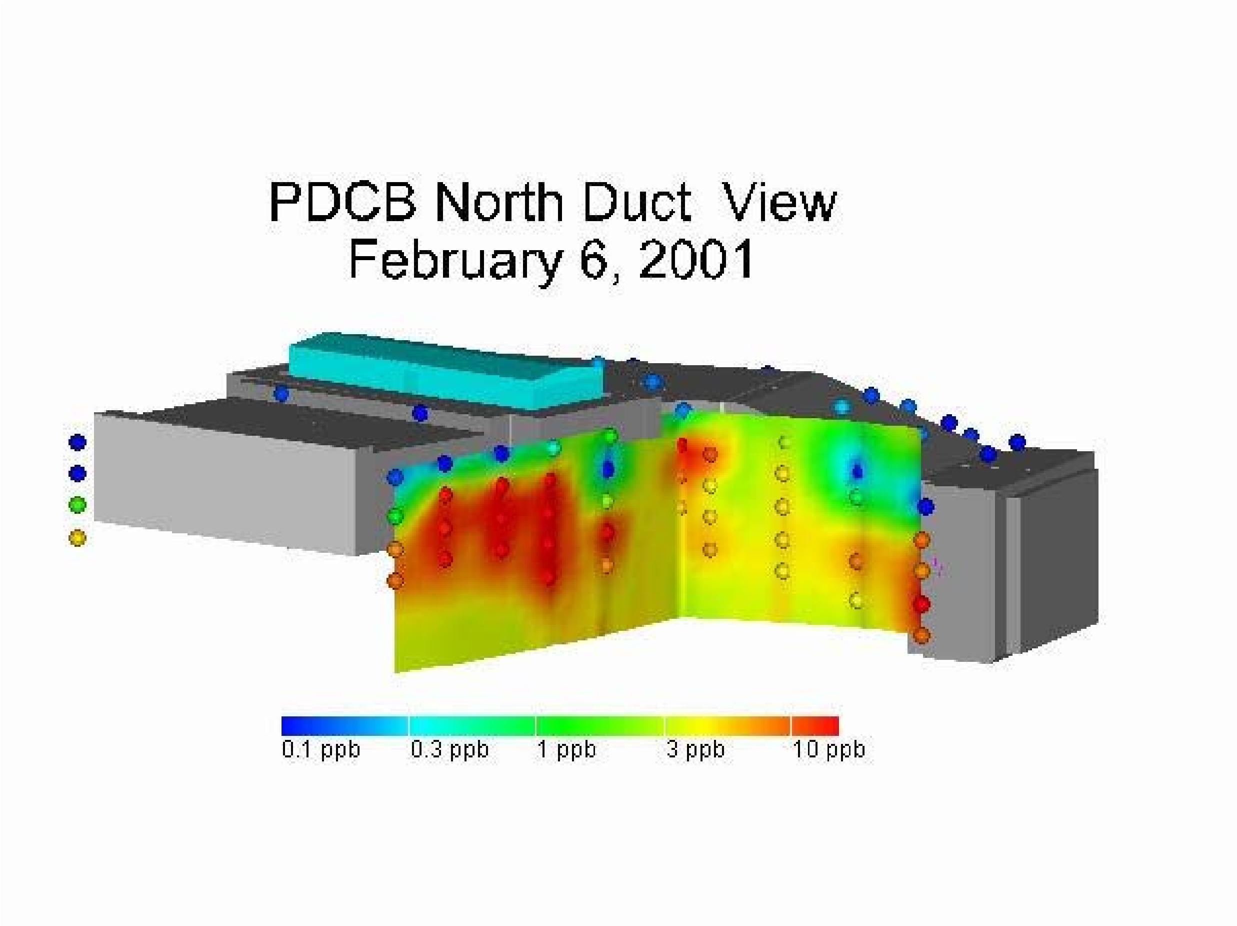


Fig. 2. Plan view of monitoring ports for the PFT leak test

A more exact determination of leak pathways has several advantages. The use of PFTs determined which of the suspect areas leaked (and the relative magnitude of the leaks) but more importantly determined what additional areas of the BGD leaked (e.g., significant cracks in the concrete duct). The Sampling and Analysis Plan (SAP) was designed to coincide with the identified gas leaks. This allowed the regulators and stakeholders to have confidence in the sampling scheme as it emphasized suspect/known leak pathways. Another advantage to using PFTs is that they were able to eliminate some of the suspect contamination pathways by determining that they were not leaking. In these regions only confirmatory type sampling was conducted, saving considerable funds and time.

