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Formal Report

# Smart 3D Subsurface Contaminant Characterization at the BGRR Decommissioning Project

## Accelerated Site Technology Deployment

## Cost and Performance Report

## December 2001

John Heiser, Paul Kalb, Terrence Sullivan,
and Lawrence Milian

**Environmental Sciences Department**

**Brookhaven National Laboratory**
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**Under Contract No. DE-AC02-98CH10886 with the**

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**DISCLAIMER**

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# EXECUTIVE SUMMARY

The Brookhaven Graphite Research Reactor (BGRR), which operated from 1951 – 1968 is currently undergoing decontamination and decommissioning (D&D). As part of this effort, many of the major structures and facilities (e.g., Above Grade Ducts, Cooling Fans, Pile Fan Sump, Transfer Canal and Instruments Houses) are being removed to eliminate contaminants and reduce the footprint of the overall facility. However, a significant cost savings (almost $5M) can potentially be realized if the large concrete Below Grade Ducts (BGD) can be decontaminated and left in place. In order to do this, soils beneath the ducts must be fully characterized to identify areas where contaminants may have leaked, what radioactive and hazardous contaminants remain, and in what concentrations. This information will then be used to evaluate whether discrete areas of localized contaminated soil can be selectively removed or, if the contamination is significant and widespread, and whether the ducts themselves must be removed for complete cleanup. The information generated from this effort is input into the BGRR BGD Characterization Report and an Engineering Evaluation/Cost Analysis (EE/CA) currently being prepared to evaluate potential options for the ducts.

This FY 01 Department of Energy Accelerated Site Technology Deployment (DOE ASTD) project combined a suite of innovative technologies to provide cost-effective characterization of the soils beneath the BGD and present the data in an easily understandable three-dimensional representation of the contaminant concentrations beneath the ducts. Conventional characterization of the soil would have required sampling a very large area in a tight grid pattern to ensure that all areas of potential contamination were evaluated. It is estimated that using baseline techniques would require approximately 2500 samples (costing ~$1.6M), depending on the level of precision required by regulators. This massive amount of data would then be difficult to manipulate and interpret in order to evaluate the extent of excavation required.

The alternative approach deployed for this ASTD began with a novel perfluorocarbon tracer (PFT) gas study to determine the potential leak pathways for contaminated water exiting the BGD. The results of the PFT test successfully identified areas where contaminated soil may be located. The Sampling and Analysis Plan (SAP) was then designed to focus on these areas, while taking fewer samples for confirmatory analyses in areas thought to be clean.

A small footprint Geoprobe® was used to install PFT sample ports, and later, take sample cores in identified locations. The soil cores were then evaluated for radiological contamination using two, state-of-the-art, field laboratory instruments previously deployed and proven in a related FY 00 ASTD effort. The Canberra *In Situ* Object Counting System (ISOCS) was used to evaluate for gamma-emitting radionuclides (e.g., Cs-137, Co-60, Am-241) in soil, concrete, steel, and debris samples from the BGD and surrounding soils. The BetaScint™ Fiber Optic Detector was used to analyze soil samples for beta-emitting radionuclides (e.g., Sr-90). These data were then input into the C Tech Environmental Visualization System (EVS-PRO), which combines data interpolation, geologic modeling, geostatistical analysis, and 3D visualization tools into a software system developed specifically for environmental contamination issues.

Using 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 were 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 localized decontamination and leaving the BGD in place), even greater overall savings may be realized. For instance, in the recently issued draft EE/CA[1] Removal Action 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 above the surface remediation goals from around the #4 expansion joint and north bustle (Alternative 3). This would result in additional cost savings of $7.1M to $8.1M.

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# INTRODUCTION AND BACKGROUND

## Brookhaven Graphite Research Reactor (BGRR)

The 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 Department of Energy's Savannah River Site (SRS). Access to the canal for removing spent fuel was through the Canal House (Building 709).

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.

This Accelerated Site Technology Deployment (ASTD) project was funded through the DOE Office of Science and Technology (DOE OST) D&D Focus Area (DDFA). A suite of innovative technologies were deployed to provide better, faster, and cheaper characterization of the soils beneath the large, Below Grade Ducts (BGD) that connected the reactor exhaust plenums with the Above Grade Ducts, Fan House, and Exhaust Stack. The BGRR Historical Site Assessment[2] identified contamination inside the 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. 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. Most of the contamination is confined to the primary ducts, but corrosion of the primary ducts has lead to contamination of the secondary ducts. Leakage of water from the ducts is likely to have resulted in contamination of the surrounding soil.

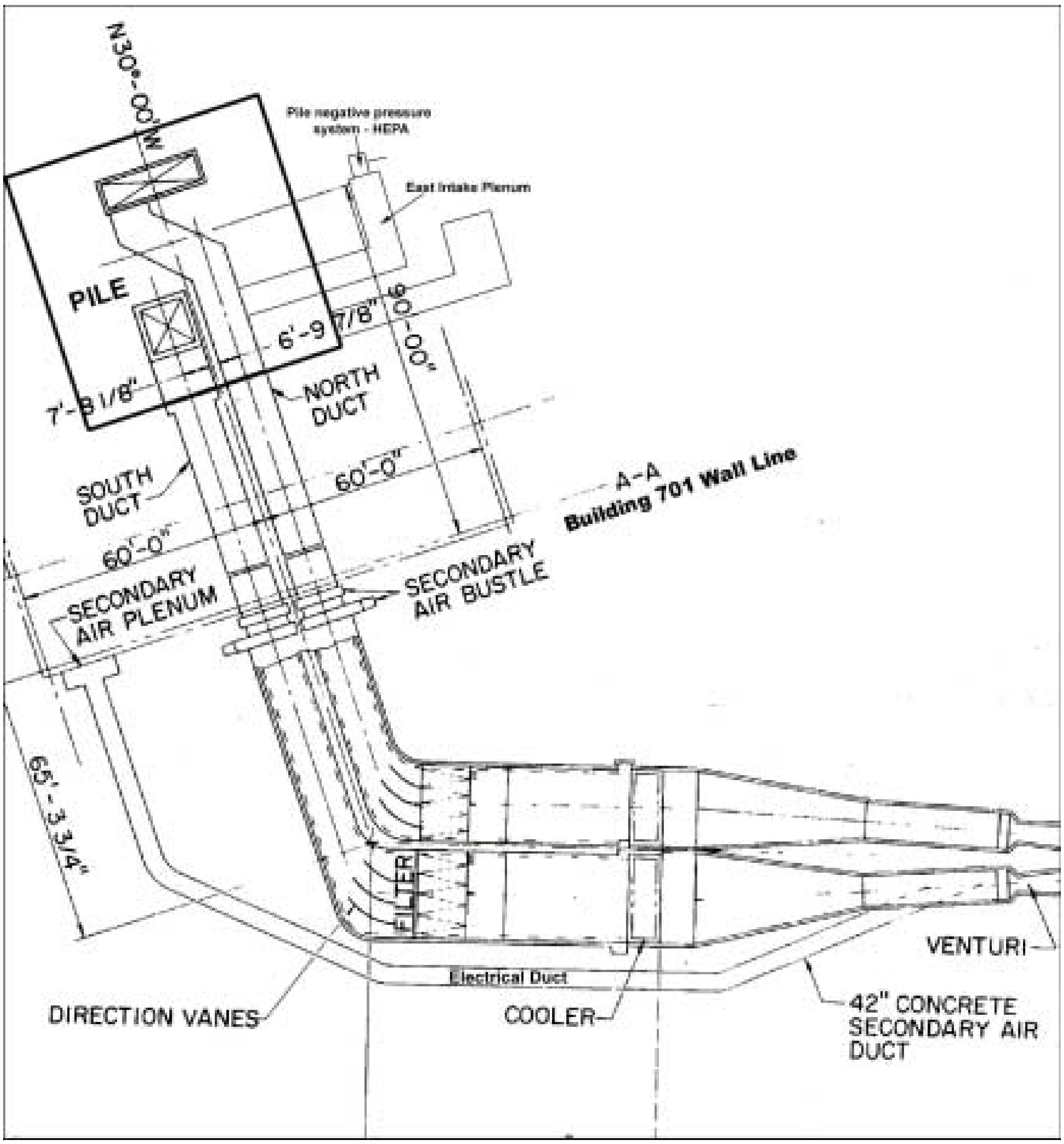


**Figure 1. Schematic plan view of the Brookhaven Graphite Research Reactor underground ducts**

The main air duct has two expansion joints and several 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. The BGRR D&D Draft EE/CA estimates the cost for removing BGD to be approximately $7 to 8M. 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, the total duration of the project will be reduced which will result in administrative cost savings ($850K per year) and reduced waste volumes for off-site disposal as low-level waste. The focus of this ASTD project was to determine the extent (location, type and level) of contamination surrounding the BGD and to present this data to the stakeholders as part of the EE/CA process.

**Strategy To Define Contamination**

Five remediation options are under consideration in the EE/CA evaluation for the BGD. These include: 1) No action, 2) Removal of just the Instrument House and associated ductwork, 3) Targeted contaminated surrounding soil hot-spot remediation, 4) Hot spot remediation with limited removal of ductwork, and 5) Removal of ductwork and surrounding soils to established cleanup levels. Option 5 involves removal of the primary ducts followed by excavation and removal of the concrete ducts and secondary plenum followed lastly, by surveying the underlying and surrounding soils and removing soil that was contaminated above cleanup goals. Options 2, 3 and 4 include removal of the primary duct, decontamination of the secondary plenum, and leaving all or part of the BGD structure in place, and filling it with sand or some other backfill material. 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 was estimated that the options 2 and 3 would save $7.1 to 8.1M compared to option 5.

While contamination is known to have leaked from the ducts, without detailed soil analyses, we lack sufficient information (e.g., extent of the leak, how far it may have spread, nuclide migration rates) to make 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 the best alternative, we must know what contaminants and concentration levels are present, and where they are located. 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.

For this ASTD project, a suite of innovative characterization tools were 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
- 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™)
- a three-dimensional (3D) visualization system to facilitate data analysis/interpretation for the stakeholders.

A state-of-the-art gaseous perfluorocarbon tracer (PFTs) technology developed at BNL was utilized to characterize leak pathways from the ducts. This, in turn, allowed determination of what soil regions under or adjacent to the ductwork were to be emphasized in the characterization process. Knowledge of where gaseous tracers leaked from the ducts yielded a conservative picture of where water may have moved into or out of the BGD. Equally as important, it showed which areas of the duct were not leaking and only a limited number of confirmatory soil explorations were required in these areas.

Contamination of soils was expected to coincide with the leak pathways out of the duct. The likely areas were believed to be the expansion joints, as determined from inspection of the duct blueprints and from internal video surveillance of the ductwork. 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 highest in these areas. While the baseline soil characterization efforts emphasize the expansion joints, the PFT leak detection system was used to confirm these expectations, give a relative sizing of the leaks, and to determine if unexpected leakage might have occurred at areas other than the expansion joints. This system uses gaseous PFTs and has been successfully deployed for other environmental applications (e.g., integrity verification in subsurface barriers) [3,4].

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 determined 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. Only confirmatory sampling was conducted in these areas, saving considerable funds and time.

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 (described later). 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 off-site laboratory for analysis as a benchmark for the field-deployable units. The data was input into the Environmental Visualization System for comparison to the PFT data and 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.

## ASTD TECHNOLOGY DESCRIPTIONS

### Perfluorocarbon Tracer Technology

Brookhaven National Laboratory (BNL) has developed a gaseous tracer technology that uses perfluorocarbon tracers (PFT) for a broad range of environmental applications. 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 ingress pathways in residential basements [5,6]. 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, 3,7]. 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 current environmental applications.

A tracer is any substance that can be easily or clearly monitored (traced) in the study media. Tracer technologies can be used for transport/dispersion studies, leak detection studies, and material location. Leak detection studies use tracers to locate and estimate leak rates in various scenarios. They can be as simple as colored dyes used to visually locate cracks and holes in tanks or as complex as mass spectroscopy detection of helium to find leaks in vacuum systems. In transport and dispersion studies, tracers are used to tag a medium to determine how it is being dispersed in a surrounding matrix.

PFT technology consists of the tracers themselves, injection techniques, samplers, and analyzers. PFTs have the following advantages over conventional tracers:

- There are negligible background concentrations of PFTs in the environment. Consequently, only small quantities are needed.
- PFTs are nontoxic, nonreactive, nonflammable, environmentally safe (contains no chlorine), and commercially available.
- PFT technology is the most sensitive of all nonradioactive tracer technologies and concentrations in the range of 10 parts per quadrillion of air (ppq) can be routinely measured.
- PFT technology is a multi-tracer technology allowing up to six PFTs to be simultaneously deployed, sampled, and analyzed with the same instrumentation. This

results in a lower cost and flexibility in experimental design and data interpretation. All six PFTs can be analyzed in 15 minutes on a laboratory-based gas chromatograph.

Because PFTs can be detected at extremely low levels, very small leaks are easily identified. 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 (see Figure 2). 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. The injection and monitoring of the tracers were accomplished using conventional low-cost monitoring methods, such as multilevel sampling ports placed using cone penetrometer (Geoprobe®) techniques.

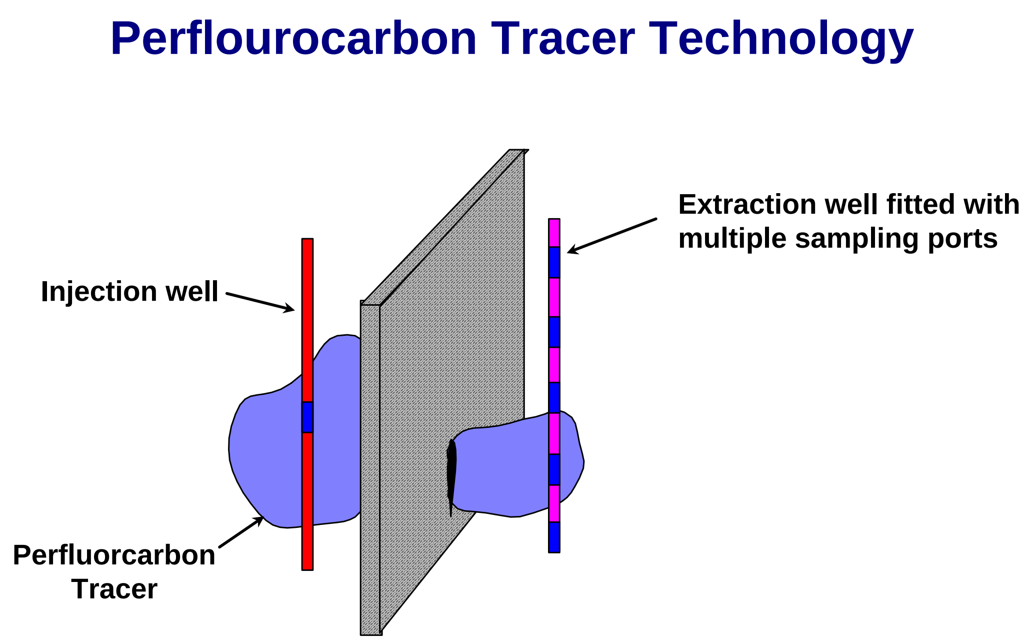


**Figure 2. Schematic of leak detection using Perfluorocarbon Tracer technology**

In the field, the PFTs can be collected in air sampling bags and/or on capillary adsorbent tracer samplers (CAT), which is a small, cigarette-sized glass tube containing a carbonaceous adsorbent specific for the PFTs. A CAT can be used dynamically (flowing a sample through the CAT), or passively (opening only one end to allow the CAT to sample by diffusion). The passive mode allows a time-integrated PFT concentration to be measured in a simple manner. The CATs are shipped back to the laboratory for PFT analysis.

With gas sample bags, the sample is collected in the field using a compatible pump. The bag is sent to the analytical laboratory where a small sample is withdrawn from the bag using a syringe and injected onto a CAT. The CAT is then placed on an automated gas chromatograph for analysis. Additionally, several real-time PFT analyzers are available for field use, one of which can detect four different PFTs down to the ambient background of the PFTs in air (in a five-minute sample). In this case, the sample that has been withdrawn from the sample bag is injected directly into the detector using the syringe.

The PFTs were introduced into the interior volumes of the BGD through the secondary air system outer cooling channels. The primary ducts carried air used for cooling from the reactor. The secondary cooling ducts circulated cooler air around the primary ducts. This kept the concrete outer portion of the ducts cool to avoid dehydration damage. Since any leakage from the BGD would have to travel through the secondary cooling ducts, it is this portion of the ducts that must be evaluated to determine whether contamination might have escaped from the primary ducts.

Access to the channels was from the air bustle and below grade vault. Inlet and outlet flexible ducting was installed to provide separate circulation loops for the north and south outer ducts to allow different tracers to be circulated in each duct. The tracer gas cylinders were connected to the circuits to allow injection of the PFTs. With the North and South Ducts isolated from each other, a different tracer was used in each cooling duct, which yielded data that was specific for each duct and helped to more accurately define leak pathways. The tracers employed are listed in Table 1.

**Table 1. 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 PFTs were distributed via a closed loop circulation system (Figure 3), which allowed for recirculation of the tracer. The rate of gas injection was determined based on the volume of the cooling channel, the source concentration of the tracer (ranged from 100 to 1000 ppm), expected diffusion rates and engineering assumptions about the cross-talk between the primary duct and reactor pile volumes with the secondary cooling ducts. Tracer injection rates ranged from 0.2 ml/min to 22 ml/min.

The injection continued for seven to ten days and the concentration of tracer was monitored at regular sampling intervals. The target goal for the interior concentration was determined through modeling based on the flow rates, injection concentration and volume, and plenum volumes. The cooling channel PFT concentration was monitored at least daily during the duration of the injection and generally ranged from 10 to 100 ppb.


**Figure 3. Pump house and flexible tubing for the North Duct circulation loop**

The injected PFTs were monitored outside of the ducts through a series of gas sample ports (installed via the Geoprobe®) in close proximity to the ducts. Installation of PFT monitoring ports using the Geoprobe® is shown in Figure 4. As shown in Figure 5, the ports themselves were of simple design: a sintered glass filter, to prevent plugging, was attached to a length of 1/8-in polypropylene tubing. Several ports were bundled together each having a different length of tubing. The bundle of ports was then lowered into the borehole until the first port reached the desired depth. Once the sampling bundle was in place, the hole was backfilled with a blended-sand mix. The sand was used to prevent vertical cross-talk from port to port and to prevent advective currents in the borehole. Backfilling was completed by slowly pouring sand down the 2¼inch hole. The sand blocked advective flow within the borehole and firmly held all the ports in place and kept them at the desired depths. The concentrations on the outside were then related to the integrity of the ducts. Figure 6 shows the monitoring well locations. 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).

**Figure 4. Geoprobe® Model 54 LT continuous push soil-probing unit used to install monitoring ports in soil adjacent to the BGRR Below Grade Ducts**

**Figure 5. Bundle of sample ports showing the sintered glass filters attached to polypropylene tubing**

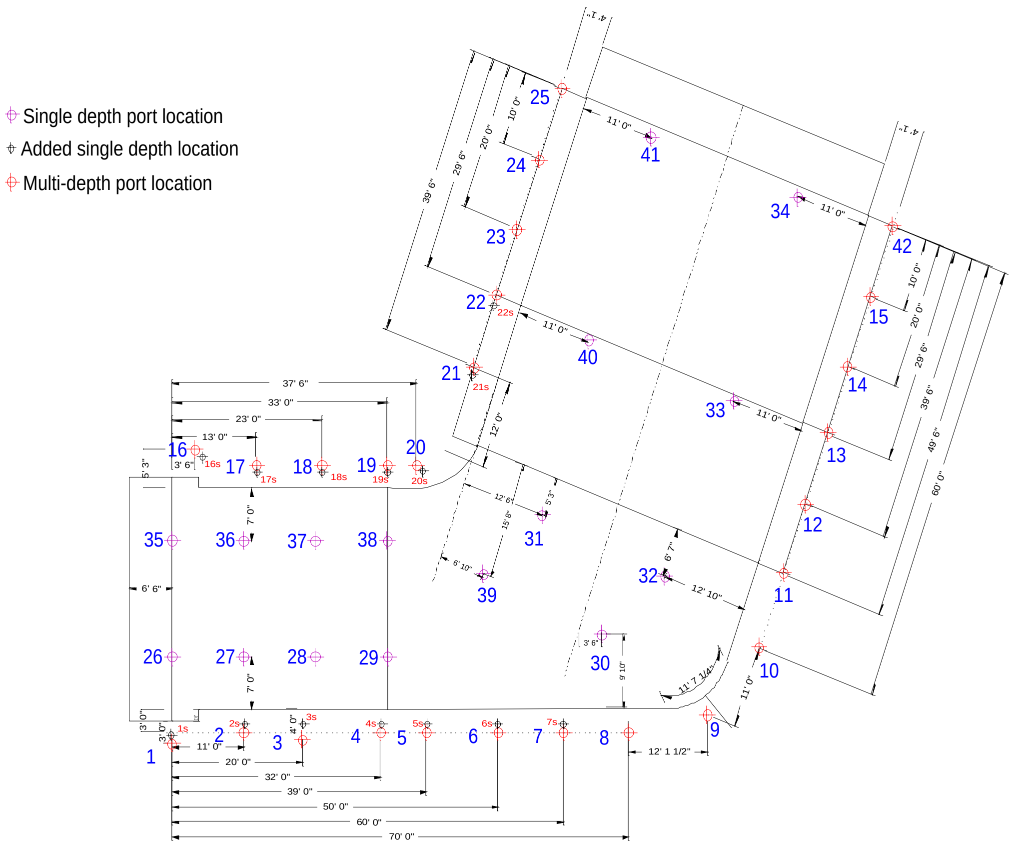


**Figure 6. Schematic of external sampling port locations**

Two injections of tracers were performed. The first, termed the preliminary injection, was designed to confirm experimental parameters, e.g., the degree of leakage from the BGD, the amount of leakage between the primary and secondary liners within the duct system, and ultimately, the appropriate tracer gas flow rates. This test also provided information on sizing and sample frequency requirements for the second injection. The second injection of tracers comprised the actual leak test, designed to determine the location and magnitude of leak pathways from the BGD.