The information gained in the PFT Tracer Gas Study was used to guide and optimize the soil characterization strategy for the BGD Sampling and Analysis Plan (SAP). Combining this information with process knowledge permitted an improved sampling plan to be developed. A complete reporting of the tracer study can be found in "Characterization of Leak Pathways in Below Grade Ducts of the BGRR Using Perfluorocarbon Tracers" (8).



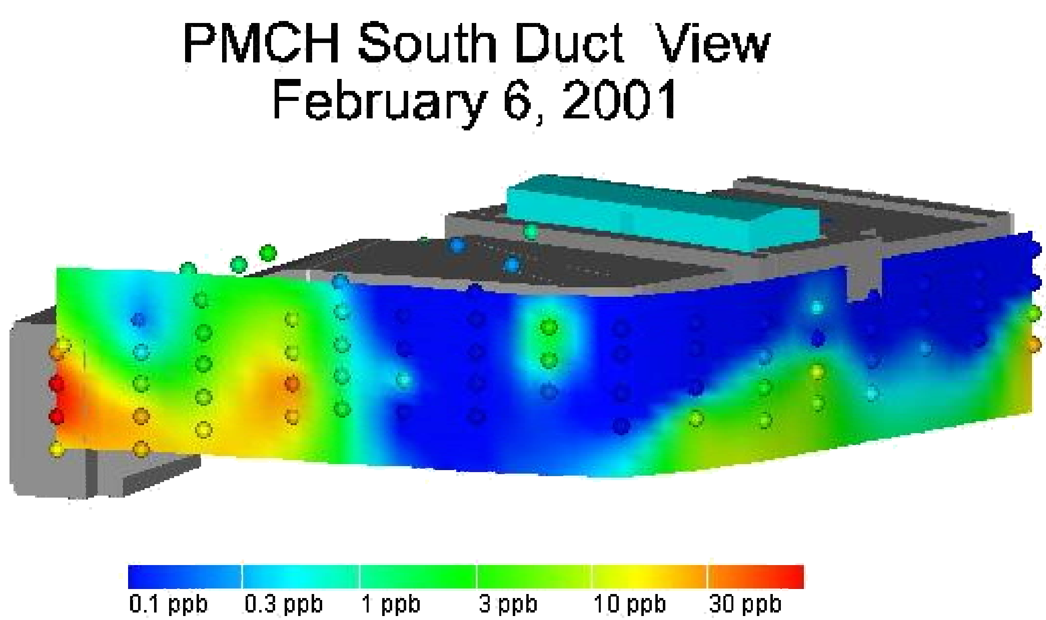


Fig. 3. PFT leak test results on the North Duct (PDCB) and the South Duct (PMCH) on February 6th, 2001.

SOIL CHARACTERIZATION

Once the leak paths were found and the SAP completed, core samples were taken from around the BGD. The cores were taken using a Geoprobe® Model 54 LT (tractor mounted) continuous push, soil-probing unit with a macro core soil sampling system. The tracked penetrometer allowed rapid deployment and use in cramped or tight areas and on uneven terrain. The cores were then surveyed in the field for gamma-emitting radionuclides using the ISOCS and for Sr-90 using the BetaScint®. A small subset of these samples was sent to an offsite laboratory for analysis as a benchmark for the field-deployable units. The data was input into the Environmental Visualization System software to provide a clear and concise three-dimensional picture of the location and extent of contamination for presentation to stakeholders. This data is currently being incorporated into the EE/CA documentation.

Perfluorocarbon Tracer Technology

Performance

The leak profile for both ducts was stable throughout the injection test providing confidence that the information provided by the test is reliable. In addition, the North Duct leak profile of o-PDCH (second test) is similar to that found by PDCB (first test). Similarly the South Duct leak profile of PMCP (second test) is similar to that found by PMCH (first test). This provides further confidence that all leak pathways from the north plenum to the surrounding soils have been defined. Examination of the concentration profiles for all tracers showed the same leak locations on both ducts.

One of the goals of the tracer study was to provide enough confidence in the knowledge of leak pathways to allow reduced soil sampling without a loss in stakeholder confidence that all of the contamination was found. The PFT concentration data are extremely stable and reproducible and provide a high level of confidence that all the leak pathways were found. The gas leak pathways represent a conservative estimate of potential liquid leak pathways, i.e., contaminated water did not necessarily leak at every gas exit point. For example, gas leaks identified above the water line in the ducts could not have resulted in release of contaminated liquid. However, areas where no gas leaked are highly unlikely to contain contaminated soil. The real measure of success for the tracer study is how well the PFT leak pathway data conforms to the contamination distribution determined from soil samples.

To this end, the contamination distribution determined from deep soil samples was correlated to the tracer gas concentrations in the soil during the leak test. It should be noted that the SAP provided for soil core samples to be taken from several areas that came up negative in the tracer study (no leaks seen). These samples were to provide confirmation that these areas were indeed clean. None of the areas determined to be leak-free in the tracer study showed Cs-137 contamination above background. The hot spots (contamination above preliminary cleanup goals) all coincide with the largest leaks seen with the use of the PFTs. This is positive confirmation that the PFT study was successful in determining all the possible leak pathways.

Leak test and characterization data from the South Duct were also very well correlated. Figure 4 shows the tracer concentrations for o-PDCH on February 14th and the Cs-137 contamination distribution in the soil surrounding the North Duct. Again, no contamination was found in areas the PFTs determined to be intact and leak free. All contamination above preliminary surface soil cleanup goals was associated with the major leak paths as determined by the PFTs. The highest soil contamination occurred at the location identified as having the highest PFT leak rate.

The excellent correlation of PFT leaks to contamination distribution, the stability of the PFT concentration profiles over the course of the leak test, and repeatability of the PFT findings (as determined from the multiple tracers all having similar profiles) are very strong evidence that the tracer technology met all goals and performed according to expectations.

Cost Evaluation - PFT Leak Test

In order to determine potential cost savings realized by using the PFT technology, the cost of sampling taking into account the tracer study results (i.e., the method used to devise the SAP) is compared to the cost of sampling if the tracer study were not available. The tracer study allowed for reduced sampling along the joints that showed little leakage and tight sampling along the bustle where large leaks were found. Based on the Canal House characterization, which is adjacent to the ducts, soil contamination occurred in narrow, discrete, vertical bands, i.e., little or no horizontal spreading occurred. Thus, to identify contaminated soil in areas known to have leaked (e.g., the bustle) required sampling on 2.5-foot intervals across the joint. At the remaining joints, two boreholes were placed at each joint, one bisecting the North Duct and one bisecting the South Duct.

In all, the SAP called for 904 samples from 32 boreholes to be taken adjacent to the ducts. This number excludes surface soil samples and blanks, which would be needed with or without the tracer study. Since the cost of these samples would be the same for both sampling schemes, they are not considered in the remainder of this analysis. The SAP called for core samples to be taken from 18" below grade level (or from the bottom of the ducts) to refusal or the water table, whichever came first. The SAP also required additional samples to be taken whenever contamination was encountered. The additional samples were used to bound the extent of the contamination. In either case, the additional boreholes needed to bound the contamination would remain the same (as the "plume" of contamination is fixed and independent of the characterization). Again, these extra samples taken to bound the contamination are not considered here, as they are equivalent in both sampling schemes.

Without the tracer study, the soil characterization would be conducted "blind", i.e., there would be no information about areas that were clean and did not require extensive characterization. It would seem obvious that the joints would be suspect and should be investigated, but the integrity of the rest of the duct would be unknown. This would require soil sampling beneath the ducts (without the tracer study the ducts would have to be removed) in a grid pattern tight enough to find the contamination with reasonable certainty. Since little would be known about leakage at the joints, they would all require close sample spacing, as per the SAP at the bustle. This would require 10 boreholes (five each for the North and South Ducts) under the joints and two in the soil adjacent to the joint (one at the north side and one at the south side).