Each test was started with the introduction of tracers into the north and South Ducts. Sampling of all external and internal ports was continued until a consistent picture of the leak pathways from the ducts emerged. Once the injection of tracers was turned off, samples were again taken to follow the decay in tracer gas concentration levels.

The BGRR below grade ducts were constructed with five major expansion joints. Figure 7, South Duct, and Figure 8, North Duct, are side views of the ducts and the location of the expansion joints in these ducts. In each case, an expansion joint exists in the bustle area labeled on the figures. It was expected that the expansion joints would be susceptible to gas leakage. Water accumulated in the ducts in the years since the BGRR was shut down and corrosion was seen during video surveillance. These figures also include the approximate location of the high water marks found inside the ducts. At the lowest elevation, near Building 701, the watermark was approximately 66 inches above the bottom of the primary duct. Therefore, gas leak pathways below the high water level required increased attention, as they may be most indicative of water leak pathways.

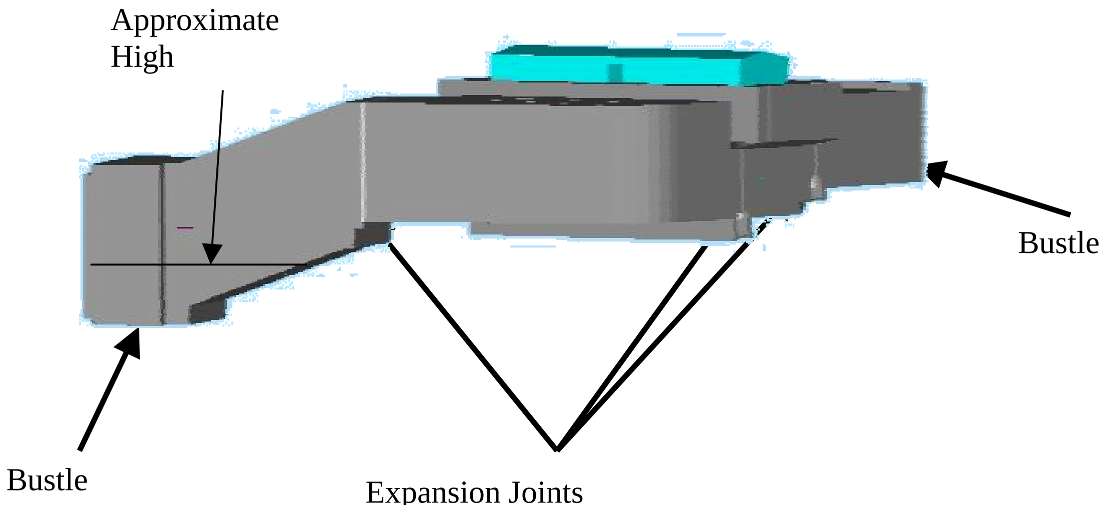


**Figure 7. South Duct features**

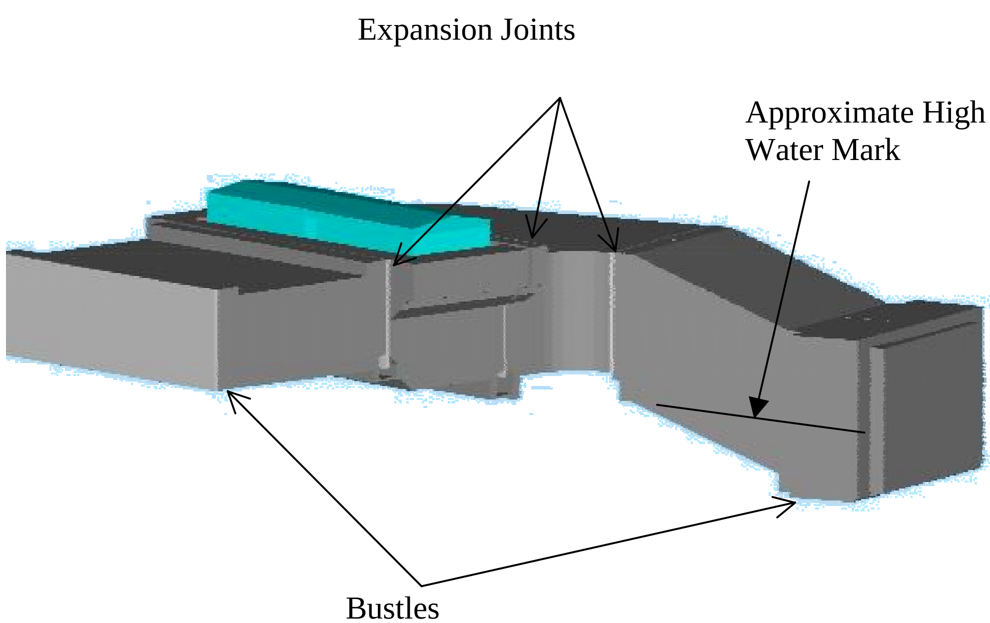


**Figure 8. North Duct features**

The data interpretation was conducted using C Tech's Environmental Visualization System (EVS-PRO), which is discussed later. EVS-PRO unites interpolation, geologic modeling, geostatistical analysis, and fully 3D visualization tools into a software system developed specifically for environmental contamination issues. One of EVS-PRO's strengths is its integrated geostatistical analysis, which provides quantitative assessment of the quality of site characterization.

Figure 9 presents representative data for the tracer PMCH at the South Duct on February 9, 2001. This profile is a fully developed profile as it represents the concentrations three days after the end of the injection period. Evidence of PMCH 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.

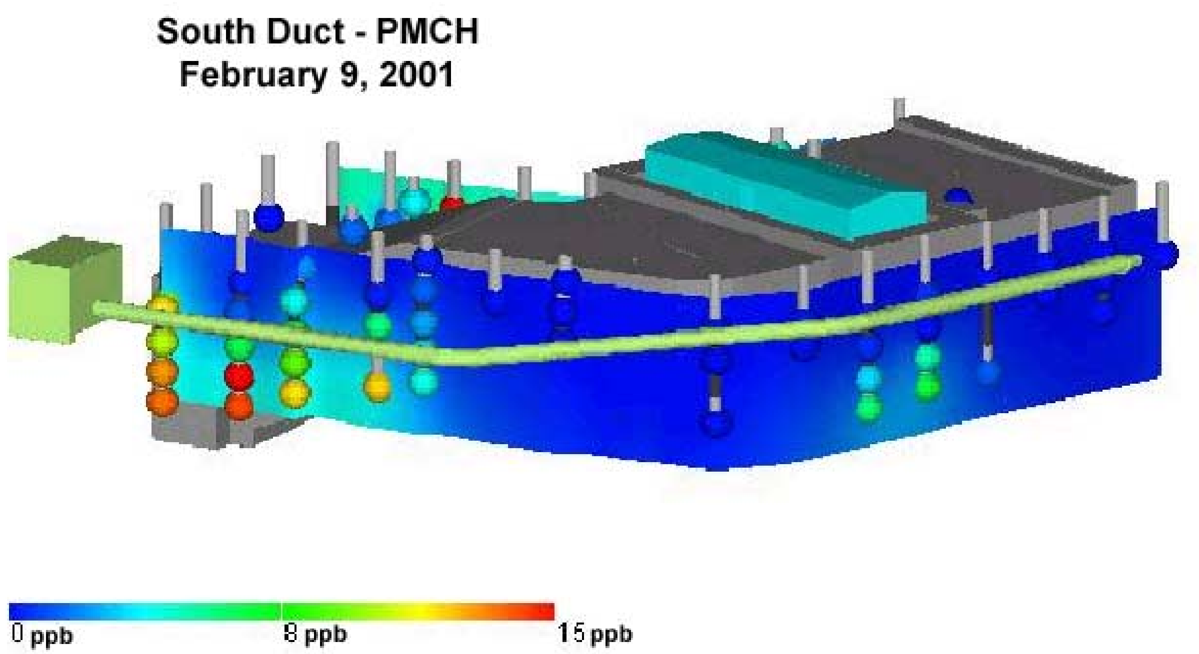


**Figure 9. PMCH concentrations at the external ports of the South Duct – February 9, 2001**

PMCP was injected in the South Duct from February 7$^{th}$ through the 16$^{th}$. Figures 10, 11, and 12 show the buildup and decline of PMCP along the south wall from February 9$^{th}$ through February 22$^{nd}$. The leak profile was remarkably stable during the injection test indicating that the information provided by the test is reliable. In addition, the 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 south plenum to the surrounding soils have been defined. Similar graphical visualizations were generated for all tracers on all sampling dates. Examination of the concentration profiles for all tracers including those injected into the North Duct (PDCB and o-PDCH) all showed the same leak locations.

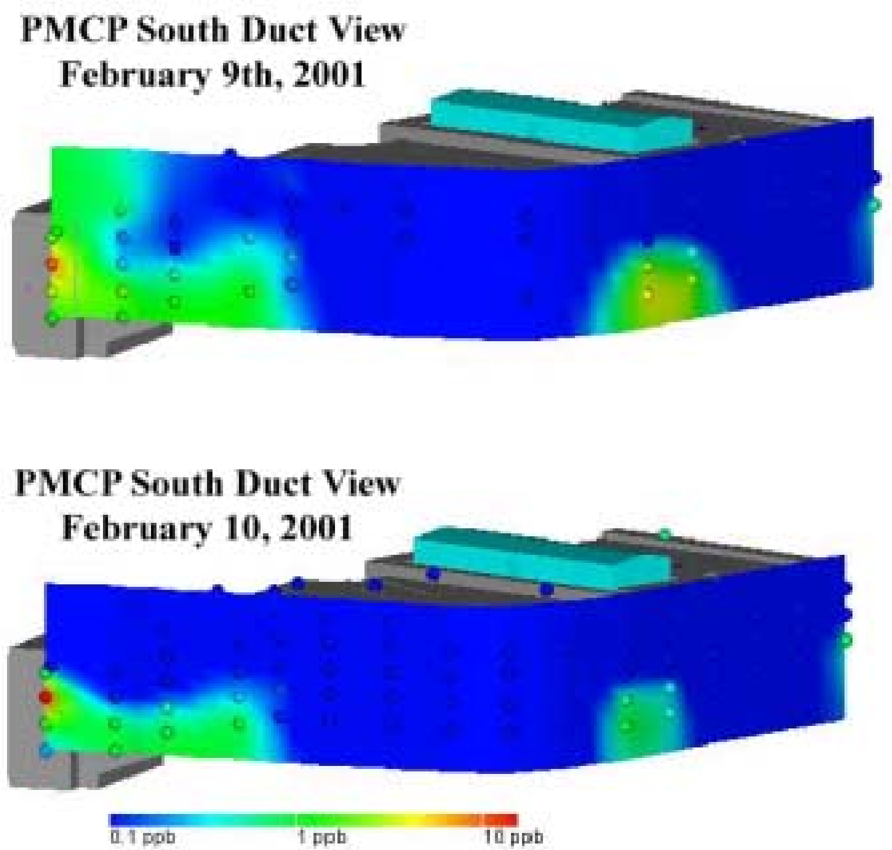


**Figure 10. PMCP concentrations on the 2$^{nd}$ and 3$^{rd}$ day after the leak test injections were started**

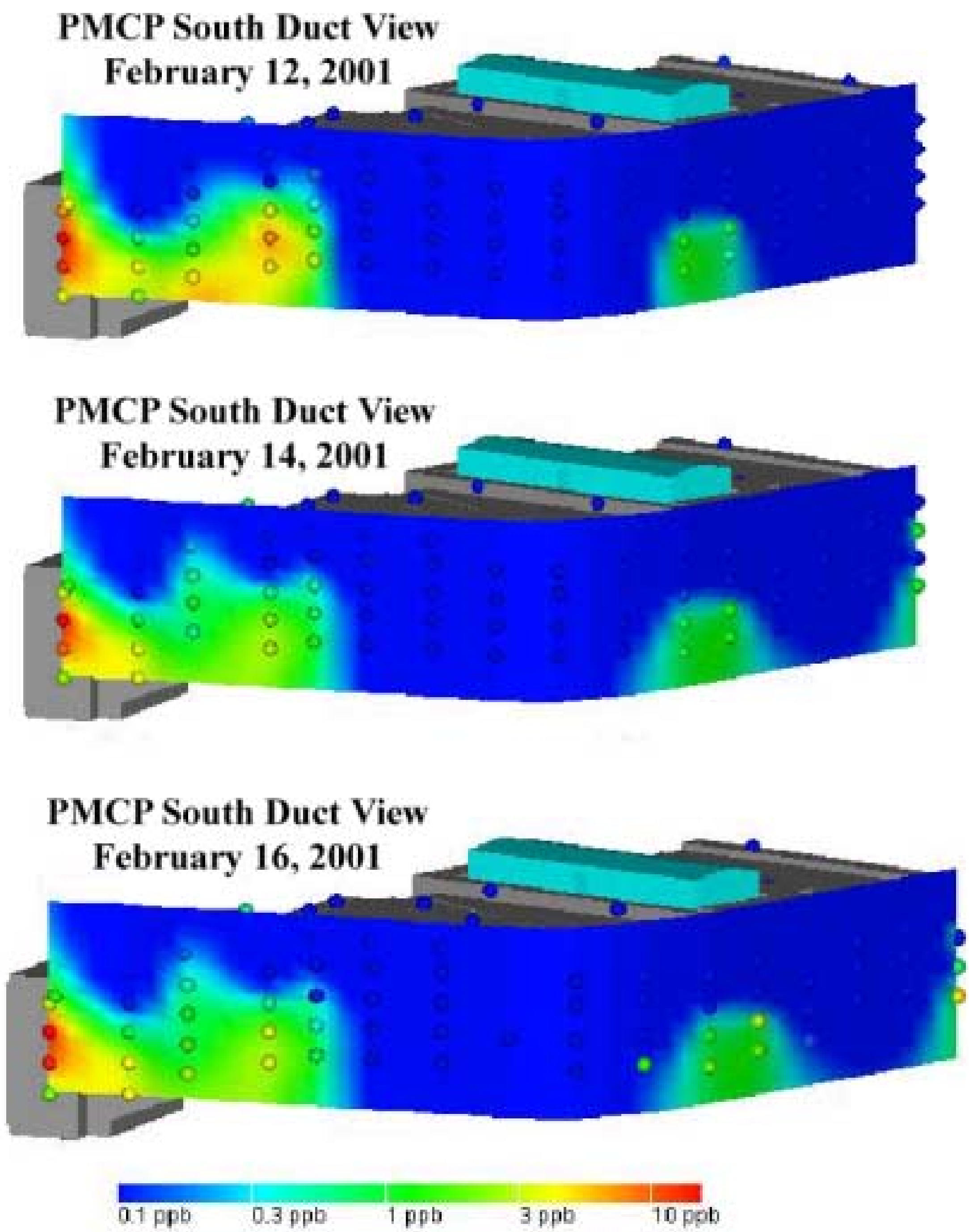


**Figure 11. PMCP concentrations on the 5th, 7th, and 9th day after the leak test injections were started**

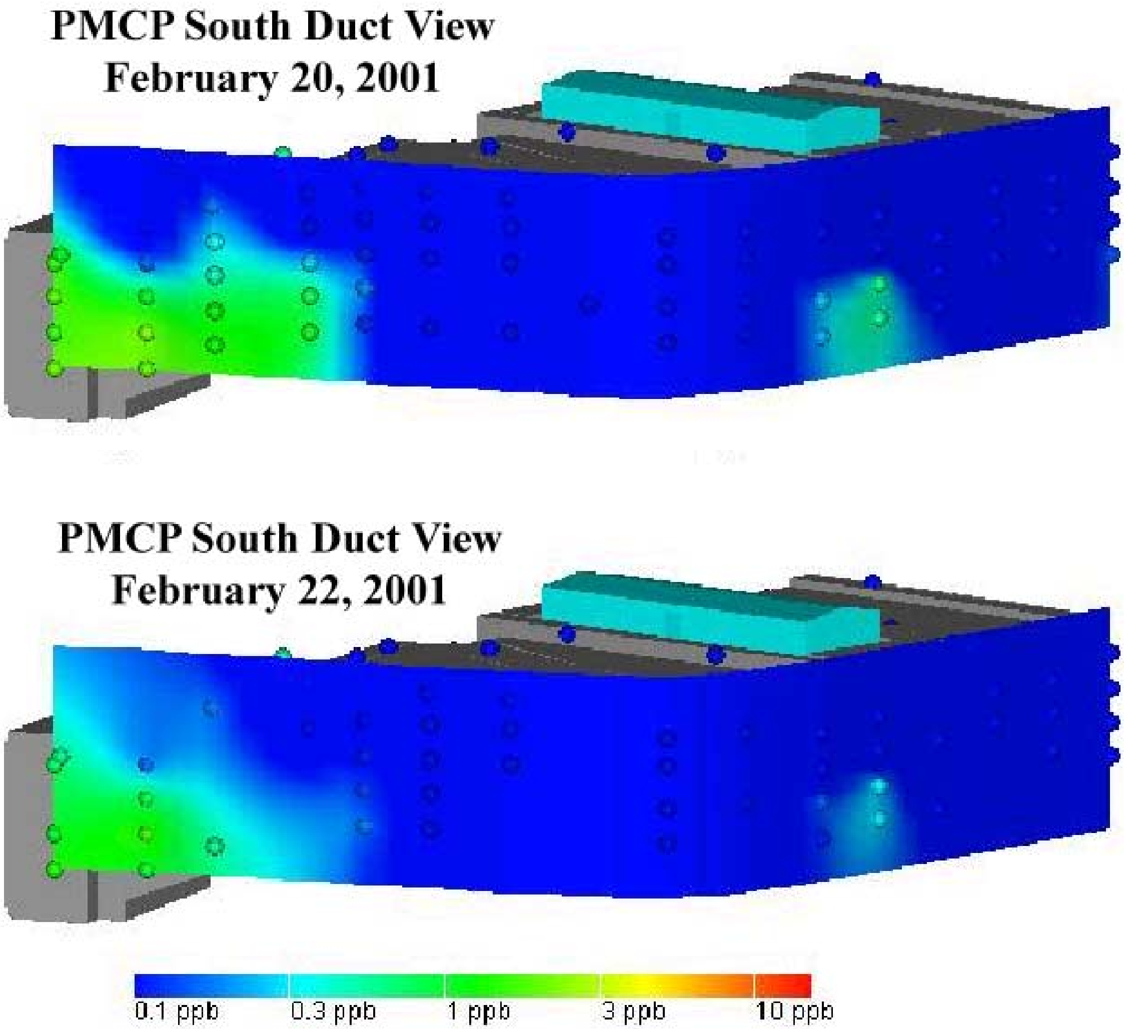


**Figure 12. PMCP concentrations four and six days after the leak test injections were stopped**

Figure 13 presents a representative data set for the tracer PMCP at the North Duct on February 9. There are several indications of leaks at this duct and the concentrations are typically higher than on the South Duct. The peak concentrations again indicate a substantial size flaw in the duct allowing release of the gas. High values (green to red) were detected at the expansion joints on either side of the filter house and some at the bustle (green to cyan, right hand side).