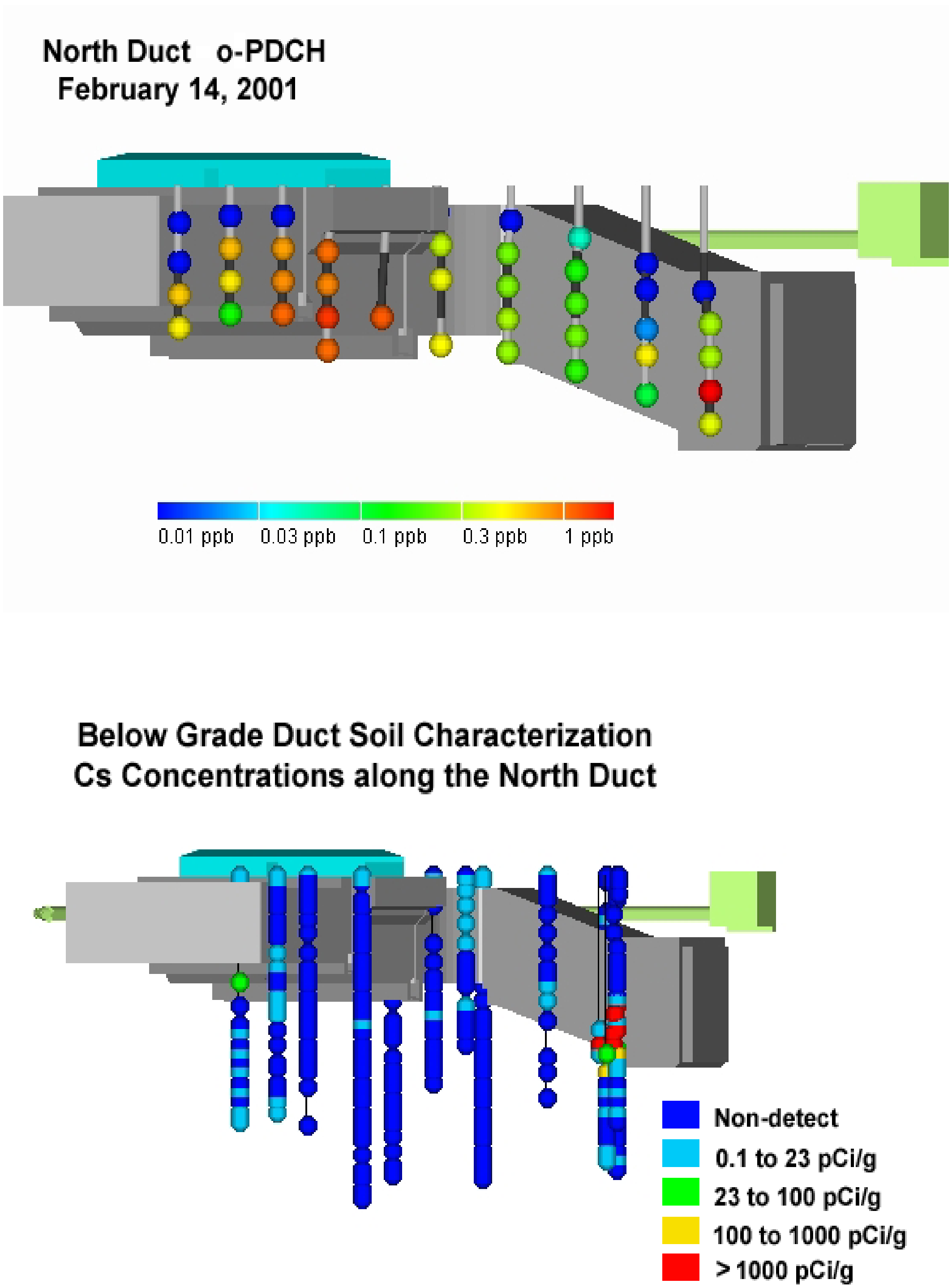


Fig. 4. Comparison of potential leak pathways identified by PFT o-PDCH and Cs soil contamination level along the North Duct.

Between joints exploratory sampling would be used. Based on the Canal House data no more than 10-foot spacing would be acceptable and less than 5-foot spacing would be neither economically feasible nor schedule compatible. It is believed that 10-foot spacing for exploratory confirmation between joints would be acceptable to the stakeholders and is considered the minimum characterization case without the tracer study (if contamination were found, bounding characterization would be required). Table II summarizes the sampling requirements of the two cases.

Table II. Borehole and Sample Requirements for the 3 Soil Characterization Alternatives

	Using PFT Tracer Gas Study	**Minimum Alternative (10 foot spacing)**
Boreholes Needed	32	98
Number of Samples	904	2542

Total costs, summarized in Table III, for the two characterization schemes include materials, cost to collect the samples, cost to analyze the samples and project management costs (management, health and safety, trades, etc). Use of the PFTs to define the potential leak pathways lead to cost savings of $849K.

Table III. Comparisons of Characterization Costs Using the Tracer Gas Study and Baseline Approaches

Description	**Using PFT Tracer Gas Study Cost ($)**	**Minimum Alternative Cost ($)**	**Cost Savings ($K)**
Materials	1,500	2,000	0.5
Sample collection	92,800	284,200	191
Gamma analysis	227,800	640,600	413
Beta analysis	180,800	508,400	328
Project Management	64,000	196,000	132
Tracer Study	215,000	N.A.	(-215)
Total	**781,900**	**1,631,200**	**849**

a) Assumes annual costs (see Appendix A for Life Cycle Cost Analysis)
b) Assumes baseline analytical costs for all scenarios.

Sample collection costs mainly consisted of collection of core samples via Geoprobe®. Some minor incidentals, such as chain of custody paperwork, are included in the project management costs. The cost for materials and operation of a Geoprobe® and a two-man crew was $1,450 per day. Each borehole consisted of 23 to 34 samples and on average required 2 workdays to complete. The SAP required 32 boreholes for collection of samples adjacent to the BGD at a cost of $92,800. The baseline minimum characterization would have required 98 boreholes at a cost of $284,200. It must also be noted that the baseline sampling would have taken an additional 130 workdays or 26 calendar weeks.

Characterization included gamma, beta, and occasional RCRA analyses. Cost for offsite laboratory analysis is $252 per sample for gamma analysis and $200 per sample for beta analysis. While actual analytical costs for this project were lower, baseline characterization costs are used here to determine savings due to the PFT Tracer Gas Study alone. The 904 samples from the

SAP would cost $227,800 for gamma analysis and $180,800 for beta analysis for a total of $408,600. The minimum baseline characterization requires 2542 samples and would cost $640,600 for gamma analysis and $508,400 for beta analysis, for a total of $1,149,000.

Project management costs are apportioned based on the length of the characterization process. A fixed cost ($1000 per day) is applied based upon the sample collection rate. It is assumed laboratory analysis would keep up with sample collection. For the ASTD alternative, this amounts to $64,000. For the minimum alternative, project management costs are estimated at $196,000.

The cost of the tracer study must also be considered. The materials costs amounted to $5K. The tracer analysis of ~1200 gas samples was performed by an onsite laboratory at a cost of $90K. Personnel cost for component installation, tracer preparation/injection, monitoring, and data reduction was $120K. The total cost for the PFT study was $215K and is deducted from the cost savings.

A life cycle cost analysis (as per standardized DOE-EM guidelines) is presented in the ASTD Cost and Performance report (2). The PFT technology is a unique system that has no real baseline equivalent. Therefore, the only comparison that can be made is between the characterization of the BGD with and without PFTs. The first analysis compares the minimum baseline characterization (assumes minimal prior knowledge of leaks from the BGD) to the characterization performed according to the SAP (with knowledge gained from PFT technology). Life cycle cost savings are calculated to be $849K with a ROI of 395%.

In summary, the PFT study performed according to expectations and provided a detailed picture of the gas leak pathways out of the BGD. The information from this test was used to support a SAP that had greatly reduced soil sample requirements compared to the baseline approach. The soil sampling focused on areas where gas leaks occurred and emphasized (via a tighter sample grid) the largest leaks. The test cost $215K but reduced the sampling requirement by over 1600 samples resulting in savings of $849K. The reduced sampling also saved at least 26 weeks of total project time.