Tracer o-PDCH was injected into the North Duct Secondary Plenum from February 10$^{th}$ through the 16$^{th}$. Figures 14 and 15 present the time evolution of o-PDCH concentration along the North Duct. The leak profile is stable during the injection test providing confidence that the information provided by the test is reliable. In addition, the leak profile of o-PDCH (second test) is similar to that found by PDCB (first test). This provides further confidence that all leak pathways from the north plenum to the surrounding soils have been defined. Similar graphical visualizations were generated for all tracers on all sampling dates.

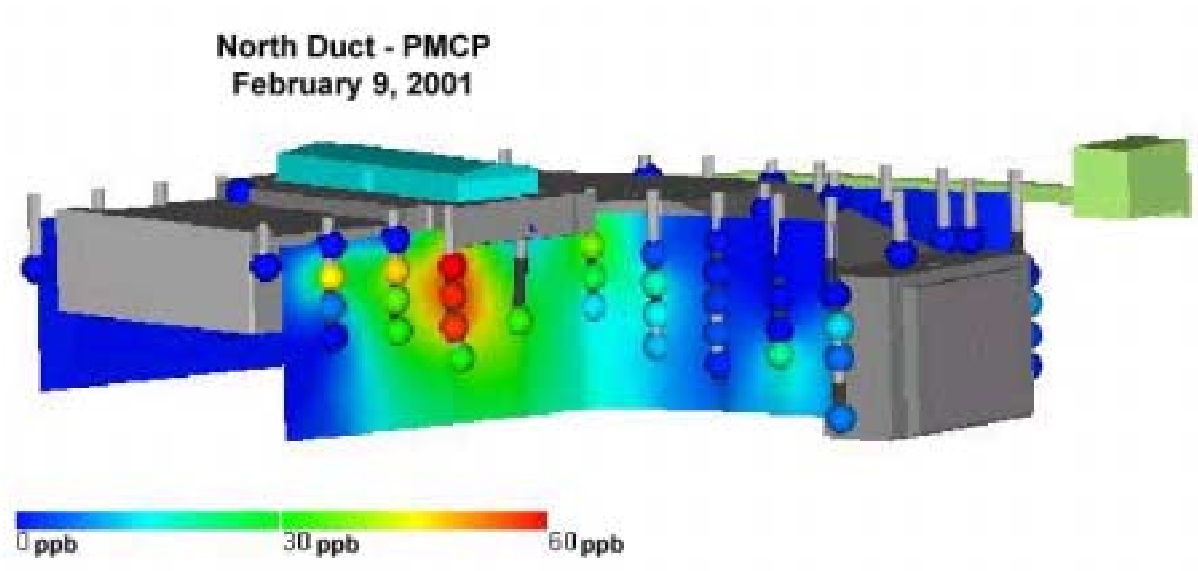


**Figure 13. PMCP concentrations at the external ports of the North Duct – February 9, 2001**

The Major Findings of the tracer analysis are:

South Duct:

- The largest leak was observed in the region of the expansion joint in the bustle near Building 701. This leak was near the high water mark found in this duct.
- The second largest leak was found at the expansion joint approximately 40 feet from building 701.
- Some evidence of leakage was found at four of the five expansion joints; .
- There was strong evidence of a leak along the bottom of the duct in the filter bed region and at the expansion joint near the instrument house.
- Large regions of the South Duct are not leaking gas. Other than the region between the first two expansion joints, there was no evidence of leakage away from the expansion joints.

North Duct:

- The largest leak was observed in the region of the expansion joint in the bustle near Building 701. This leak was below the high water mark found in this duct.
- A similar size leak was found along the expansion joint in the filter bed nearest to the instrument house. This leak appeared to occur fairly uniformly along the length of the expansion joint.
- Considerable leakage was observed on either side of this expansion joint.

- There was strong evidence of a leak along the bottom of the duct approximately 10 feet past the bustle near Building 701 and 10 feet before the expansion joint at the instrument house.
- The North Duct leaked at a much higher rate than the South Duct. Evidence of leakage was detected at most sampling locations.

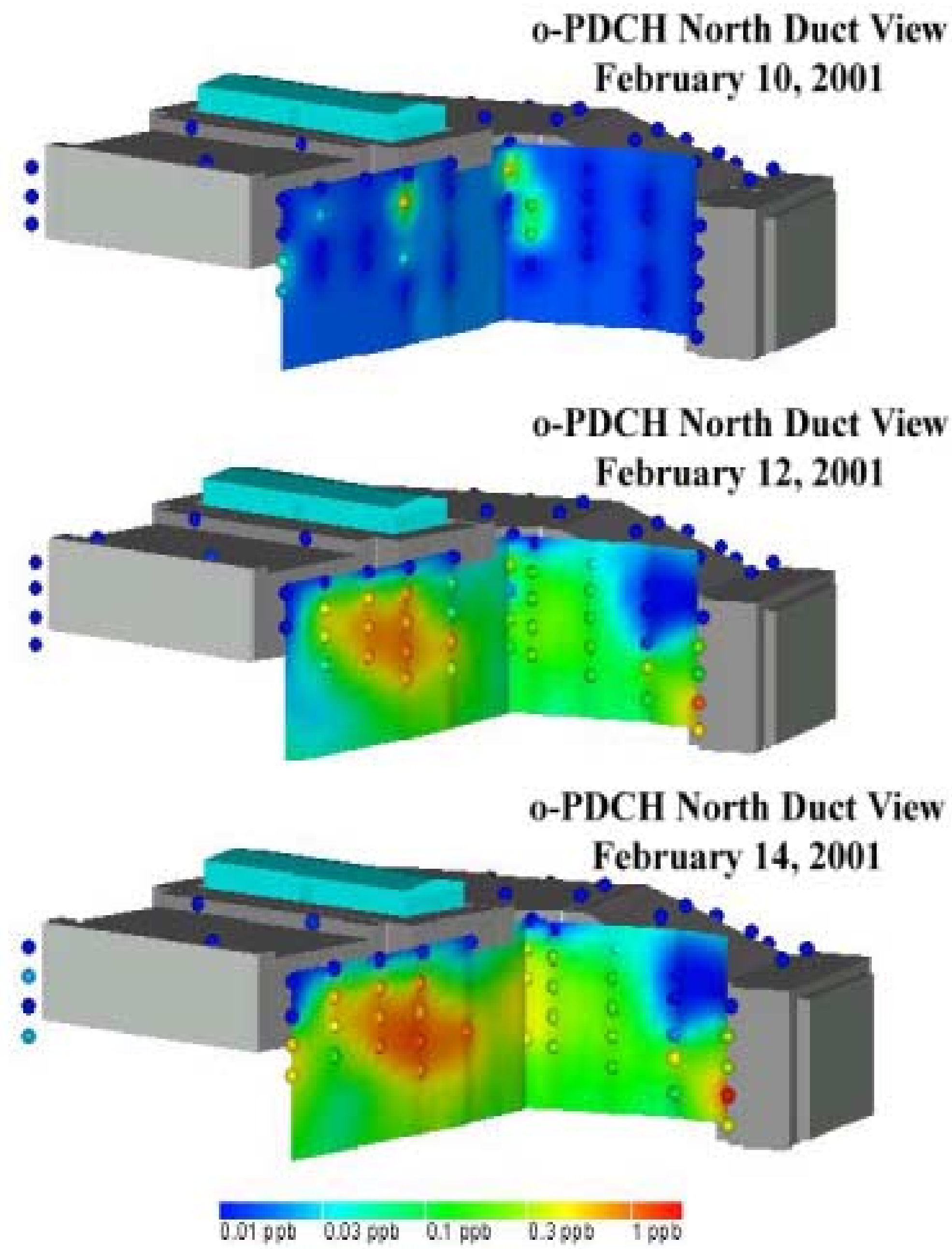


**Figure 14. o-PDCH concentrations on the 1$^{st}$, 3$^{rd}$, and 5$^{th}$ day after the start of injection**

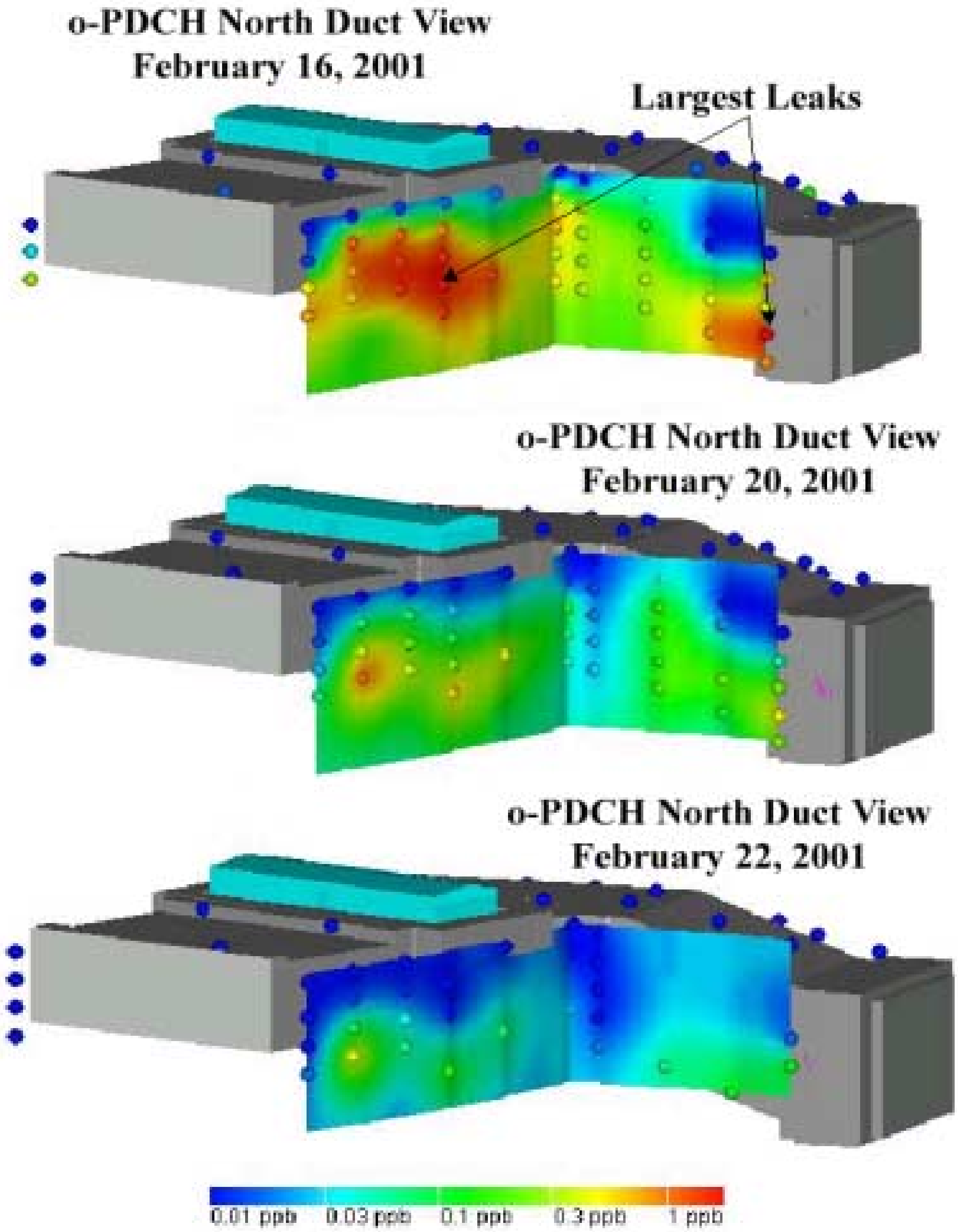


**Figure 15. o-PDCH concentrations at the end of the injection, and four and six days after the injection was stopped**

The information gained in the PFT Tracer Gas Study was used to guide and optimize the soil characterization strategy for the BGD 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].

## Small Footprint Geoprobe®

To install the tracer gas sampling ports and to retrieve soil samples (as cores), BNL chose to use a compact probing machine from Geoprobe®. The Model 54LT is a rugged, hydraulically-driven penetrometer designed for tight spaces and rough terrain. This track-mounted unit is narrow enough to fit through standard 36-in. doors and can get into confined, enclosed places that a vehicle-mounted unit cannot access. It is equipped with rear outriggers for stability and is powered by a 22 Hp, liquid-cooled, industrial diesel engine. The unit is capable of supplying 25,000 pounds of pull and is a continuous push soil-probing unit.

For the tracer gas studies, the Geoprobe® was used to push a 2.125-in O.D. steel rod into the subsurface at each monitoring well location (see Figure 4) and then withdrawn and the resultant hole used for installation of the monitoring ports. Using the single Geoprobe® unit the 121 monitoring ports were installed in approximately one week.

The compact unit was particularly useful 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 (see Figure 16) and avoid damaging it during coring and probing operations. The resultant trench made the use of 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 (see Figure 17).

**Figure 16. The underground electrical duct running along the side of the south cooling duct**

**Figure 17. Geoprobe® installing ports along the South Duct, between the electrical duct and the BGD**

After completion of the tracer gas studies, the Geoprobe® was used for soil coring and retrieval. The unit was able to take samples of adequate size to meet ISOCS, BetaScint™, and laboratory analysis requirements. The system performed very well and was utilized in two other on-site projects where its small size was advantageous. Performance and cost are discussed later.

### *In Situ* Object Counting System (ISOCS)

*In situ* gamma spectroscopy has been shown to be cost-effective in almost all applications where field sampling and laboratory analyses are the baseline technologies. Results can be obtained immediately following field acquisitions, thereby reducing the time delays incurred by physical sampling and laboratory analysis.

ISOCS is a complete *In Situ* Object Counting System developed by Canberra for use in a wide variety of measurement applications. The battery-operated system provides traditional spectra of counts as a function of gamma energy, which is then converted to radionuclide concentration by applying pre-defined geometry templates in the analysis software. The ISOCS software overcomes the limitations of traditional (tedious and expensive) efficiency calibration techniques and allows practical modeling and accurate assay of almost any object in the workplace.

**Figure 18. The ISOCS configured in the field laboratory mode for characterizing BGD soil, concrete, and debris**

The gamma radiation detector utilizes a high-purity germanium crystal for high-resolution and high-efficiency gamma radiation detection. The ISOCS system, configured as a field laboratory at the BGRR is shown in Figure 18. Annular side shields of either 19 mm (0.75 in) or 44 mm (1.75 in.) lead thickness effectively reduce the detection of interfering radiation from items in the vicinity of the detector and from background radiation, resulting in improved system sensitivity.

The ISOCS efficiency calibration software provides the user with the ability to quantify nuclide activity easily and reliably. This software employs a mathematical calibration technique that includes detector-specific characteristics, accounts for collimators and/or shields, and models the physical object to be assayed. It uses a combination of Monte Carlo calculations and discrete ordinate attenuation computations to derive efficiency curves (fraction of gammas emitted from the object that interact in the detector for an energy interval) for each specific *in situ* analysis. Objects are modeled from one of a set of generic sample shapes, such as boxes, cylinders, planes, spheres, pipes, etc. These basic geometry templates have many parameters that can be modified to create an accurate representation of the sample object and detector geometry. Efficiencies can be generated in a few minutes in the field and can be modified easily if needed.

The versatility of the ISOCS system has been demonstrated in numerous situations during initial characterization and decommissioning efforts at the BGRR. Under a previously funded ASTD project, BNL deployed the ISOCS to characterize contamination in place (e.g., contaminated equipment) and as a mobile field laboratory for rapid analyses of volumetric soil samples. Surface soil detection sensitivities of less than 1 pCi/g have been attained with count times as short as 10 minutes for common gamma emitters such as Cs-137. Final results have been reported the same day, following data review and validation. Use of this technology provided significant cost savings, which are discussed in the "ASTD Cost and Performance Report, Comparability of ISOCS Instrument in Radionuclide Characterization at the Brookhaven National Laboratory"[9].

For the current ASTD initiative, soil core samples were evaluated for gamma-emitting radionuclides. Deep (>18") soil samples were collected in two-foot sections below grade to refusal or groundwater using either a Geoprobe® or hand auger. Soil was collected at the most likely locations for contamination based on results of the Tracer Gas Study and duct construction (expansion joints). In addition, samples were taken in expected clean areas to ascertain if the soil is contaminated. These samples were brought to the surface and measured using ISOCS.

ISOCS (and BetaScint™, discussed later) was used to determine the location and extent of the contamination. Previous results from the Pile Fan Sump and the BGRR Canal indicate that there is little horizontal spread of contamination from water leakage from underground structures. When contamination above the preliminary cleanup goals was encountered, additional sampling was conducted in order to determine the extent of contamination in terms of area and depth. Use of near real-time radiological characterization facilitated quick evaluation of whether additional coring was required. This allowed timely use of the Geoprobe® rather than having to redeploy the unit later. Had off-site analysis been used, several weeks would be required for analysis and the Geoprobe® unit may have already been de-mobilized. Additionally, the control areas set up around each borehole location would also have been removed and would require additional radiological controls support.

Four-foot Geoprobe® core samples were split in half prior to analysis to more precisely determine the vertical location of the contamination. If contamination was found, additional bounding core samples were taken at 90° intervals around the borehole (parallel and perpendicular to the BGD) and three feet further away from the borehole. The samples were taken from approximately the same depth(s) as the original sample. This procedure was continued at three-foot increments until the boundaries were determined.

Soil above the BGD had to be removed for access to portions of the ducts. This soil was also screened using ISOCS and will be evaluated for possible use as fill after work on the BGD is complete.

The results from this study can be used to address any one of several BGD alternatives, which will be evaluated in the EE/CA.

**BetaScint™**

Strontium 90 (Sr-90), a fission product commonly associated with nuclear reactors, is a pure beta emitter and thus is not directly detected by gamma spectroscopy. Conventional Sr-90 analysis requires chemical separation of the strontium from the sample matrix, followed by in-growth of the Yttrium 90 (Y-90) progeny for analysis, a time consuming procedure that often takes 1 - 4 weeks. Detection of Sr-90 was accomplished by means of a field-deployable, high-energy, beta scintillation detector manufactured by BetaScint, Inc. This system can measure Sr-90 and U-238 at approximately 1 pCi/g above background with a 5-minute count time.

The BetaScint™ system consists of a multi-layer beta scintillation detector array with a beta radiation entrance window measuring 30-cm by 60-cm. Scintillating fibers are fashioned into ribbons, which are stacked vertically. Soil samples are prepared, transferred to large area counting trays, and positioned beneath the detector window for analysis. Beta particles that pass through the detector window excite electrons in the scintillating ribbons resulting in the emission of light pulses, which are counted by photomultiplier tubes. Coincident circuitry to detect simultaneous events in several ribbon layers distinguishes high-energy betas (Sr-90) from lower energy contaminants and background. The BetaScint™ system, installed at the BGRR field laboratory is shown in Figure 19.

Following ISOCS evaluation, BetaScint™ was used to survey soil samples. Since BetaScint™ requires approximately 2 kilograms of soil, two (or more) samples were composited to obtain enough soil to count.

**Figure 19. Loading soil samples for BetaScint characterization of Sr-90**

**Three-Dimensional Visualization Software**

Presentation of complex radiological characterization data to regulators and stakeholders in a straightforward and simple manner was one of the primary objectives of this ASTD initiative. A three-dimensional visualization tool coupled with geostatistical modeling components that allows sophisticated data analysis and presentation was used to present subsurface soil characterization in a clear, concise manner. EVS-PRO unites data interpolation, geostatistical analysis, and fully 3D visualization tools into a single software system. These tools can improve site assessment and enhance the capability to analyze and present data for assessments, remediation planning, and regulatory reporting.

The visualization aspects of the tool allow a 3D representation of the contamination around the duct. The geostatistical modeling aspects of the tool allow optimization of sample location and thereby reduce uncertainty and added cost associated with grid-style sampling. This approach also permits estimation of cleanup zones as a function of confidence in meeting the cleanup goals. These modeling tools will facilitate decisions BNL may have to make to optimize the sample locations and types of additional characterization work (if needed) and to determine the extent of soil remediation or removal required to allow the BGD to be abandoned in place.

EVS-PRO was developed to meet the needs of the environmental engineer and the environmental program manager as they relate to the following areas:

- *Site assessment:* Determination of optimal locations for collecting data in order to best determine the spatial extent of contamination at the lowest possible cost.
- *Site evaluation:* Determination of the spatial extent of contamination. EVS-PRO's "Min-Max Plume" technology quantifies the statistical variation in the volume and mass estimates resulting from the current level of characterization.
- *Communication:* Visual presentation of site geology and the contamination that is present is critical for effective communication. EVS-PRO can integrate geologic information, environmental contamination data, site maps (showing buildings, roads, and other features), and aerial photographs into a single visualization. EVS-PRO provides both still and animated 3D visualization.

Figure 20 is an example output (from another site) generated by EVS-PRO, which highlights the capabilities of the software as it integrates a number of different pieces of information into a single visualization. The solid region represents the volume predicted to have contamination above the threshold with 50% probability. Dimensions (elevation, easting, and northing) are provided on the figure as a frame of reference. The ground surface is represented as the sloping colored plane at the top of the figure. The elevation of the ground surface was determined from the data supplied as part of the problem. The ground elevation contour key is at the bottom right of the figure. Site features such as the local river and buildings are draped over the ground-surface contour map. The river can be seen as the blue line on the northern part of the map. Buildings are difficult to see from this perspective; however, a residential community can be seen at the southeast corner as the series of small markings. In the subsurface region of the visualization, lines with a series of circular markers represent well locations and data collection points as a function of elevation. The circles are color-coded to match the measured value at that point. The concentration key, at the top left of the figure, indicates blue as the lowest concentration and red as the highest. The figure also integrates the data on the bedrock elevation at the site and constrains the plume boundary to be above the bedrock at all locations. This constraint can be seen in the rise and fall of the lower surface of the plume to match the change in bedrock elevation. The red regions in the plume lying just above the bedrock at the southwest corner of the plume indicate high predicted concentrations; it can be inferred from the visualization that the contaminant has migrated downward to the bottom of the aquifer. The figure can be rotated when using the software to provide alternative views of the contamination plume. This emphasizes the value of a 3D representation of the data.

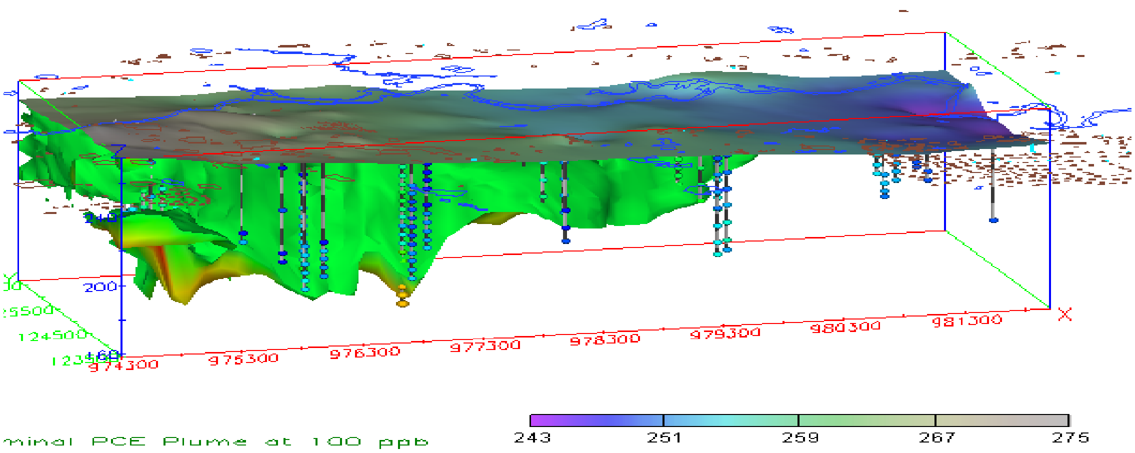


**Figure 20. Example output from EVS-PRO software (volume predicted to contain PCE at levels greater than 100 ppb) [Example does not contain data from BNL]**

## PERFORMANCE AND COST SAVINGS

This section discusses the performance and cost savings for the technologies used at the BGRR under this ASTD program. Technology performance compared to expectations, the cost of the technology, and the cost and schedule savings associated with each technology are presented. In addition, the total cost and schedule savings that the integrated technologies brought to the BGRR D&D project is evaluated.

### Perfluorocarbon Tracer Technology

The PFT technology proved completely successful in meeting the goal of defining the leak pathways and resulted in considerable cost savings by justifying a reduced sampling regimen. The information gained in this study was used to guide and optimize soil characterization studies around the BGD. Combining this information with process knowledge permitted an improved sampling plan to be developed.

***Performance***

The technology proved to be easy to use and simple to install. Installation of the key components (external monitoring ports) was completed by a two-person crew using the Geoprobe®, inexpensive polypropylene sampling lines, and a sand backfill. A simple air circulation loop was used to inject and circulate the tracers in the plenum of the ducts. All components were off-the-shelf. The component installation was completed in one week and the tracer injections completed two weeks after that. Tracer analysis was performed using a proven, specially designed gas chromatograph.

The tracer injections were accomplished using small injection quantities. Levels in the ducts quickly reached equilibrium and were very close to the optimum level determined through modeling. Figure 21 presents the concentrations at the two internal monitoring locations in the south secondary plenum during the entire testing period. The figure demonstrates the excellent agreement between the two locations indicating that the tracer was well mixed in the plenum. An equilibrium concentration of approximately 100 ppb was maintained during the injection period. Once the injection was stopped on February 5th, the concentrations in both locations decreased at a steady rate.

Of greater importance is the behavior of the tracers external to the ducts, at the monitoring ports. The leak profile for the North Duct was stable throughout the injection test providing confidence that the information provided by the test is reliable. In addition, the leak profile of o-PDCH (second test) is similar to that found by PDCB (first test). This provides further confidence that all leak pathways from the north plenum to the surrounding soils have been defined. Similar graphical visualizations were generated for all tracers on all sampling dates. Examination of the concentration profiles for the tracer PMCP, injected in the north secondary plenum from February 7th – 9th, showed a similar leak pattern to the other tracers injected into the North Duct (PDCB and o-PDCH).

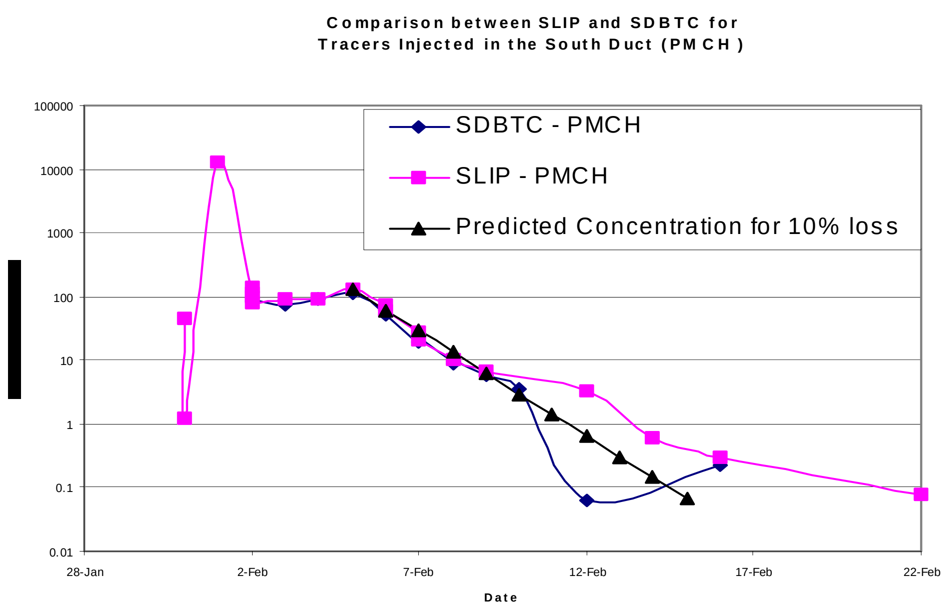


**Figure 21. PMCH concentration in the South Duct secondary plenum**

The leak profile for the South Duct is remarkably stable during the injection test providing confidence that the information provided by the test is reliable. In addition, the 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 south plenum to the surrounding soils have been defined. Similar graphical visualizations were generated for all tracers on all sampling dates. Examination of the concentration profiles for all tracers including those injected into the North Duct (PDCB and o-PDCH) all showed the same leak locations.

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. While the concentration data are extremely stable and reproducible and thus, provide a high level of confidence that all the leak pathways were found, confirmation from soil samples is required. 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. 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.

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. Figure 22 shows the color contour distributions for the tracer gas o-PDCH on February 14$^{th}$ for the North Duct. Figure 23 shows the Cs-137 soil contamination distribution for the North Duct. 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 PFTs. This is positive confirmation that the PFT study was successful in determining all of the possible leak pathways.

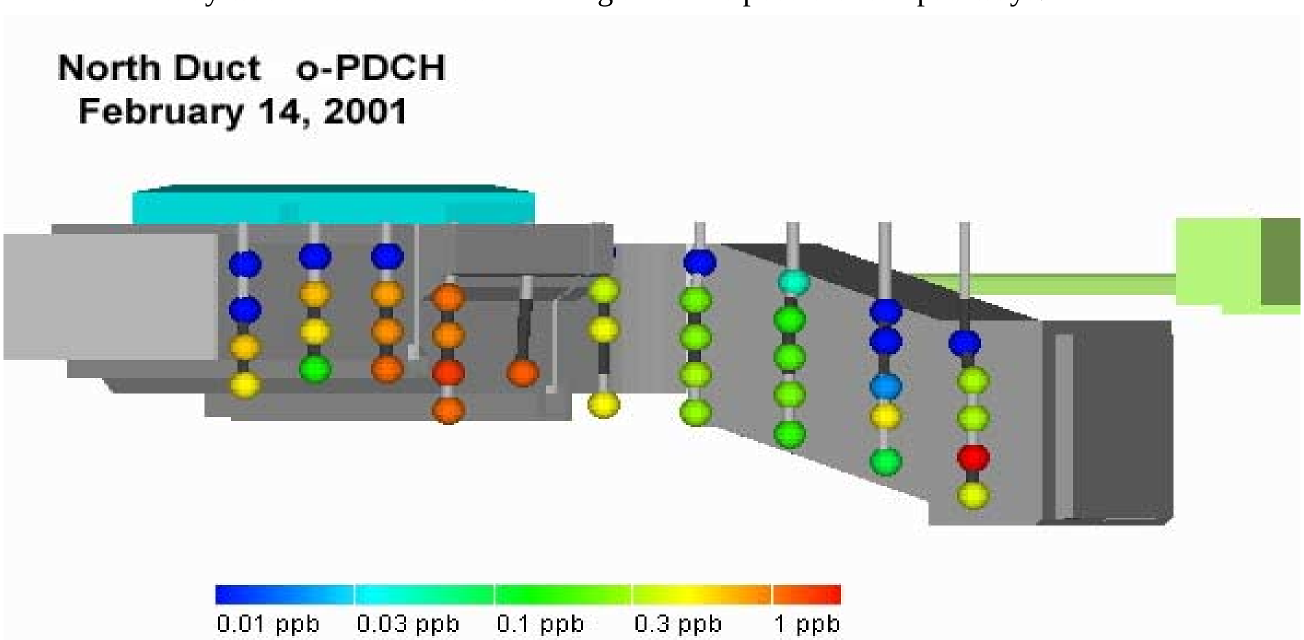


**Figure 22. Tracer (o-PDCH) concentrations along the North Duct showing leak locations**

Leak test and characterization data from the South Duct were also very well correlated. Figure 24 shows the tracer concentrations for PMCP on February 16th for the South Duct. Figure 25 shows the Cs-137 contamination distribution in the soil surrounding the South 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 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.

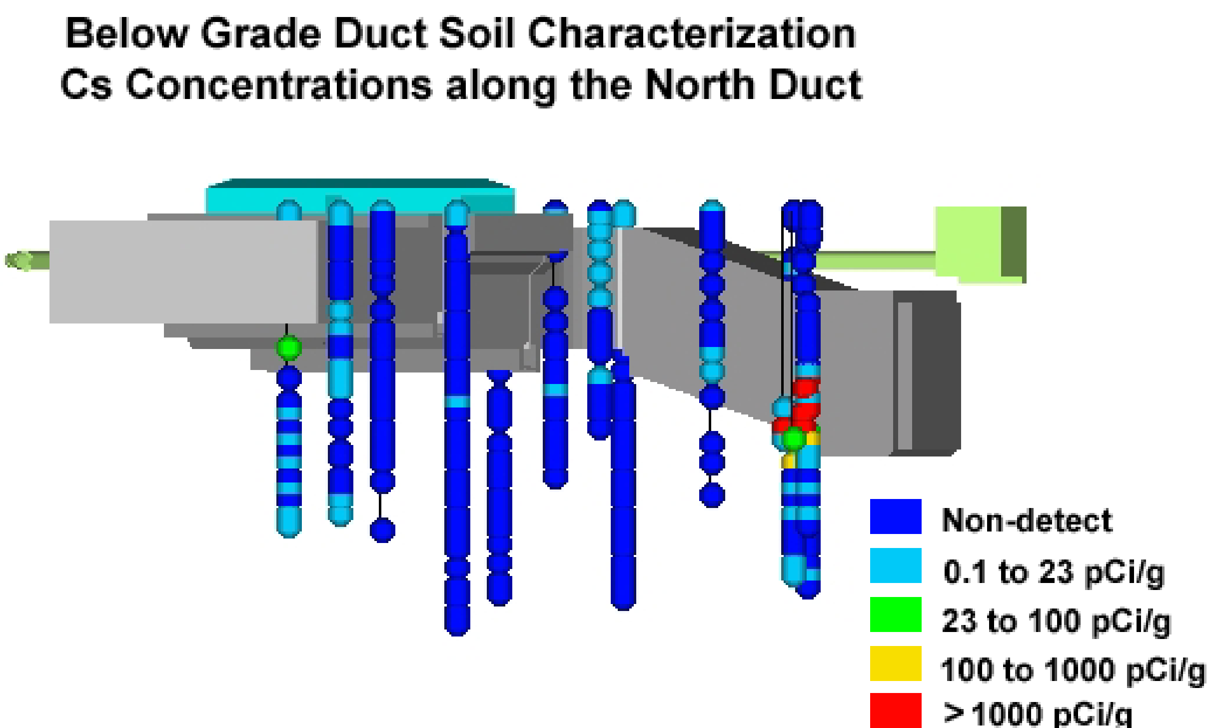


**Figure 23. Cesium contamination in the soil surrounding the North Duct**

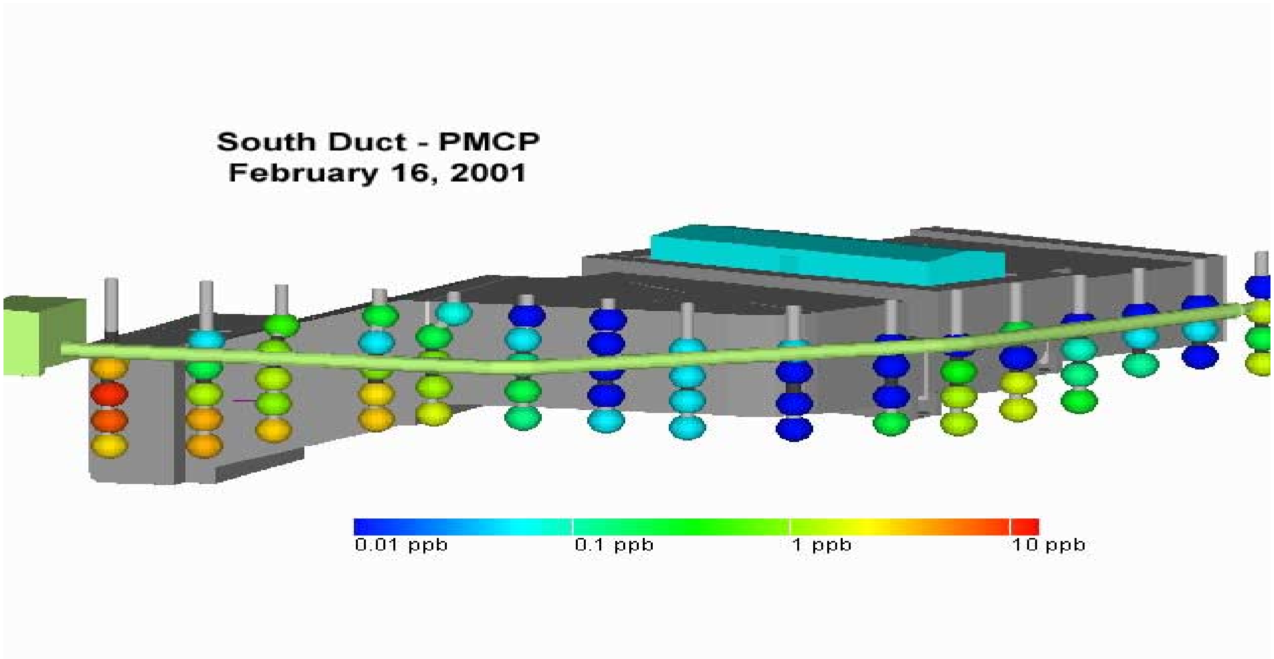


**Figure 24. Tracer (PMCP) concentrations along the South Duct showing leak locations**

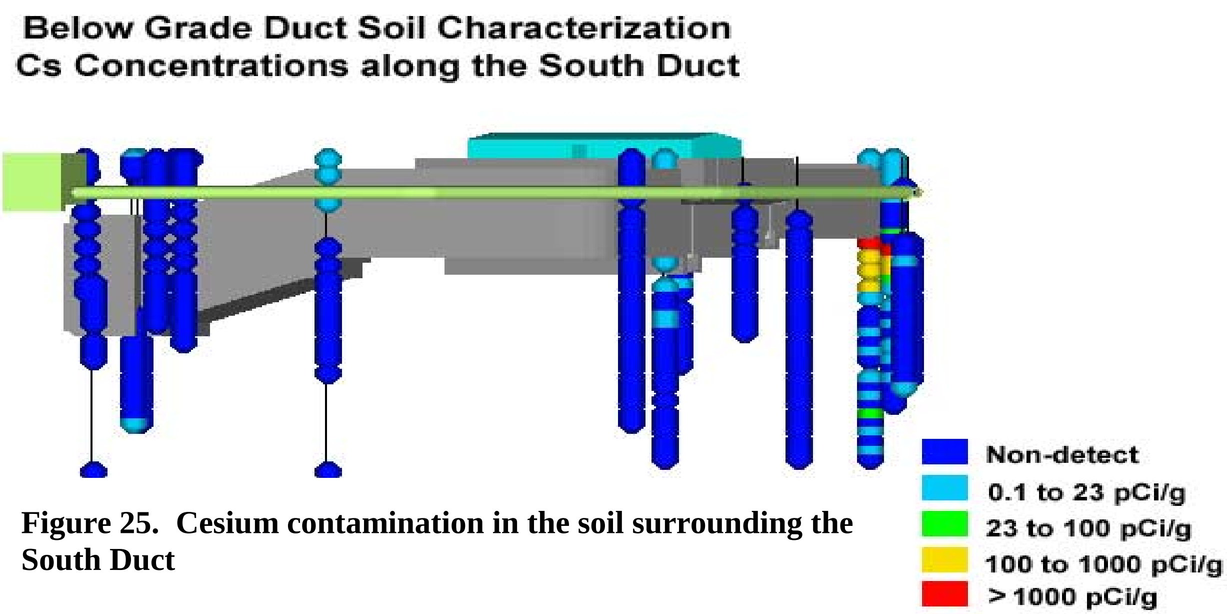


**Figure 25. Cesium contamination in the soil surrounding the South Duct**

### *Cost Evaluation*

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. Figure 26 shows the sampling plan for the BGD based on the tracer study results. The Xs represent borehole locations that were sampled and include the four bias locations used to confirm the "no-leak" findings from the tracer study. Numbers/symbols represent the tracer gas monitoring locations. Table 2 summarizes the sample requirements under the SAP. Each cell column represents an approximately 2.5 x 2.5 grid laid over the BGD. A grid box with a number in it represents a borehole location and the number in the box is the maximum number of samples required at that location. Table 2 supplements Figure 26.