Small Footprint Geoprobe®

Performance

The compact small footprint Geoprobe® unit was particularly useful for the PFT gas study and soil sampling on the southeast corner of the BGD. At this point there is an electrical duct running in very close proximity to the BGD. This electrical duct had to be unearthed to precisely locate it to avoid damaging it during coring and probing operations. The resultant trench made using a conventional Geoprobe® or similar unit impossible without first backfilling the trench so that the unit could be driven into place. The small, track-mounted unit was able to be driven into the trench and positioned close enough to the BGD to be able to probe between the electrical duct and the BGD.

Cost Evaluation

The small footprint Geoprobe® was most useful in accessing areas that would otherwise require terrain or structural alterations and facilitated rapid and efficient deployment of the other innovative characterization technologies. The cost savings associated with the Geoprobe® are difficult to quantify because it is hard to estimate how long it would take to restructure the site (or alter characterization plans) to make it fully accessible by the conventional truck-mounted probing systems. While cost savings over conventional probing technologies were realized, these costs were not included in overall project cost savings due to these uncertainties.

In-Situ Object Counting System (ISOCS)

The ISOCS gamma spectroscopy system again proved extremely valuable to the BGRR D&D project. In the second ASTD deployment of this technology at the BGRR, the system was used as a mobile field laboratory to provide rapid, high-quality analyses of gamma-emitting radionuclides. Every soil sample collected was analyzed using ISOCS (with a percentage also being sent to an independent offsite laboratory for confirmation). The gamma spectroscopy data from ISOCS was then input into the EVS-PRO software to provide a profile of the contamination around the BGD.

The initial ISOCS deployment at BGRR (FY 99 ASTD) provided the performance comparison of ISOCS with traditional laboratory analysis (9). A data quality assessment was performed for ISOCS in this earlier study and will not be repeated here. In summary, ISOCS compared very favorably to conventional gamma analysis in sensitivity, accuracy, and precision.

In this deployment the ISOCS proved to be reliable, durable, and efficient. In all, the ISOCS unit analyzed approximately 1700 samples over the course of 6 months. This included the ~900 deep soil samples taken from around the BGD, an additional 500 soil samples taken from near the BGD, and 300 structural samples taken from the BGD. The 500 additional soil samples were a mix of surface soil samples (some taken adjacent to the BGD) and deep soil samples. The surface soil samples were taken to characterize the topsoil contamination over and around the BGD. The deep soil samples were taken from areas nearby the BGD but were expected to be clean. These provided blanks and bias samples. The 300 structural samples were comprised of concrete core, steel, aluminum, asphalt and other miscellaneous odd samples taken from the BGD. These samples were taken when coring through the ducts to characterize below the ducts and as part of the characterization of the ducts themselves.

Cost Evaluation

This cost evaluation will consider only the tangible cost savings ISOCS brought to the project, but the intangibles are worthy of recognition. Rapid turn-around of samples allowed optimal use of equipment and manpower. No schedule delays occurred while waiting for laboratory analysis to be returned from an offsite laboratory. It is difficult to estimate how much time would have been wasted waiting for contract laboratory analysis of samples but past experience implies it would have been considerable. Such savings were maximized when sampling areas that were waiting to be declared clean and thus no further sampling was needed or for areas that needed radiological analysis prior to completing health and safety preparation (i.e., work permits).

ISOCS was also able to “catch up” to normal sampling delays. Often site preparation for sampling took longer than the sampling. Engineering controls to minimize contamination spread, site markings, equipment set up, etc., would cause breaks in the sample collection process. Thus, samples tended to come in spurts; a large number of samples in a short time period followed by a lull in sample collection while the next area was prepared. The ISOCS was limited by time-per-sample but could be operated for extended hours and was dedicated to the BGD project. Off-site contract laboratories operate under “normal” working hours, have many other clients to consider, and may not be able to increase their output to meet the BGRR project demands. Delays in response time would be anticipated following times of increased sample collection. Near the end of the characterization effort a large sample backlog occurred. The site preparation was followed by the sample collection, which was rapid and large (many surface soil samples). An outside laboratory might not have been capable of rapid turn-around for so many samples or more likely would have charged premium rates to get the required turn-around. ISOCS was able to handle the last-minute sample analysis demands without a delay in getting the data into the EE/CA.