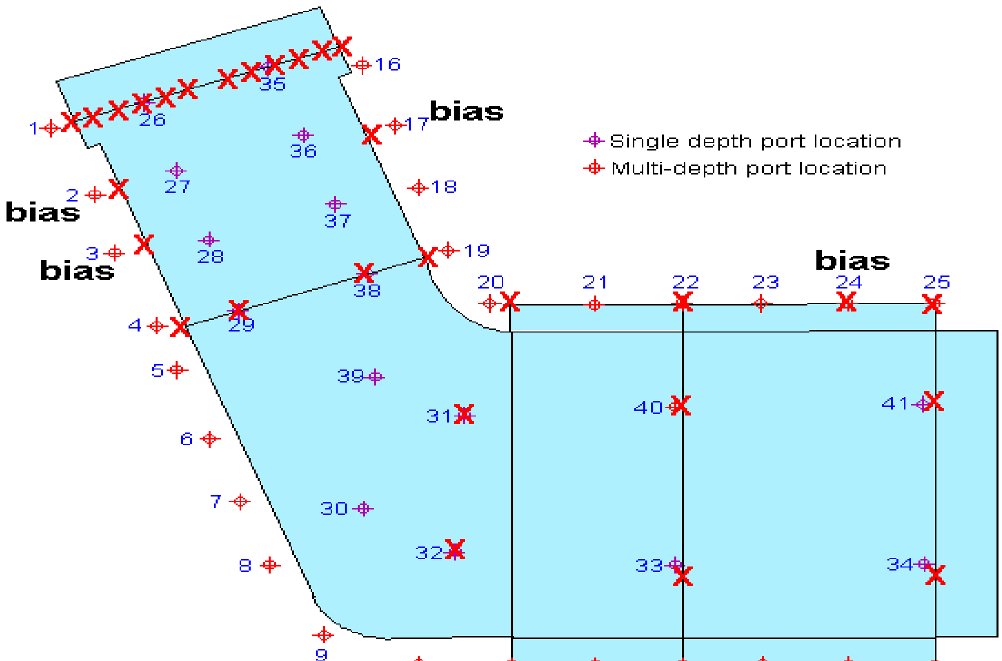


**Figure 24. Borehole locations for soil sampling around the BGD as per the SAP**

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 those 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 inches 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).

Between joints exploratory sampling would be used. Based on 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). Figure 27 shows the baseline sampling plan expected if the tracer study had not been performed. This sampling scheme results in 2542 samples from 98 borehole locations. Table 3 summarizes the sample requirements under the baseline sampling plan. Each cell represents an approximately 2.5 x 2.5 grid laid over the BGD. A grid box with a number in it represents a borehole location and the number in the box is the maximum number of samples required at that location. Table 3 supplements Figure 27.

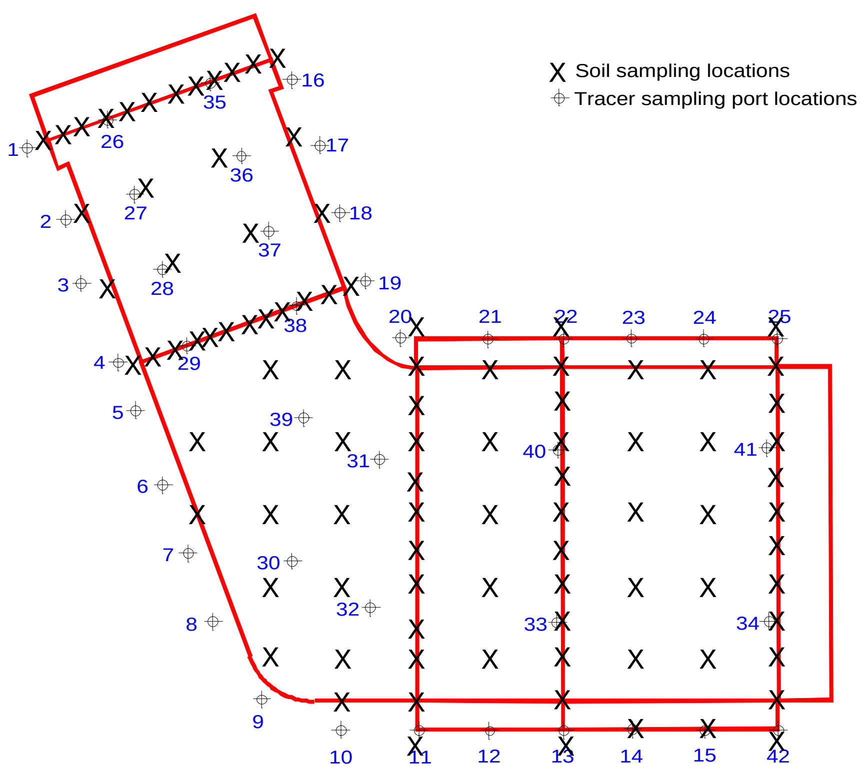


**Figure 27. Sample collection borehole locations that would be required without prior knowledge of leakage from the BGD**

Total cost for the two characterization schemes includes cost to collect the samples, cost to analyze the samples and project management costs (management, health and safety, trades, etc). Cost savings were estimated at $849K and are summarized in Table 4.

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 requires 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.

Analysis included gamma, beta, and occasional RCRA checks. Cost for off-site laboratory analysis is $252 per sample for gamma analysis and $200 per sample for beta analysis. While actual analytical costs for this ASTD project were lower, baseline characterization costs are used here to determine savings due to using the PFT Tracer Gas Study alone. The 904 samples from the ASTD alternative used for the SAP would cost $227,800 for gamma analysis and $180,800 for beta analysis, for a total of $408,600. The 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. Project management costs for the alternative, are estimated at $196,000.

The cost of the tracer study must also be considered. The materials costs are outlined in Table 5 and amount to $5K. The cost for sample bags is taken from the bag failure rate. These gas collection bags are reusable but fail (valve seals after cleaning) at a regular rate. It was assumed that 10% of the bags would be consumed and need replacement. The cost of the circulation pumps is included even though the pumps were not consumed. They are available for future use but since no additional on-site deployments have been identified at this time, the cost should be included. The tracer analysis of ~1200 gas samples was performed by an on-site 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 Appendix A. 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 analysis compares the baseline characterization (assumes minimal prior knowledge of leaks from the BGD) to the characterization performed according to the ASTD alternative (with knowledge gained from PFT technology). Cost savings are calculated to be $849K with a ROI of 395%.

**Table 2. Summary of Samples Required Under the Sample and Analysis Plan for the Alternative ASTD Approach**

| | |
|---|---|
| **Number of soil samples** | **904** |
| **Number of Borehole Locations** | **32** |
| **Cost @ $252/sample for gamma spec** | **$227,808** |
| **Cost @ $200/sample for beta analysis** | **$180,800** |
| **Cost to collect samples ($1450/day)** | **$92,800** |
| **Time to collect samples (days)** | **64** |
| **Associated management costs** | **$64,000** |

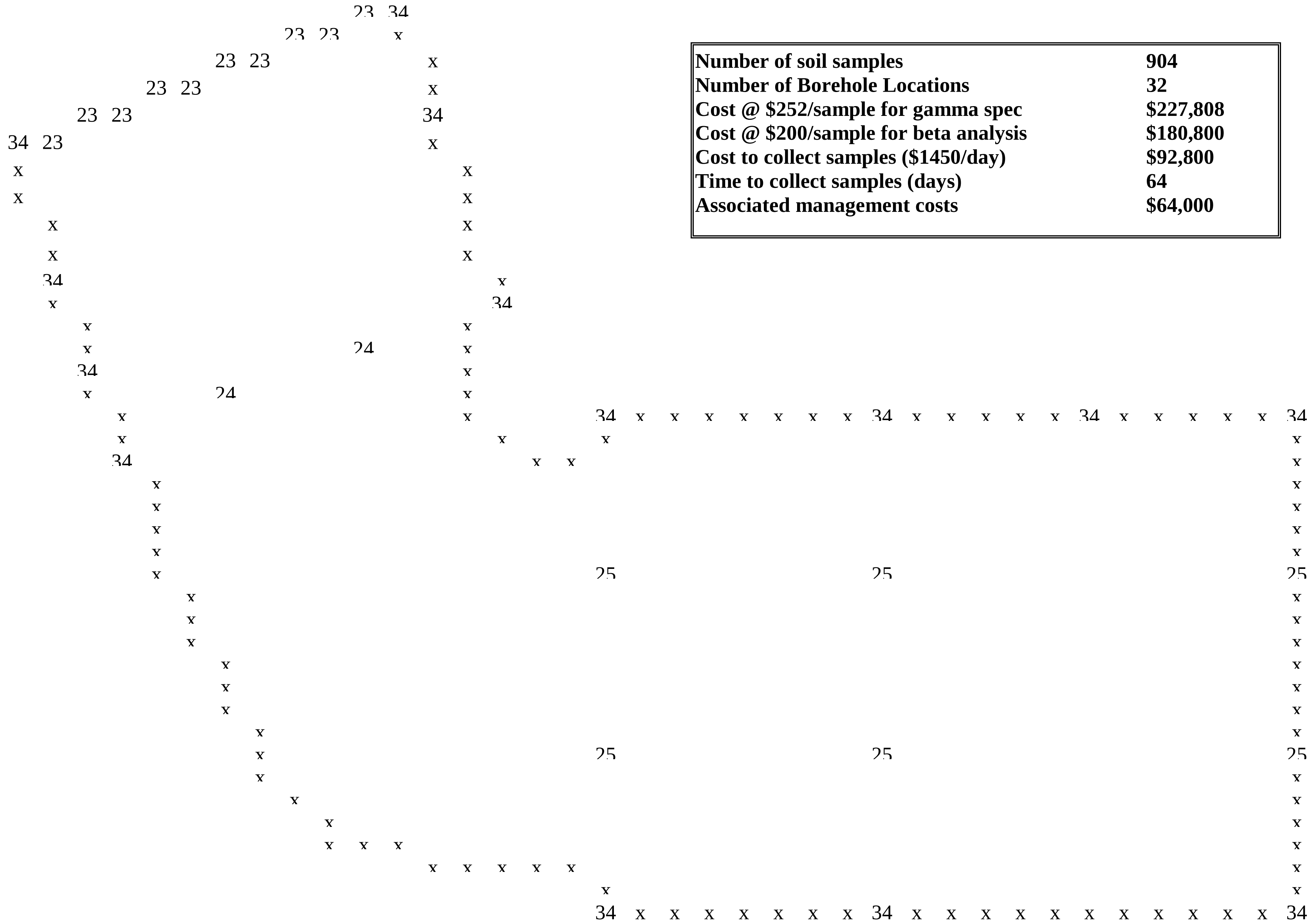

**Table 3. Summary of Samples Required Under the Alternative Characterization Plan**

| | |
|---|---|
| **Number of soil samples** | **2542** |
| **Number of Borehole Locations** | **98** |
| **Cost @ $252/sample for gamma spec** | **$640,584** |
| **Cost @ $200/sample for beta spec** | **$508,400** |
| **Cost to collect samples ($1450/day)** | **$284,200** |
| **Time to collect samples (workdays)** | **196** |
| **Associated management costs** | **$196,000** |

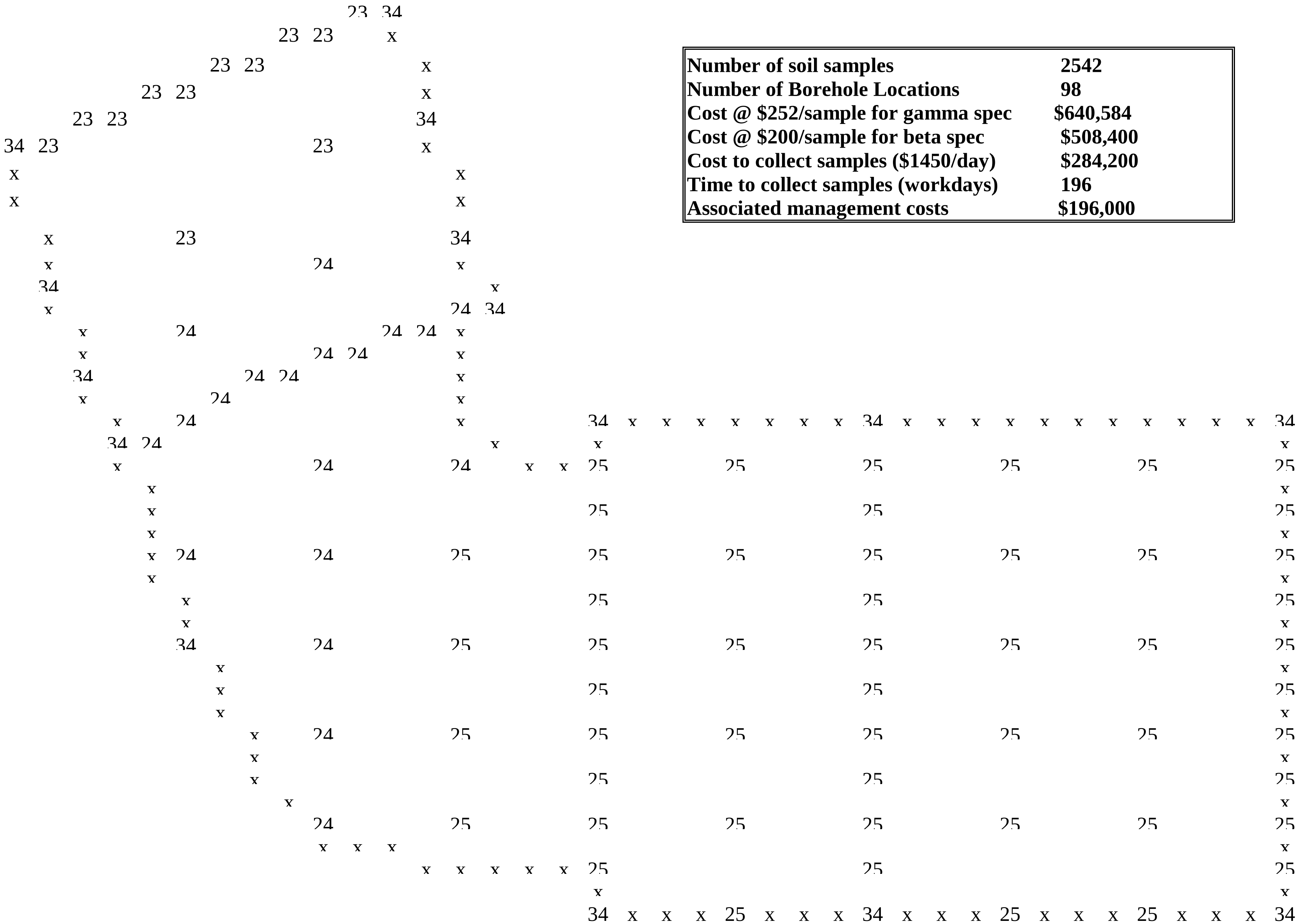

**Table 4. Comparisons of Characterization Costs Using the Tracer Gas Study and Baseline Approaches[a,b]**

| 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

**Table 5. Materials Costs for Tracer Gas Study at the BGRR**

| Material | Quantity | Unit cost ($) | Item cost ($) |
|---|---|---|---|
| Gas sampling bags | 30 | 8 | 240 |
| Tracers | 4 | 500 | 2000 |
| Polypropylene tubing (ft) | 3000 | 0.07 | 210 |
| Sintered glass filters | 112 | 0.5 | 56 |
| Sand (100 lb. Bags) | 5 | 7 | 35 |
| Circulation pumps[a] | 2 | 800 | 1600 |
| Flexible ducting (ft) | 160 | 1 | 160 |
| Diesel fuel (gal) | 60 | 1.5 | 90 |
| Misc. (fittings, etc) | -- | -- | 300 |
| **Total material cost for project** | | | **$4,691** |

a) Not consumed

**Table 6. Costs for Tracer Gas Study at the BGRR**

| Item | Cost ($) |
|---|---|
| Labor | 120,000 |
| Laboratory analysis | 90,000 |
| Materials | 4,691 |
| **Total** | **214,691** |

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 one-year and life cycle cost savings of $849K. Since the useful life was conservatively estimated to be one year for this technology, annual and life cycle cost savings are equivalent. The reduced sampling also saved 26 weeks of total project time.

## Small Footprint Geoprobe®

### *Performance*

The compact small footprint Geoprobe® unit was particularly useful 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 (see Figure 16) and 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 (see Figure 17).

Seven monitoring boreholes were placed in the trench and had to be positioned between the electrical duct and the BGD. The four eastern-most positions were very tight; the gap between the concrete of the BGD and the electrical duct was only about one foot. The small-footprint of the LT-54 allowed positioning the unit and probe in the optimal location for the tracer study. If the boreholes could not be placed between the two ducts they would have been relocated to the outside of the electrical duct. This would have resulted in an additional three to four feet of soil between the monitoring ports and the leaks (if any). The added distance would have caused slightly reduced sensitivity and increased the time of the test by three days (due to the longer diffusion path).

The LT-54 was powerful enough to push the 2 1/8 inch rod into the subsurface with only occasional refusal (believed to be due to structural piers not on the original blueprints). Depth of penetration was 40 feet through coarse sand and as many as 7 boreholes were placed daily (including porting and finishing). The entire 42 access boreholes (131 ports) were installed in under two weeks. The LT-54, with is small size and accurate movement (remotely guided and track steering allow pivoting in place), was far more rapidly deployed from one borehole location to another and repositioning (between core samples or when refusal occurred at a shallow depth) of the unit was far easier. The very small footprint required only small level surfaces to correctly position the unit for probing. A larger unit would require grading changes or chocking of the unit, all of which take time and resources. For soil sample collection, the BGRR program also employed two outside contracted Geoprobe® units that were truck mounted. This was done to expedite sample collection rather than rely on the single LT-54. There were several locations that the truck-mounted units could not access and the rented units were relegated to core sample collection on the paved areas of relatively flat terrain.

**Figure 28. Geoprobe® being used in the canal deep pit**

In a secondary deployment, the LT-54 was also used in the BGRR Canal House characterization. Fuel elements from the BGRR were charged and discharged from the south face of the reactor pile. Spent fuel was lowered into the canal pit and then into the deep pit of the Canal House. The deep pit served to shield, store, and prepare fuel elements and activated sources for shipment and disposal. Water from the deep pit was believed to have leaked into the surrounding soils. In order to characterize the extent of contamination under the canal, boreholes were drilled through the Canal House floor and into the subsurface. Core samples were taken every two feet. The Canal House characterization was performed while the Canal House was still intact (pre-decommissioning). The entry path was down a narrow set of stairs and through standard doorways. The compact LT-54 was lowered down into the canal and driven through the doorways (see Figure 28). Once inside the unit was used to probe through previously cored holes in the concrete floor and into the subsurface. The macro-core tool purchased with the LT-54 was used to collect soil samples. Without this unit, sample collection under the floor would have been limited to the depth of a hand auger and complete characterization would have had to wait until after the Canal House structure was removed. This would have impacted the health and safety assessment for Canal House removal and subsequent soil cleanup due to limited knowledge of the soil contamination below the facility. It may also have caused programmatic delays as the characterization would have to be complete before the soil cleanup could commence.

***Cost Evaluation***

The Geoprobe® and all the equipment and spare parts cost $60K ($42K for the LT-54 and the balance as parts such as macro cores, a groundwater sampler, spare probe rods, etc.). As stated above, the Geoprobe® was most useful in accessing areas that would otherwise require terrain or structural alterations and in rapid deployment. This alone made the Geoprobe® an essential part of the characterization efforts. Most of the cost savings are intangible as 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 truck-mounted probing systems. It is anticipated that between 0.5 and 2 man-months labor would have been required for alterations and delays in deploying the Geoprobe® from location to location. This range of savings is between $10K and $40K.

Additional cost savings are expected based on using an operator-owned unit versus a contracted unit. The LT-54 with a two-man crew cost approximately $1000 per day to operate. The contracted units were $1450 per day with a two-man crew based on weekly rental. Each day of operation of the LT-54 for sample collection or tracer monitoring port installation saved ~$500.

These costs were not included in overall project cost savings however, since amortization time for this equipment is uncertain.

While not directly part of the BGD ASTD, the Canal House deployment of the LT-54 saved the BGRR D&D program time and money. The Geoprobe® system provided a means to accomplish the characterization under the deep pit without first removing the external structures. The floor of the canal was pre-cored and the LT-54 was then used to collect core samples through the core holes. The characterization of the soil below the canal provided a safer and more rapid removal of the Canal House for remediation. The cost savings for this cannot be quantified. The path forward to remove the canal building without characterization of the contamination below it is uncertain. No formal planning for this path was made so no estimate of cost can be made.

### ***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 off-site 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.

#### ***Performance***

The initial ISOCS deployment at BGRR (FY 99 ASTD) provided the performance comparison of ISOCS with traditional laboratory analysis.[10] 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 a workhorse. 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 near 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.

Soil sample preparation was very simple; the samples were emptied from the core collection sleeves into polyethylene bottles that had previously been calibrated for ISOCS calculations. In the case of surface soil samples, the samples were transferred from the plastic bags used to collect the samples into polyethylene bottles. Sample weights were recorded and the bottles were placed into the ISOCS chamber for counting. Data were recorded on a portable-computer data acquisition system.

The ISOCS (see technical description earlier) requires the geometry of the sample to be input. For soil samples, the geometry remained constant (cylindrical bottles all the same size). The 300 structural samples were all unique shapes and all required sample-specific ISOCS modeling. The ISOCS efficiency computation allows accurate efficiency calibrations to be performed rapidly for a wide variety of sample shapes, sizes, densities, and distances between the sample and the detector. Objects are modeled from one of a set of generic sample shapes, such as boxes, cylinders, planes, spheres, pipes, etc. These basic geometry templates have many parameters that can be modified to create an accurate representation of the sample object and detector geometry.

The structural samples were all measured and weighted prior to counting with the ISOCS. Geometry modeling was performed after counting and the analysis "re- calculated" with the proper geometry inputs. The ability to accurately and quickly characterize unique combinations of materials and geometries is one of the greatest assets of the ISOCS technology.

Procedurally, ISOCS operation is straightforward. Each morning quality control (QC) (e.g., efficiency, photo-peak centroid, etc.) and background checks were performed. The cryogenic dewar needed to be filled once or twice weekly. When the system was occasionally left idle for short periods of time there were no problems in resuming its use. In contrast, it was also put through a period where it was operational 5 to 6 days per week for up to 18 hours per day without failure. This was expected, as the ISOCS is engineered for *in situ* use and is rugged by design.

The ISOCS also proved to require little maintenance. While a maintenance contract is in place (thus costs for maintenance would remain fairly constant), downtime for the time critical task of characterizing the BGD soils was of significant concern. The ISOCS did not need any repair maintenance and had no down time due to system failures. The ISOCS ability to perform with no delays in schedule was a big advantage. The characterization of the BGD is a time-critical project as the EE/CA and thus, final remediation schedule, is dependent on this task.

Another major advantage was that ISOCS provided rapid turn-around on time-critical samples. Much of the characterization effort was exploratory in nature and when contamination was found additional sampling was required. If the initial samples could not be analyzed rapidly then equipment and/or crews either would remain idle or would be redeployed and have to be brought back at a later date (after sample analysis was completed). In many cases, this equipment deployment is very time consuming and expensive. ISOCS allowed optimal use of resources during the characterization efforts.

***Cost Evaluation***

This cost evaluation will consider only the tangible cost savings ISOCS brought to the project, but the intangibles are at least 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 off-site 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 were waiting to be declared clean and needed no further sampling 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 itself. 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 achieve the required turn-around. ISOCS was able to handle the last minute sample crunch 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 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 all 1700 samples would have been $428K. Total cost savings attributable to ISOCS are $297.7K (neglecting capital costs).

The standardized life cycle cost analysis is presented in Appendix B. Cost savings over the five-year life are calculated to be $842K with a ROI of 96%.

**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. The data from BetaScint™ was fed into the EVS-PRO software to provide a profile of the Sr-90 contamination around the BGD.

***Performance***

This effort represents the second deployment for BetaScint™ at the BGRR to provide Sr-90 soil characterization. The BetaScint™ system consists of a multi-layer beta scintillation detector array, with a beta radiation entrance window measuring 30-cm by 60-cm. The large window yields results that are more representative than those obtained from typical sample aliquots of several grams or less of material. However, this does require fairly large sample volumes; BetaScint™ typically requires approximately 2 kilograms of soil. The core samples taken were two-foot sections roughly two inches in diameter. BetaScint™ analysis required that two (or more if the cores were not completely full) samples be composited to obtain enough soil to count. Soil samples were prepared by sieving out the rocks and particles larger than ¼ inch and then transferring the material to large area counting trays. The soil is spread evenly across the tray and the tray is positioned beneath the system entrance window for analysis. Following instrument calibration using a known source strength in a similar media and geometry, the concentration of Sr-90 in the soil (pCi/g) is determined in minutes. BetaScint™ provides rapid, reliable analytical results.

BetaScint™ operations were as flawless as those for ISOCS. System operation/maintenance consisted of a daily background check and reference standard check and occasionally cleaning the window to make certain no particulates adhered to it. (The plastic window built up static charges and for very dry soil, particles would occasionally be drawn to the plastic.) 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.). Depending on the soil characteristics (e.g., moisture content) the sample preparation step could become the rate-limiting step (for an operator working alone). During the later parts of the characterization effort, sample preparation was moved to a two-person operation in order to keep up with the BetaScint™ analyses. However, the rapid count time for BetaScint™ allowed more samples per day to be counted than for ISOCS.

Quantification of Sr-90 using conventional EPA laboratory methods typically takes a minimum of two weeks (accelerated turn-around, which is costly) or a month (standard turn-around). The BetaScint™ system produces accurate and precise results with a quick turn-around time (approximately 5-10 minutes) with a detection sensitivity of approximately 1 pCi/g.

In its current configuration, BetaScint™ is not capable of counting samples other than soil samples. Therefore, the 300 structural samples were not analyzed via BetaScint™. As stated, soil core samples were composited in at least a 2:1 ratio to obtain BetaScint™ samples. This was needed only for core samples, which were identified as deep soil samples in the SAP. Any core sample that was to be sent off-site for confirmatory analysis was not analyzed using the BetaScint™ because of the compositing issue. The sample would have to be blended with another and would not be recoverable. For surface soil samples, ample quantities were available for BetaScint™ analysis without compositing. In all, 725 samples were analyzed using the BetaScint™ system.

### *Cost Evaluation*

The cost of conventional baseline Sr-90 analysis (including transportation) is approximately \$200/sample and usually requires two to four weeks. BetaScint™ analyses cost about \$50/sample. The 725 samples cost \$36K to be analyzed via BetaScint™. The SAP called for confirmation, by 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 BetaScint™ were \$108.5 (excludes capital investment).

The standardized life cycle cost analysis is presented in Appendix C. Cost savings (with a 5 year lifetime) are calculated to be \$471K with a ROI of 80%.

## 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 even 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 able to make informed decisions regarding the remediation.

### *Performance*

The EVS-PRO software was used to analyze 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 simple. To illustrate the intuitive nature of the EVS-PRO visualizations compare the EVS-PRO data output for PMCP on February 16$^{th}$ for the South Duct in Figure 29 to the same data set in tabular form (Table 7) and to the graphical presentation of the data in Figure 30. In Figure 29, red colors represent high concentrations of tracer, green to yellow represent mid-range leaks and blue represents "clean" or leak-free areas. It is easy to see where leaks are located on the ducts and it is clear that some locations show tracers in elevated concentration but that those tracers are "drifting" over via diffusion. The bulls-eye patterns make pinpointing a leak simple. The color contours are easy to correlate to a leak. Using the data in Table 7 it is difficult to pick out the high, medium, and low tracer concentrations and then to match them up to locations is even more difficult as the sample locations and elevations need to be referenced to the duct maps (i.e., Figure 3). The graph in Figure 30 shows obvious differences in concentrations but again needs correlation to location and elevation. To the layperson, if it is not obvious what the data states, it may appear as if there are many leaks rather than tracer emanating from a few holes and traveling to other ports.

EVS-PRO simplifies the data even further in that it allows the user to have a virtual 3D image projected on the screen. This allows all sides of the duct to be viewed from one image. The viewer does not have to remember the last view to compare to the present view. A seamless transition from one area to another is possible. For the BGD a movie was prepared that showed the north side of the BGD and slowly rotated the ducts to show the south side and top views. This gave the audience the feel of "walking" around the ducts and looking at the leaks. A copy of the 3D movie is included on the CD that accompanies this report.

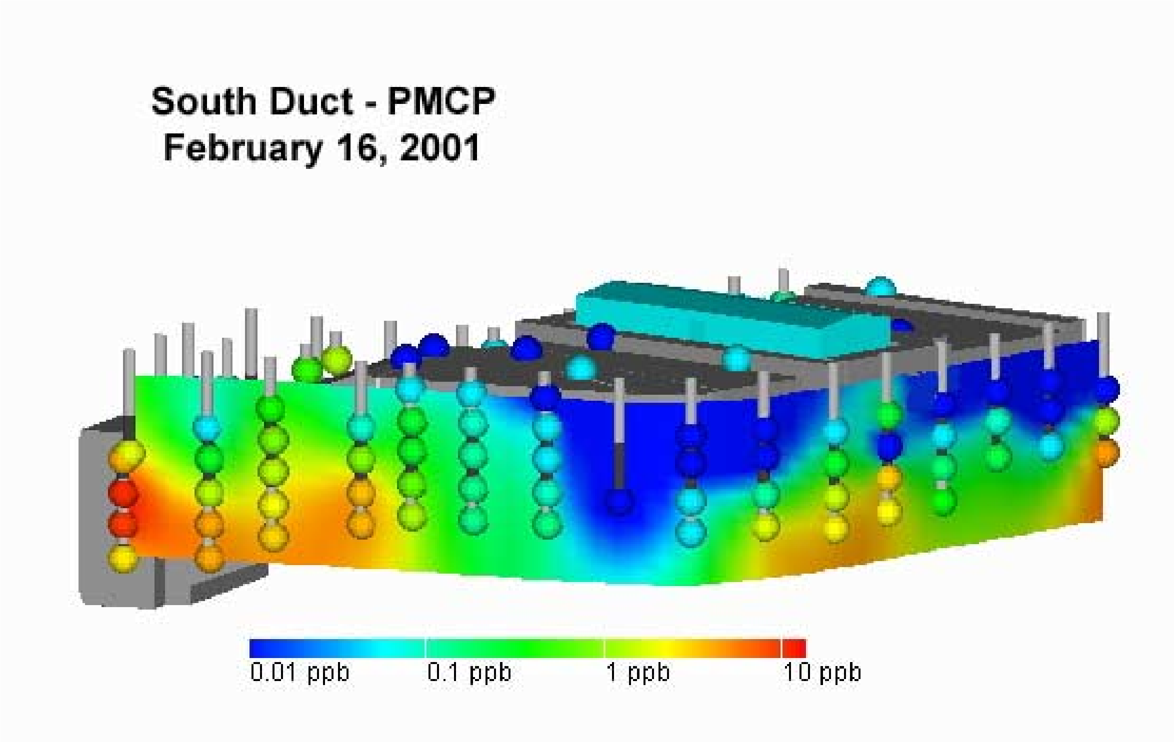


**Figure 29. Visualization of PMCP tracer concentrations on February 16$^{th}$ (data from Table 7)**

The EVS-PRO's 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 was very 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.

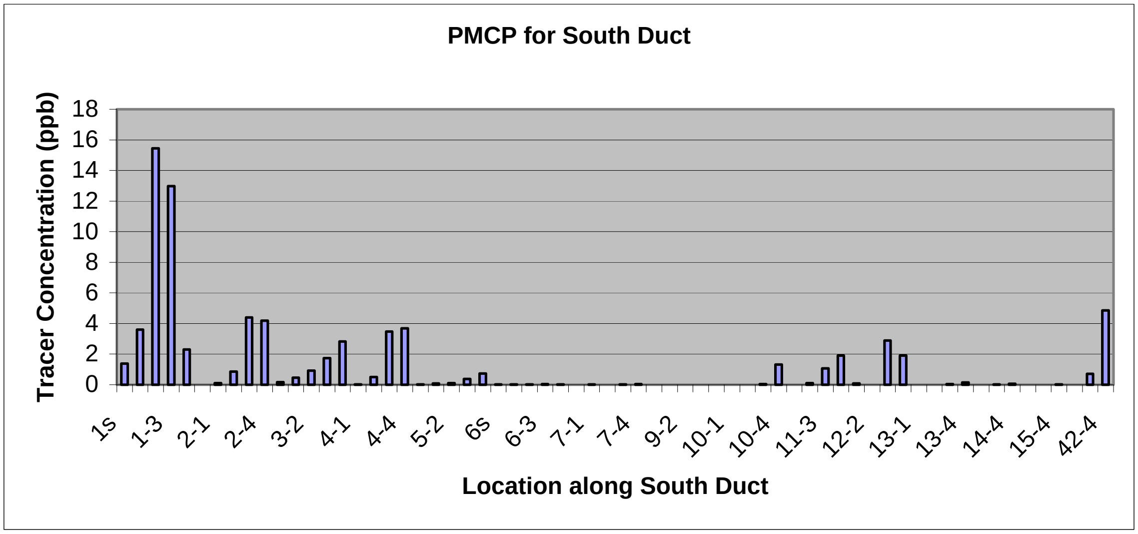


**Figure 30. Tracer concentrations versus location on South Duct for PMCP on February 16th (data from Table 7)**

EVS-PRO outputs were generated for the soil contamination profile surrounding the BGD. These visualizations will be incorporated into the upcoming EE/CA. Figure 31 shows cesium concentrations in the soil surrounding the BGD. The view is of the South Duct looking up so that soil concentrations beneath the duct can also be seen. Figure 32 depicts the cesium concentrations in the soil surrounding the BGD but the viewpoint is looking at the North Duct and from above so the soil concentrations above the ducts can also be seen. These two representations give a fairly clear understanding of the extent of contamination surrounding the BGD and incorporate approximately 800 soil samples (see Appendix D). The EVS-PRO software also allows simple and rapid changes to the way data are presented. For instance, contamination data can be displayed as all soil samples tested (Figure 33), any sample that had detectable contamination (Figure 34) or only those samples that were above the soil cleanup guidelines (Figure 35). The first shows the extent of the characterization and produces confidence that the characterization was thorough. The middle figure gives an idea of the extent of the contamination and the last gives a better feel for how big (or small) the remediation effort needs to be.

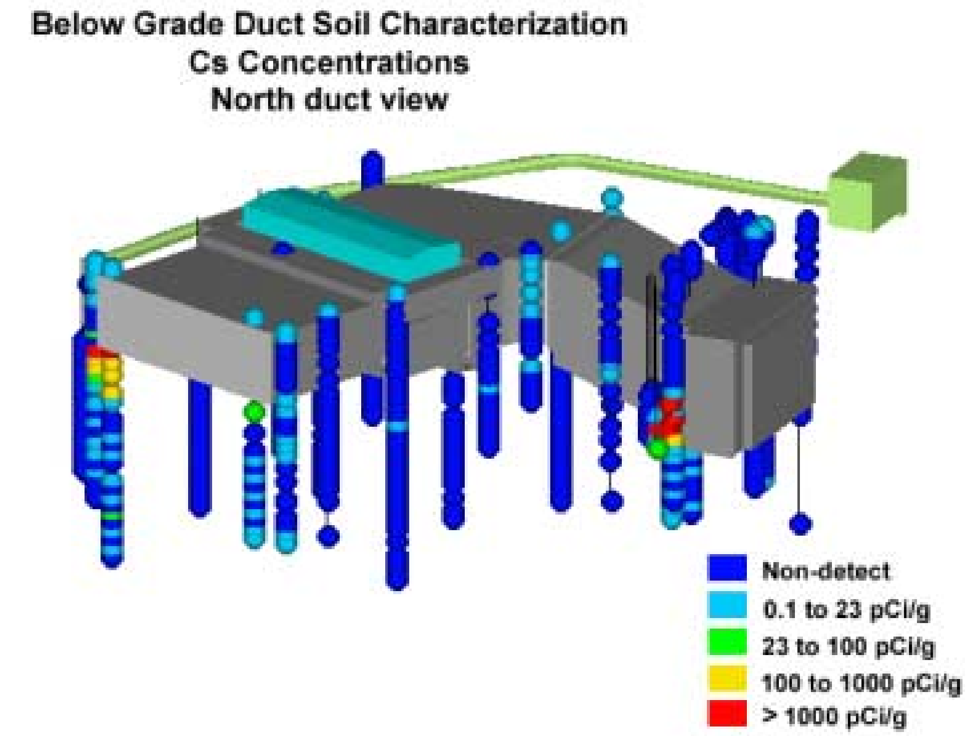


**Figure 31. North view visualization of cesium contamination in the soil surrounding the BGD (data from Appendix D)**

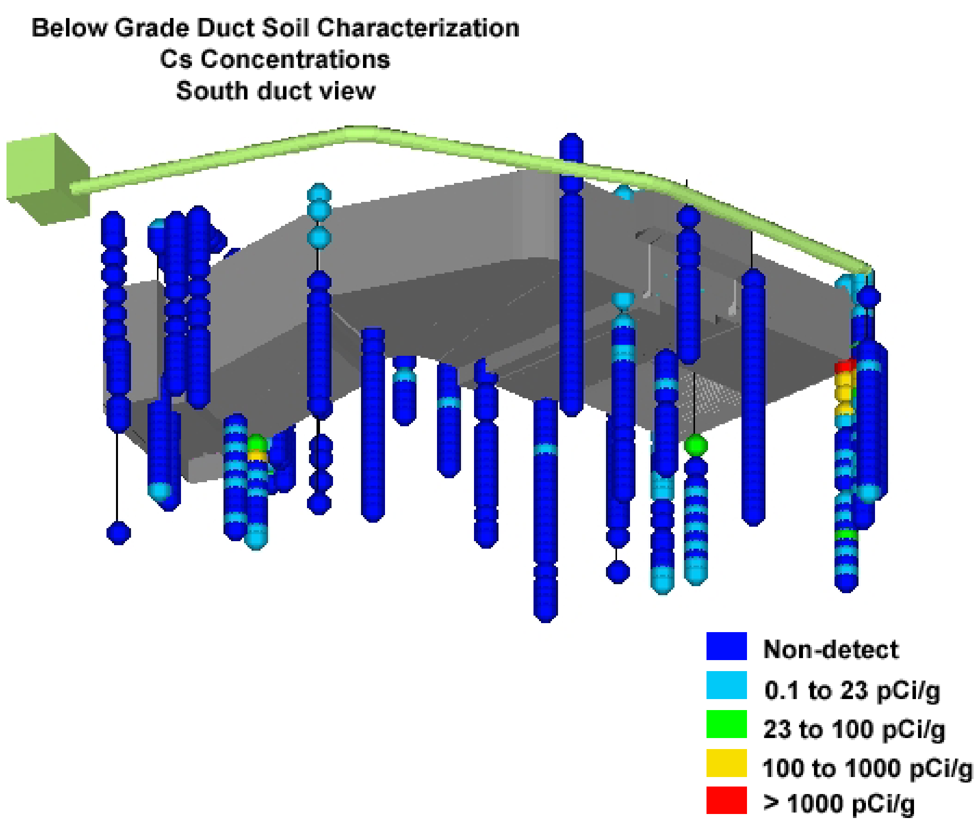


**Figure 32. South view visualization of cesium contamination in the soil surrounding the BGD (data from Appendix D)**

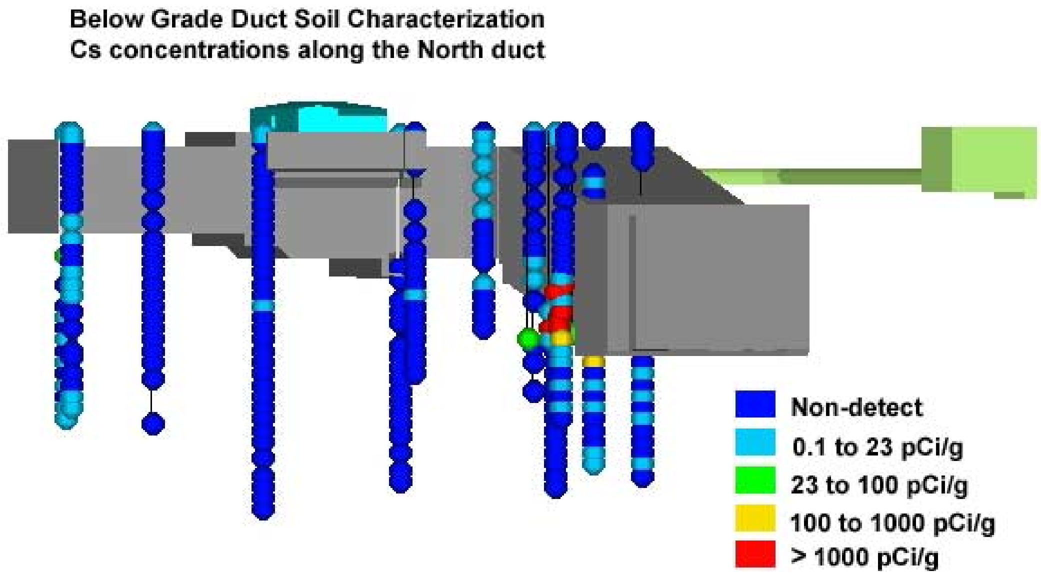


**Figure 33. Visualization of cesium contamination in the soil surrounding the BGD showing all samples analyzed**

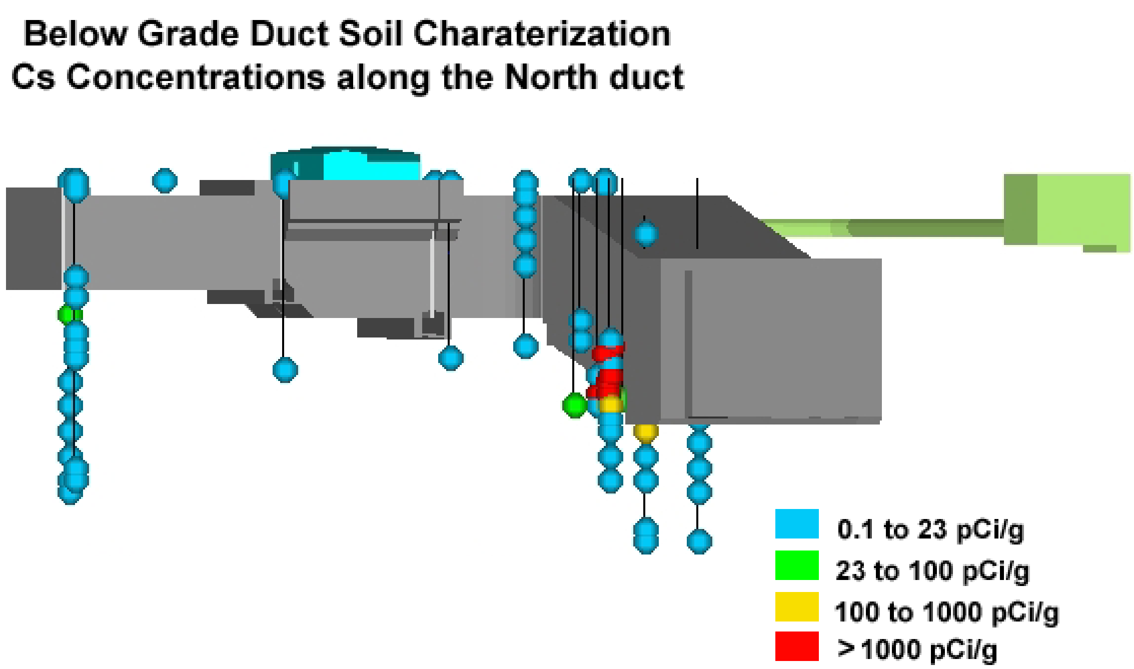


**Figure 34. Visualization of cesium contamination in the soil surrounding the BGD showing all samples with detectable contamination**