The conventional baseline method requires shipping samples to an off-site laboratory (with a one to four week turn-around) at a total cost of about \$252/sample (based on current contract values). Based on data evaluated for the previous ISOCS deployment at BGRR, ISOCS analysis cost for *ex-situ*, field laboratory analyses is about \$76 per sample. As mentioned, ISOCS analyzed ~1700 samples. By agreement with the regulators, BNL sent a percentage of the samples off-site for confirmatory analysis. This was done to assure the regulators that data from ISOCS was equivalent to conventional gamma spec data. The SAP called for confirmation, by an outside laboratory, of 30% of the samples that fell within 0.5 to 1.5 times the cleanup goal.

Of the 1700 samples, 1400 were soil samples and 300 were structural samples. None of the 300 structural samples were sent off-site for confirmatory testing. Of the 1400 soil samples, only 16 fell within the 0.5 to 1.5 range requiring 5 to be sent off-site for confirmation at a cost of \$1260. The cost of using the ISOCS for 1700 samples was \$129K. Total cost of analysis of the 1700 samples was therefore \$130.3K (129K + 1.3K). The cost for off-site analysis of 1700 samples without the ISOCS would have been \$428K. Total cost savings attributable to ISOCS are \$297.7K (excluding capital investment). Cost savings over the five-year life are calculated to be \$842K with a ROI of 96% (2).

BetaScint™

This is also the second deployment for BetaScint™ at the BGRR. BetaScint™ was used to survey soil samples for Sr-90. The performance comparability of the BetaScint Industries Strontium-90 Spectrometer to baseline technologies was discussed in the final report for the first ASTD deployment (9) and will not be discussed here. As with ISOCS, BetaScint™ compared very favorably to conventional Sr-90 analysis. In all, 725 samples were analyzed using the BetaScint™ system. The data from BetaScint™ was fed into the EVS-PRO software to provide a profile of the Sr-90 contamination around the BGD.

Quantification of Sr-90 using conventional EPA laboratory methods typically takes a minimum of two weeks (accelerated turn-around/costly) to a month (standard turn-around). For BetaScint™ sample preparation was more complicated than ISOCS, as it requires more steps. All soil transfer/handling had to be done in a contamination area with the related health and safety precautions (e.g., protective clothing, frisking out, etc.). After sample preparation, the BetaScint™ system produces accurate and precise results with a quick turn-around time (approximately 5-10 minutes) and detection sensitivity of approximately 1 pCi/gram. Depending on the soil characteristics (e.g., moisture content) the sample preparation step could become the rate-limiting step (for an operator working alone).

Cost Evaluation

The cost of conventional baseline Sr-90 analysis (including transportation) is approximately \$200/sample and usually requires 2 to 4 weeks. BetaScint™ analyses cost about \$50/sample so the cost of 725 samples was \$36K. The SAP called for confirmation, by an outside laboratory, of 30% of the samples that fell within 0.5 to 1.5 times the cleanup goal. Of the 725 samples, 7 fell within this range requiring 2 to be sent off-site for confirmatory analysis at a cost of $500. The total cost to analyze the 725 samples was $36.5 ($36K + $0.5K). If all 725 samples had been sent for off-site analysis the cost would have been $145K. Therefore the total cost savings due to the use of BetaScint™ were $108.5 (excluding capital investment). Cost savings (with a five year lifetime) are calculated to be $471K with a ROI of 80% (2).

Three-Dimensional Visualization Software

The EVS-PRO software allows a clearer and more intuitive presentation of characterization data to stakeholders. All too often stakeholders are inundated with tables of numbers, statistics, and charts and expected to accept conclusions about data at face value. Public meetings give site owners a short time frame to convince stakeholders that the proposed cleanup is adequate and that characterization data supports the proposal. If the data and trends cannot be made clear and understandable to the layperson then the data may prove useless. Data presented in a clear, concise, and intuitive manner allows the stakeholder to be quickly educated about the remediation and allowed to make informed decisions regarding the remediation.

Performance

The EVS-PRO software was used to analyze and provide 3D visualizations of the data from the PFT leak study and the radiological contamination data obtained from the soil samples (surface and deep). In the PFT study approximately 1200 samples were collected over 2 weeks. The EVS-PRO software proved very easy to use and made interpretation of the data clear and simple. It is easy to see where leaks are located on the ducts (Figures 3 and 4). The visualization also highlights the spatial correlation among the data and makes it clear that some locations show tracers in elevated concentration but that those tracers are "drifting" over via diffusion. The color contours are easy to correlate to a leak. It would be extremely difficult to determine the high, medium, and low tracer concentrations and then to match them up to locations along the ducts with 131 data points for each day of the PFT test. To the layperson, if it is not obvious what the data states, it is difficult to defend remedial action decisions.