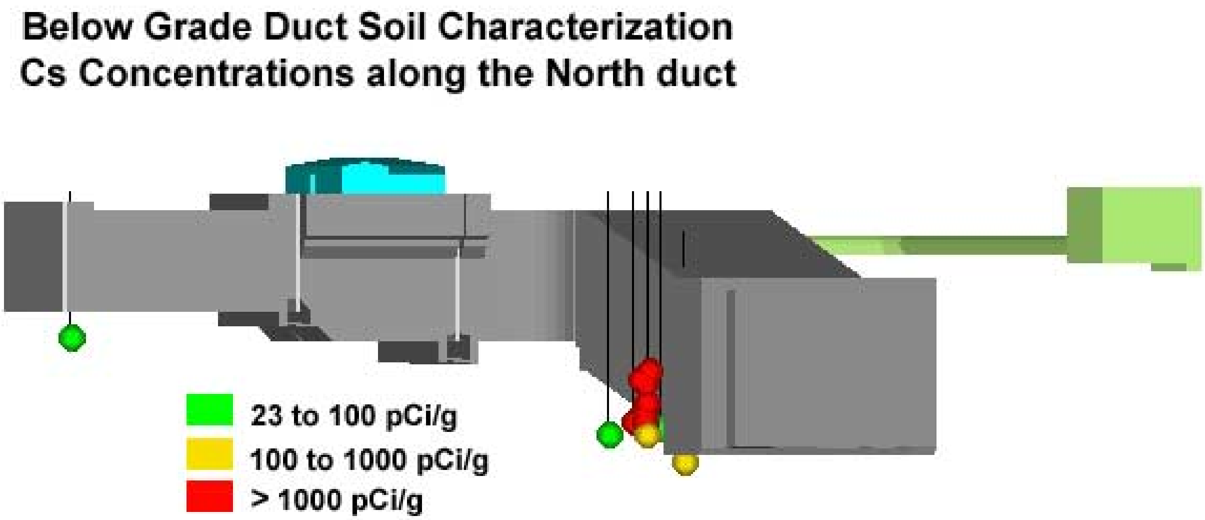


**Figure 35. Visualization of cesium contamination in the soil surrounding the BGD showing all samples with contamination above the cleanup guidelines**

***Cost Evaluation***

The cost evaluation for the EVS-PRO software cannot be properly quantified. EVS-PRO is an enabling technology that improves communication between 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 3-dimensional spatial presentation that can be clearly understood by all stakeholders. This more effective presentation of the characterization data 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.

**Table 7. PFT Concentration Data for February 16th**

| Location | Port | PDCB | PMCH | o-PDCH | PMCP | Location | Port | PDCB | PMCH | o-PDCH | PMCP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | S | 0.000 | 0.305 | 0.004 | 1.008 | 7 | 4 | 0.000 | 0.000 | 0.000 | 0.005 |
| 1 | 1 | 0.000 | 0.335 | 0.008 | 1.521 | 8 | 3 | 0.007 | 0.000 | 0.000 | 0.010 |
| 1 | 2 | 0.000 | 0.321 | 0.011 | 1.807 | 9 | 1 | 0.000 | 0.000 | 0.000 | 0.003 |
| 1 | 3 | 0.000 | 0.350 | 0.009 | 1.528 | 9 | 2 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1 | 4 | 0.000 | 0.567 | 0.009 | 2.008 | 9 | 3 | 0.000 | 0.000 | 0.000 | 0.007 |
| 2 | S | 0.002 | 0.020 | 0.000 | 0.013 | 9 | 4 | 0.000 | 0.000 | 0.000 | 0.003 |
| 2 | 1 | 0.045 | 0.618 | 0.000 | 0.165 | 10 | 1 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2 | 2 | 0.126 | 1.884 | 0.004 | 0.995 | 10 | 2 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2 | 3 | 0.106 | 1.883 | 0.012 | 2.237 | 10 | 3 | 0.000 | 0.000 | 0.000 | 0.001 |
| 2 | 4 | 0.095 | 1.429 | 0.019 | 1.930 | 10 | 4 | 0.000 | 0.000 | 0.000 | 0.011 |
| 3 | S | 0.019 | 0.235 | 0.000 | 0.175 | 11 | 1 | 0.000 | 0.000 | 0.000 | 0.000 |
| 3 | 1 | 0.065 | 0.843 | 0.002 | 0.340 | 11 | 3 | 0.038 | 0.084 | 0.015 | 0.253 |
| 3 | 2 | 0.085 | 1.057 | 0.003 | 0.463 | 11 | 4 | 0.023 | 0.065 | 0.010 | 0.232 |
| 3 | 3 | 0.139 | 1.783 | 0.009 | 1.179 | 12 | 1 | 0.026 | 0.050 | 0.000 | 0.066 |
| 3 | 4 | 0.063 | 0.854 | 0.013 | 1.207 | 12 | 2 | 0.008 | 0.000 | 0.000 | 0.011 |
| 4 | S | 0.000 | 0.030 | 0.000 | 0.024 | 12 | 3 | 0.070 | 0.205 | 0.010 | 0.626 |
| 4 | 1 | 0.000 | 0.000 | 0.000 | 0.004 | 12 | 4 | 0.061 | 0.174 | 0.017 | 0.552 |
| 4 | 2 | 0.011 | 0.094 | 0.004 | 0.273 | 13 | 1 | 0.000 | 0.000 | 0.000 | 0.004 |
| 4 | 3 | 0.031 | 0.447 | 0.009 | 0.804 | 13 | 2 | 0.000 | 0.000 | 0.000 | 0.004 |
| 4 | 4 | 0.037 | 0.556 | 0.012 | 1.041 | 13 | 3 | 0.003 | 0.005 | 0.000 | 0.016 |
| 5 | S | 0.000 | 0.000 | 0.000 | 0.009 | 13 | 4 | 0.012 | 0.026 | 0.000 | 0.074 |
| 5 | 1 | 0.002 | 0.035 | 0.000 | 0.054 | 14 | 2 | 0.000 | 0.000 | 0.000 | 0.005 |
| 5 | 2 | 0.007 | 0.099 | 0.000 | 0.113 | 14 | 3 | 0.002 | 0.000 | 0.000 | 0.009 |
| 5 | 3 | 0.016 | 0.236 | 0.000 | 0.191 | 14 | 4 | 0.004 | 0.000 | 0.000 | 0.018 |
| 5 | 4 | 0.010 | 0.119 | 0.000 | 0.120 | 15 | 2 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6 | S | 0.000 | 0.007 | 0.000 | 0.003 | 15 | 3 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6 | 1 | 0.002 | 0.026 | 0.000 | 0.012 | 15 | 4 | 0.000 | 0.000 | 0.000 | 0.003 |
| 6 | 2 | 0.002 | 0.026 | 0.000 | 0.016 | 42 | 1 | 0.000 | 0.000 | 0.000 | 0.000 |
| 6 | 4 | 0.000 | 0.010 | 0.000 | 0.012 | 42 | 2 | 0.000 | 0.000 | 0.000 | 0.000 |
| 7 | S | 0.000 | 0.000 | 0.000 | 0.006 | 42 | 3 | 0.000 | 0.014 | 0.000 | 0.016 |
| 7 | 1 | 0.000 | 0.000 | 0.000 | 0.001 | 42 | 4 | 0.000 | 0.027 | 0.000 | 0.141 |
| 7 | 2 | 0.002 | 0.000 | 0.000 | 0.003 | | | | | | |

# SUMMARY AND CONCLUSIONS

This Cost and Performance report summarizes the results obtained in deploying a suite of innovative technologies for characterizing soils surrounding and beneath the BGRR Below Grade Ducts. Additional details on the results of the PFT study and on the data obtained in the characterization study itself can be obtained in supporting documentation[8,11]. Significant cost savings were realized by deploying each of these technologies, in addition to the overall project cost savings associated with the decision to leave the BGD in place (this decision had not been made at the time this report was finalized).

Deployment of the PFT technology eliminated the need to search blindly for contaminated soil and thus provided the greatest cost savings compared with baseline characterization techniques. Reduction in the number of samples required resulted in a life cycle cost savings of $849K. In addition, this technique improved the level of confidence that all potential leak areas were identified and characterized. While the Geoprobe® provided ready access to areas that otherwise would have been extremely difficult to reach and was less expensive to operate than contracted equipment, no credit for associated savings is included in this analysis. ISOCS and BetaScint™ each provided large one-year cost savings of $292K and $109K, respectively. Since these systems are expected to be used continually over the next five years, large life cycle cost savings ($842K and $471K, respectively) were estimated. The EVS-PRO 3D data system demonstrated numerous benefits for manipulating and presenting data in a manner that is straightforward and easy to comprehend, but again, no cost-savings credit is assumed.

Potential cost savings associated with deployment of these technologies are summarized in Tables 8 and 9. When considered together, this suite of innovative technologies are 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 $2.1. The estimated cost savings associated with leaving the BGD in place boosts potential cost savings to between $8.3M and 9.3M.

**Table 8. 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 9. 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** |

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

# APPENDIX A

**Life Cycle Cost Savings from the use of the Perfluorocarbon Tracer Technology at the BGRR**

## Calculation of Life Cycle Cost Savings from Use of Science or Technology
## Worksheet 1: Operating & Maintenance Annual Recurring Costs

PBS #: ____________________

Technology ID: ____________________

Technology Name: Perfluorocarbon Tracers

Deployment Date: FY01

Baseline Technology: Full Characterization with core samples taken on 10 foot centers

Related Site Need #: ____________________

| **Expense Cost Items*** | **Before (B) Annual Costs** | **After (A) Annual Costs** |
|---|---|---|
| 1. Equipment | $0 | $0 |
| 2. Purchased Raw Materials and Supplies | $2,000 | $1,500 |
| 3. Process Operation Costs: | | |
| a. Utility Costs | $0 | $0 |
| b. Labor Costs | $284,200 | $92,800 |
| c. Routine Maintenance Costs for Processes | $0 | $0 |
| d. Process Costs | $0 | $0 |
| e. Other | $1,149,000 | $408,600 |
| Subtotal | $1,433,200 | $501,400 |
| 4. PPE and Related Health/Safety/Supply Costs | $0 | $0 |
| 5. Waste Management Costs: | | |
| a. Waste Container costs | $0 | $0 |
| b. Treatment/Storage/Disposal Costs | $0 | $0 |
| c. Inspection/Compliance Costs | $0 | $0 |
| Subtotal | $0 | $0 |
| 6. Recycling – Material Collection/Separation/Preparation Costs: | | |
| a. Material and Supply Costs | $0 | $0 |
| b. Operations and Maintenance Labor Costs | $0 | $0 |
| c. Vendor Costs for Recycling | $0 | $0 |
| Subtotal | $0 | $0 |
| 7. Administrative/Other Costs | $196,000 | $64,000 |
| **Total Annual Cost:** | **$1,631,200** | **$566,900** |

* See attached Supporting Data and Calculations.

## Calculation of Life Cycle Cost Savings from Use of Science or Technology
## Worksheet 2: Itemized Project Funding Requirements*
### (i.e., One-Time Implementation Costs)

| Category | | | | | Cost $ |
|---|---|---|---|---|---|
| **INITIAL CAPITAL INVESTMENT** | | | | | |
| 1. Design | | | | | $0 |
| 2. Purchase | | | | | $5,000 |
| 3. Installation | | | | | $100,000 |
| 4. Other Capital Investment (explain) | | | | | $0 |
| **Subtotal: Capital Investment = (C)** | | | | | $105,000 |
| **INSTALLATION OPERATING EXPENSES** | | | | | |
| 5. Planning/Procedure Development | | | | | $20,000 |
| 6. Training | | | | | $0 |
| 7. Miscellaneous Supplies | | | | | $0 |
| 8. Startup/Testing | | | | | $0 |
| 9. Readiness Reviews/Management Assessment/Administrative Costs | | | | | $0 |
| 10. Other Capital Investment (explain) | | | | | $90,000 |
| **Subtotal: Installation Operating Expenses = (E)** | | | | | $110,000 |
| 11. All company adders (G&A/PHMC Fee, MPR, GFS, Overhead, taxes, etc.) (if not contained in above items) | | | | | $0 |
| **Total Project Funding Requirements = (C + E)** | | | | | $215,000 |
| **Useful Project Life = (L)** | 1 | Years | Time To Implement | 0 | Months |
| **Estimated Project Termination/Disassembly Cost (if applicable) = (D)** (Include Demobilization costs. Only for Projects where L < 5 years; D = 0 if L > 5 years) | | | | | $0 |
| **TOTAL LIFE CYCLE COST SAVINGS CALCULATION** | | | | | |
| (Before – After) x (Useful Life) – (Total Project Funding Requirements + Termination) | | | | | |
| Total Life Cycle Cost Savings Estimate = (B – A) x L – (C + E + D) = | | | | | **$849,300** |
| **RETURN ON INVESTMENT CALCULATION** | | | | | |
| Return on Investment (ROI) % = (Before – After) – [(Total Project Funding Requirements + Termination)/Useful Life] / [Total Project Funding Requirements + Termination] x 100 | | | | | |
| ROI = {(B – A) – [(C + E + D)/L]}/(C + E + D) x 100 = | | | | | **395%** |
| O&M Annual Recurring Costs: | | | Project Funding Requirements: | | |
| Annual Costs, Before (B) = | | $1,631,200 | Capital Investment (C) = | | $105,000 |
| Annual Costs, After (A) = | | $566,900 | Installation Op Expenses (E) = | | $110,000 |
| Net Annual Savings (B – A) = | | $1,064,300 | Total Project Funds (C + E) = | | $215,000 |
| Note: Before (B) and After (A) are O&M Annual Recurring costs from Worksheet 1. | | | | | |

* See attached Supporting Data and Calculations.

# Worksheet 3

ESTIMATE BASIS FOR: Perfluorocarbon tracers (minimum case)

***GENERAL***

The useful lifetime is taken as one year as the PFTs are for characterization only. Other costs are analytical laboratory costs for off-site laboratory analysis ($252 per sample for gamma analysis and $200 per sample for beta analysis).

***INITIAL CAPITAL INVESTMENT***

The PFT technology required modeling prior to installation of ports and tracer injection lines. This amounted to $20K. No capital equipment was purchased but the “technology” is a capital purchase as it does not replace soil sampling but rather allows a reduced number of samples to be taken. The process cost (per year), before and after, is based on soil samples taken. The cost of the PFT tracer characterization to justify the reduced sampling scheme. Therefore this is a capital cost associated with the improved SAP. Materials cost included the tracer gases and plumbing and totaled $5K. The capital installation costs include the plumbing installation (monitoring and injection ports) and the actual injection and gas sampling cost and data reduction. All costs associated with gathering data are included in the capital installation cost and amount to $100K. Total capital investment was $105K.

***INSTALLATION AND STARTUP***

The installation operating expenses include the design modeling and tracer gas analysis (at a contract laboratory) and amounted to $110K

***TRADITIONAL (BASELINE) TECHNOLOGY/METHOD***

The baseline is performing a full characterization of the soils surrounding the ducts. Cost for off-site laboratory analysis is $252 per sample for gamma analysis and $200 per sample for beta analysis. The baseline characterization requires 2542 samples and would cost $640,600 for gamma analysis and $508,400 for beta analysis. The baseline characterization would also require drilling 98 boreholes at a cost of $284,200. Total cost for the baseline is $1,433K

***NEW TECHNOLOGY/METHOD***

The alternative SAP, which was approved following the PFT characterization, required 32 boreholes for collection of samples adjacent to the BGD at a cost of $92,800. The 904 samples from the SAP would cost $227,800 for gamma analysis and $180,800 for beta analysis. Total cost amounts to $501K

***COST SAVINGS/COST AVOIDANCE/RISK REDUCTION***

Cost savings are calculated to be $849K with a ROI of 395%.

# APPENDIX B

## Life Cycle Cost Savings from the use of ISOCS at the BGRR

## Calculation of Life Cycle Cost Savings from Use of Science or Technology
## Worksheet 1: Operating & Maintenance Annual Recurring Costs

PBS #: ______
Technology ID: ______
Technology Name: ISOCS
Deployment Date: FY01
Baseline Technology: Gamma spectroscopy
Related Site Need #: ______

| Expense Cost Items* | Before (B) Annual Costs | After (A) Annual Costs |
|---|---|---|
| 1. Equipment | $0 | $0 |
| 2. Purchased Raw Materials and Supplies | $500 | $500 |
| 3. Process Operation Costs: | | |
| a. Utility Costs | $0 | $0 |
| b. Labor Costs | $0 | $0 |
| c. Routine Maintenance Costs for Processes | $0 | $10,694 |
| d. Process Costs | $0 | $0 |
| e. Other | $343,400 | $129,200 |
| Subtotal | $343,400 | $139,894 |
| 4. PPE and Related Health/Safety/Supply Costs | $0 | $0 |
| 5. Waste Management Costs: | | |
| a. Waste Container costs | $0 | $0 |
| b. Treatment/Storage/Disposal Costs | $0 | $0 |
| c. Inspection/Compliance Costs | $0 | $0 |
| Subtotal | $0 | $0 |
| 6. Recycling – Material Collection/Separation/Preparation Costs: | | |
| a. Material and Supply Costs | $0 | $0 |
| b. Operations and Maintenance Labor Costs | $0 | $0 |
| c. Vendor Costs for Recycling | $0 | $0 |
| Subtotal | $0 | $0 |
| 7. Administrative/Other Costs | $0 | $0 |
| **Total Annual Cost:** | **$343,900** | **$140,394** |

* See attached Supporting Data and Calculations.