EVS-PRO also simplifies data interpretation even further by creating 3D movies and virtual 3D images that may be viewed on a monitor. This allows all sides of the duct to be viewed by the user. A seamless transition from one area to another is possible. A movie was prepared of the BGD that begins with the north side of the BGD and slowly rotats the ducts to show the south side and top views. This gives the audience the feel of "walking" around the ducts and looking at the leaks.

The EVS-PRO output from the tracer study, including the movie, was presented at a stakeholders meeting to discuss the characterization efforts at the BGRR and was very well received. The public acceptance of the accuracy of knowledge of leak pathways from the ducts appeared high. The data was also presented to regulators as part of the SAP approval process. The regulators expressed a high degree of satisfaction with the data presentation and the SAP was approved.

EVS-PRO outputs were generated for the soil contamination profile surrounding the BGD. These visualizations will be incorporated into the upcoming EE/CA.

Cost Evaluation

The cost evaluation for the EVS-PRO software cannot be properly quantified. EVS-PRO software is an enabling technology that improves communication among data analysts, program managers, regulators, and other stakeholders. EVS-PRO's power is in its ability to transform large quantities of data into an effective three-dimensional, spatial presentation that can be clearly understood by all stakeholders. This presentation of the characterization data is more effective and makes it easier for all parties to understand the nature and extent of the problem and come to agreement on the next phase of the remediation project.

CONCLUSIONS

A suite of innovative technologies was deployed to characterize the radionuclide levels (Cs, Sr, Co, and Am) in soils around and beneath the BGRR. All of the technologies performed as well or better than expected. The characterization could not have been completed in the same time or at the same costs without the use of these technologies. The major advantages of this approach include:

- The use of PFTs to define potential radionuclide release pathways from the BGD resulted in lower soil sample density and provided greater confidence that leaks were not missed in comparison with the baseline approach.
- The use of the track-mounted Geoprobe® permitted samples to be collected where other techniques would be inadequate (between electrical duct and the BGD), led to reduced sampling costs, and provided the flexibility to sample as needed when contamination was detected.
- The ISOCS and BetaScint™ detection systems led to sharply reduced sampling costs compared with conventional baseline analyses and provided rapid turn-around, which was used to define new sample locations required to bound the extent of contamination.
- The use of EVS-PRO to visualize and interpret the data provided an effective method to communicate results with various stakeholder groups.

Potential cost savings associated with deployment of these technologies are summarized in Tables 4 and 5. Reported cost savings are based on the quantity of conventional baseline characterization samples that would have been required without the innovative technologies deployed under this ASTD project. When considered together, this suite of innovative technologies is estimated to have saved more than $1.2M in the first year alone. When using the DOE Life Cycle Cost methodology, the cost savings grow to $2.1M. The estimated cost savings associated with leaving the BGD in place ($7.1 to 8.1M) boosts potential cost savings to between $9.2 and $10.2M.

Table IV. One-Year Estimated Cost Savings Associated With Deployment of the ASTD Alternative Characterization Technologies

Technology	One-Year Cost Savings[a]
Perfluorocarbon Tracer Leak Detection	$849,000
Geoprobe® LT-54	N.C.
ISOCS Gamma Spectroscopy	$297,000
BetaScint™ Sr-90 detection	$108,500
EVS-PRO Visualization Software	N.A.
Total Savings due to ASTD Technologies	**$1,254,500**

a) N.C. = not computed; N.A. = not applicable

Table V. Life Cycle Cost Savings Associated With Deployment of the ASTD Alternative Characterization Technologies

Technology	Life- Cycle Cost Savings[a]
Perfluorocarbon Tracer Leak Detection	$849,000
Geoprobe® LT-54	N.C.
ISOCS Gamma Spectroscopy	$842,000
BetaScint™ Sr-90 detection	$471,000
EVS-PRO Visualization Software	N.A.
Total Savings due to ASTD Technologies	**$2,162,000**

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