## Calculation of Life Cycle Cost Savings from Use of Science or Technology
## Worksheet 2: Itemized Project Funding Requirements*
**(i.e., One-Time Implementation Costs)**

| **Category** | **Cost $** |
|---|---|
| **INITIAL CAPITAL INVESTMENT** | |
| 1. Design | $0 |
| 2. Purchase | $148,800 |
| 3. Installation | $0 |
| 4. Other Capital Investment (explain) | $0 |
| **Subtotal: Capital Investment = (C)** | $148,800 |
| **INSTALLATION OPERATING EXPENSES** | |
| 5. Planning/Procedure Development | $0 |
| 6. Training | $27,000 |
| 7. Miscellaneous Supplies | $0 |
| 8. Startup/Testing | $0 |
| 9. Readiness Reviews/Management Assessment/Administrative Costs | $0 |
| 10. Other Capital Investment (explain) | $0 |
| **Subtotal: Installation Operating Expenses = (E)** | $27,000 |
| 11. All company adders (G&A/PHMC Fee, MPR, GFS, Overhead, taxes, etc.) (if not contained in above items) | $0 |
| **Total Project Funding Requirements = (C + E)** | $175,800 |
| **Useful Project Life = (L)** 5 Years; Time To Implement 0 Months | |
| **Estimated Project Termination/Disassembly Cost (if applicable) = (D)** (Include Demobilization costs. Only for Projects where L < 5 years; D = 0 if L > 5 years) | $0 |
| **TOTAL LIFE CYCLE COST SAVINGS CALCULATION** | |
| (Before – After) x (Useful Life) – (Total Project Funding Requirements + Termination) | |
| Total Life Cycle Cost Savings Estimate = (B – A) x L – (C + E + D) = | **$841,730** |
| **RETURN ON INVESTMENT CALCULATION** | |
| Return on Investment (ROI) % = (Before – After) – [(Total Project Funding Requirements + Termination)/Useful Life] x 100 / [Total Project Funding Requirements + Termination] | |
| ROI = {(B – A) – [(C + E + D)/L]}/(C + E + D) x 100 = | **96%** |

| O&M Annual Recurring Costs: | | Project Funding Requirements: | |
|---|---|---|---|
| Annual Costs, Before (B) = | $343,900 | Capital Investment (C) = | $148,800 |
| Annual Costs, After (A) = | $140,394 | Installation Op Expenses (E) = | $27,000 |
| Net Annual Savings (B – A) = | $203,506 | Total Project Funds (C + E) = | $175,800 |

Note: Before (B) and After (A) are O&M Annual Recurring costs from Worksheet 1.

* See attached Supporting Data and Calculations.

# Worksheet 3

ESTIMATE BASIS FOR: *In Situ* Object Counting System (ISOCS)

***GENERAL***

The ISOCS unit useful lifetime is taken as the term of cleanup of legacy waste at BNL. The cleanup goal is 2006 giving a lifetime of 5 years. [Budget changes have moved the final cleanup projection to 2008, this would add two more years to the ISOCS lifetime, but the number of samples per year would presumably drop in a proportionate amount.]

***INITIAL CAPITAL INVESTMENT***

The ISOCS unit was purchased under a previous ASTD but is included here as it would be a normal capital investment for other users.

***INSTALLATION AND STARTUP***

Training costs include operation of the ISOCS as well as education in modeling procedures. Total training costs were $27K

***TRADITIONAL (BASELINE) TECHNOLOGY/METHOD***

The baseline is sending samples off-site for gamma spectroscopy. BNL's current cost for this service averages $252 per sample but for standard soil samples the cost is $202 per sample. The $202 per sample cost was used since most of the samples taken were standard soil samples. Materials cost is for plastic sample collection bottles and is required for both methods. Total baseline cost is $343K.

***NEW TECHNOLOGY/METHOD***

The ISOCS was shown to perform as well as off-site analysis. Cost for ISOCS includes the manpower, maintenance and material costs and totals $140K

***COST SAVINGS/COST AVOIDANCE/RISK REDUCTION***

Cost savings are calculated to be $842K with a ROI of 96%.

# APPENDIX C

**Life Cycle Cost Savings from the use of BetaScint™ at the BGRR**

# Calculation of Life Cycle Cost Savings from Use of Science or Technology
## Worksheet 1: Operating & Maintenance Annual Recurring Costs

| | |
|---|---|
| PBS #: | |
| Technology ID: | |
| Technology Name: | BetaScint™ |
| Deployment Date: | FY01 |
| Baseline Technology: | Sr-90 beta analysis |
| Related Site Need #: | |

| Expense Cost Items* | Before (B) Annual Costs | After (A) Annual Costs |
|---|---|---|
| 1. Equipment | $0 | $0 |
| 2. Purchased Raw Materials and Supplies | $50 | $50 |
| 3. Process Operation Costs: | | |
| a. Utility Costs | $0 | $0 |
| b. Labor Costs | $0 | $0 |
| c. Routine Maintenance Costs for Processes | $0 | $0 |
| d. Process Costs | $0 | $0 |
| e. Other | $154,000 | $36,250 |
| Subtotal | $154,000 | $36,250 |
| 4. PPE and Related Health/Safety/Supply Costs | $0 | $0 |
| 5. Waste Management Costs: | | |
| a. Waste Container costs | $0 | $0 |
| b. Treatment/Storage/Disposal Costs | $0 | $0 |
| c. Inspection/Compliance Costs | $0 | $0 |
| Subtotal | $0 | $0 |
| 6. Recycling – Material Collection/Separation/Preparation Costs: | | |
| a. Material and Supply Costs | $0 | $0 |
| b. Operations and Maintenance Labor Costs | $0 | $0 |
| c. Vendor Costs for Recycling | $0 | $0 |
| Subtotal | $0 | $0 |
| 7. Administrative/Other Costs | $0 | $0 |
| **Total Annual Cost:** | **$154,050** | **$36,300** |

* See attached Supporting Data and Calculations.

## Calculation of Life Cycle Cost Savings from Use of Science or Technology
## Worksheet 2: Itemized Project Funding Requirements*
### (i.e., One-Time Implementation Costs)

| **Category** | **Cost $** |
|---|---|
| **INITIAL CAPITAL INVESTMENT** | |
| 1. Design | $0 |
| 2. Purchase | $87,500 |
| 3. Installation | $0 |
| 4. Other Capital Investment (explain) | $0 |
| **Subtotal: Capital Investment = (C)** | $87,500 |
| **INSTALLATION OPERATING EXPENSES** | |
| 12. Planning/Procedure Development | $0 |
| 13. Training | $30,200 |
| 14. Miscellaneous Supplies | $0 |
| 15. Startup/Testing | $0 |
| 16. Readiness Reviews/Management Assessment/Administrative Costs | $0 |
| 17. Other Capital Investment (explain) | $0 |
| **Subtotal: Installation Operating Expenses = (E)** | $30,200 |
| 18. All company adders (G&A/PHMC Fee, MPR, GFS, Overhead, taxes, etc.) (if not contained in above items) | $0 |
| **Total Project Funding Requirements = (C + E)** | $117,700 |
| **Useful Project Life = (L)** 5 Years; Time To Implement 0 Months | |
| **Estimated Project Termination/Disassembly Cost (if applicable) = (D)** (Include Demobilization costs. Only for Projects where L < 5 years; D = 0 if L > 5 years) | $0 |
| **TOTAL LIFE CYCLE COST SAVINGS CALCULATION** | |
| (Before – After) x (Useful Life) – (Total Project Funding Requirements + Termination) | |
| Total Life Cycle Cost Savings Estimate = (B – A) x L – (C + E + D) = | **$471,050** |
| **RETURN ON INVESTMENT CALCULATION** | |
| Return on Investment (ROI) % = (Before – After) – [(Total Project Funding Requirements + Termination)/Useful Life] / [Total Project Funding Requirements + Termination] x 100 | |
| ROI = {(B – A) – [(C + E + D)/L]}/(C + E + D) x 100 = | **80%** |

| O&M Annual Recurring Costs: | | Project Funding Requirements: | |
|---|---|---|---|
| Annual Costs, Before (B) = | $154,050 | Capital Investment (C) = | $87,500 |
| Annual Costs, After (A) = | $36,300 | Installation Op Expenses (E) = | $30,200 |
| Net Annual Savings (B – A) = | $117,750 | Total Project Funds (C + E) = | $117,700 |

Note: Before (B) and After (A) are O&M Annual Recurring costs from Worksheet 1.

* See attached Supporting Data and Calculations.

# Worksheet 3

ESTIMATE BASIS FOR: BetaScint™

***GENERAL***

The BetaScint™ unit useful lifetime is taken as the term of cleanup of legacy waste at BNL. The cleanup goal is 2006 giving a lifetime of 5 years. [Budget changes have moved the final cleanup projection to 2008, this would add two more years to the BetaScint™ lifetime, but the number of samples per year would presumably drop in a proportionate amount.]

***INITIAL CAPITAL INVESTMENT***

The BetaScint™ unit was purchased under a previous ASTD but is included here as it would be a normal capital investment for other users.

***INSTALLATION AND STARTUP***

Training costs include operation and sample preparation of the BetaScint™. Total training costs were $30K

***TRADITIONAL (BASELINE) TECHNOLOGY/METHOD***

The baseline is sending samples off-site for Sr-90 analysis. BNL's current cost for this service averages $200 per sample. Materials cost is for plastic sample collection bags and is required for both methods. Total baseline cost is $154K.

***NEW TECHNOLOGY/METHOD***

The BetaScint™ was shown to perform as well as off-site analysis. Cost for BetaScint™ includes the manpower, maintenance and material costs and totals $36K

***COST SAVINGS/COST AVOIDANCE/RISK REDUCTION***

Cost savings are calculated to be $471K with a ROI of 80%.

# APPENDIX D

## $^{137}$Cs Soil Contamination Data for Soils Surrounding the Below Grade Ducts at the BGRR

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 21ASB1DS- | 1 | 1.5'-2.0' | ND |
| 21ASB1DS- | 2 | 2'-4' | ND |
| 21ASB1DS- | 3 | 4'-6' | ND |
| 21ASB1DS- | 04a | 6'-8' | ND |
| 21ASB1DS- | 05a | 8'-10' | ND |
| 21ASB1DS- | 06a | 10'-12' | ND |
| 21ASB1DS- | 07a | 12'-14' | ND |
| 21ASB1DS- | 08a | 14'-18' | ND |
| 21ASB1DS- | 10a | 18'-22' | ND |
| 21ASB1DS- | 12a | 22'-26' | ND |
| 21ASB1DS- | 14a | 26'-28' | ND |
| 21ASB1DS- | 15a | 28'-30' | ND |
| 21ASB1DS- | 16a | 30'-32' | ND |
| 21ASB1DS- | 17a | 32'-34' | ND |
| 21ASB1DS- | 18a-R | 34'-36- | ND |
| 21ASB1DS- | 19a-R | 36'-38' | ND |
| 21ASB1SS- | 1 | 0.0'-0.5' | ND |
| 21ASB1SS- | 2 | 0.5'-1.0' | ND |
| 21ASB1SS- | 3 | 1.0'-1.5' | ND |
| 21ASBDS- | 1 | 1.5'-2.0' | ND |
| 21ASBDS- | 02f | 2'-6' | ND |
| 21ASBDS- | 02a | 4 | ND |
| 21ASBDS- | 04f | 6'-10' | ND |
| 21ASBDS- | 04a | 8 | ND |
| 21ASBDS- | 06f | 10'-14' | ND |
| 21ASBDS- | 06a | 12 | ND |
| 21ASBDS- | 08a | 14'-18' | ND |
| 21ASBDS- | 10a | 18'-22' | ND |
| 21ASBDS- | 12a-R | 22'-26' | ND |
| 21ASBDS- | 12a | 22'-26' | ND |
| 21ASBDS- | 14a | 26'-30' | ND |
| 21ASBDS- | 14b | 26'-30' | ND |
| 21ASBDS- | 16a | 30'+2" | ND |
| 21ASBDS- | 16b | 30'-32' | ND |
| 21ASBDS- | 17b | 32'-34' | ND |
| 21ASBDS- | 18b | 34'-36' | ND |
| 21ASBDS- | 19b | 36'-38' | ND |
| 21ASBDS- | 20b | 38'-40' | ND |
| 21ASBDS- | 21b | 40'-42' | ND |
| 21ASBDS- | 22b | 42'-44' | ND |
| 21ASBDS- | 23b | 44'-46' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 21ASBGW- | 1 | 70' | ND |
| 21ASBSS- | 1 | 0.0'-0.5' | ND |
| 21ASBSS- | 2 | 0.5'-1.0' | ND |
| 21ASBSS- | 3 | 1.0'-1.5' | ND |
| 22ASB2DS- | 1 | 1.5'-2.0' | ND |
| 22ASB2DS- | 2 | 2'-4' | ND |
| 22ASB2DS- | 3 | 4'-6' | ND |
| 22ASB2DS- | 4 | 6'-8' | ND |
| 22ASB2DS- | 5 | 8'-10' | ND |
| 22ASB2DS- | 6 | 10'-14' | ND |
| 22ASB2DS- | 8 | 14'-18' | ND |
| 22ASB2DS- | 10 | 18'-22' | ND |
| 22ASB2DS- | 12 | 22'-26' | ND |
| 22ASB2DS- | 14 | 26'-28' | ND |
| 22ASB2DS- | 15 | 28'-30' | ND |
| 22ASB2DS- | 16 | 30'-32' | ND |
| 22ASB2DS- | 17 | 32'-34' | ND |
| 22ASB2DS- | 18 | 34'-36' | ND |
| 22ASB2DS- | 19 | 36'-38' | ND |
| 22ASB2DS- | 20 | 38'-40' | ND |
| 22ASB2DS- | 21 | 40'-42' | ND |
| 22ASB2SS- | 1 | 0.0'-0.5' | ND |
| 22ASB2SS- | 2 | 0.5'-1.0' | ND |
| 22ASB2SS- | 3 | 1.0'-1.5' | ND |
| 23AS1DS- | 2 | 2-6' | 1.3 |
| 23AS1DS- | 4 | 6-14' | 0.4 |
| 23AS1DS- | 10 | 18-22' | ND |
| 23AS1DS- | 12 | 22-26' | ND |
| 23AS1DS- | 14 | 26-28' | ND |
| 23AS1DS- | 15 | 28-30' | ND |
| 23AS1DS- | 16 | 30-32' | ND |
| 23AS1DS- | 17 | 32-34' | ND |
| 23AS1DS- | 18 | 34-36' | ND |
| 23AS1DS- | 19 | 36-38' | ND |
| 23AS1DS- | 20 | 38-40' | ND |
| 23AS1DS- | 21 | 40-42' | ND |
| 23AS1DS- | 22 | 42-44' | ND |
| 23AS1DS- | 23 | 44-46' | ND |
| 23AS1DS- | 24 | 46-50' | ND |
| 23AS1GW- | 1 | 70' | ND |
| 23AS1SS- | 1 | 0.0'-0.5' | 1.1 |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 27DS- | 1 | 1.5-2.0' | ND |
| 27DS- | 2 | 2'-4' | ND |
| 27DS- | 3 | 4'-6' | ND |
| 27DS- | 4 | 6'-8' | ND |
| 27DS- | 5 | 8'-10' | ND |
| 27DS- | 7 | 12'-14' | ND |
| 27DS- | 8 | 14'-16' | ND |
| 27DS- | 9 | 16'-18' | ND |
| 27DS- | 10 | 18'-20' | ND |
| 27DS- | 11 | 20'-22' | ND |
| 27DS- | 12 | 22'-24' | ND |
| 27DS- | 13 | 24'-26' | ND |
| 27DS- | 14 | 26'-28' | ND |
| 27DS- | 15 | 28'-30' | ND |
| 27DS- | 16 | 30'-32' | ND |
| 27DS- | 17 | 32'-34' | ND |
| 27DS- | 18 | 34'-36' | ND |
| 27DS- | 19a | 36'-38' | ND |
| 27DS- | 20a | 38'-40' | ND |
| 27DS- | 21a | 40'-42' | ND |
| 27DS- | 22a | 42'-44' | ND |
| 27DS- | 23a | 44'-46' | ND |
| 27DS- | 24a | 46'-48' | ND |
| 27DS- | 25a | 48'-50' | ND |
| 27DS- | 26a | 50'-52' | ND |
| 27DS- | 27a | 52'-54' | ND |
| 27DS- | 28a | 54'-56' | ND |
| 27DS- | 29a | 56'-58' | ND |
| 27DS- | 30a | 58'-60' | ND |
| 27SS- | 1 | 0.0'-0.5' | ND |
| 27SS- | 2 | 0.5'-1.0' | ND |
| 27SS- | 3 | 1.0-1.5' | ND |
| 31SBE50CC- | 1 | 0.0'-0.5' | 0.5 |
| 31SBE50CC- | 01-R | 0.0'-0.5' | 0.5 |
| 31SBE50DS- | 1 | 1.5'-2.0' | ND |
| 31SBE50DS- | 2 | 2'-4' | ND |
| 31SBE50DS- | 3 | 4'-6' | ND |
| 31SBE50DS- | 17 | 32'-34' | ND |
| 31SBE50DS- | 18 | 34'-36' | ND |
| 31SBE50DS- | 19 | 36'-38' | ND |
| 31SBE50DS- | 20 | 38'-40' | ND |
| 31SBE50DS- | 21 | 40'-42' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 31SBE50DS- | 22 | 42'-44' | ND |
| 31SBE50DS- | 23 | 44'-46' | ND |
| 31SBE50DS- | 24 | 46'-48' | ND |
| 31SBE50DS- | 25 | 48'-50' | ND |
| 31SBE50DS- | 26 | 50'-52' | ND |
| 31SBE50DS- | 27 | 52'-54' | ND |
| 31SBE50DS- | 28 | 54'-56' | ND |
| 31SBE50DS- | 29 | 56'-58' | ND |
| 31SBE50DS- | 30 | 58'-60' | ND |
| 31SBE50SS- | 1 | 0.0'-0.5' | ND |
| 31SBE50SS- | 2 | 0.5'-1.0' | ND |
| 31SBE50SS- | 3 | 1.0'-1.5' | ND |
| 31SBWCC- | 1 | 0.0'-0.5' | 0.8 |
| 31SBWDS- | 1 | 1.5'-2.0' | ND |
| 31SBWDS- | 2 | 2' 4' | ND |
| 31SBWDS- | 18 | 34'-36' | ND |
| 31SBWDS- | 19 | 36'-38' | ND |
| 31SBWDS- | 20 | 38'-40' | ND |
| 31SBWDS- | 21 | 40'-42' | ND |
| 31SBWDS- | 22 | 42'-44' | ND |
| 31SBWDS- | 23 | 44'-46' | ND |
| 31SBWDS- | 24 | 46'-48' | ND |
| 31SBWDS- | 25 | 48'-50' | ND |
| 31SBWDS- | 26 | 50'-52' | ND |
| 31SBWDS- | 27 | 52'-54' | ND |
| 31SBWDS- | 28 | 54'-56' | ND |
| 31SBWDS- | 29 | 56'-58' | ND |
| 31SBWDS- | 30 | 58'-60' | 0.2 |
| 31SBWSS- | 1 | 0.0'-0.5' | ND |
| 31SBWSS- | 2 | 0.5'-1.0' | ND |
| 31SBWSS- | 3 | 1.0'-1.5' | ND |
| 35S2SDS- | 1 | 1.5'-2.0' | 0.6 |
| 35S2SDS- | 12 | 22'-24' | 14.7 |
| 35S2SDS- | 15-R | 28'-30' | 1.4 |
| 35S2SDS- | 15 | 28'-30' | 1.4 |
| 35S2SDS- | 16 | 30'-32' | ND |
| 35S2SDS- | 17 | 32'-34' | ND |
| 35S2SDS- | 18 | 34'-36' | ND |
| 35S2SDS- | 13 | 24'-26' | 4.5 |
| 35S2SDS- | 19 | 36'-38' | 0.7 |
| 35S2SDS- | 14 | 26'-28' | ND |
| 35S2SDS- | 20 | 38'-40' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 35S2SDS- | 21 | 40'-42' | ND |
| 35S2SDS- | 22 | 42'-44' | ND |
| 35S2SDS- | 23 | 44'-46' | ND |
| 35S2SDS- | 24 | 46'-48' | ND |
| 35S2SDS- | 25 | 48'-50' | ND |
| 35S2SDS- | 26 | 50'-52' | ND |
| 35S2SDS- | 27 | 52'-56' | ND |
| 35S2SDS- | 29 | 56'-58' | ND |
| 35S2SDS- | 30 | 58'-60' | ND |
| 35S2SDS- | 31 | 60'-62' | ND |
| 35S2SDS- | 32 | 62'-64' | ND |
| 35S2SDS- | 33 | 64'-66' | ND |
| 35S2SDS- | 34 | 66'-68' | ND |
| 35S2SSS- | 1 | 0.0'-0.5' | 0.8 |
| 35S2SSS- | 2 | 0.5'-1.0' | 0.5 |
| 35S2SSS- | 3 | 1.0'-1.5' | 0.3 |
| 36AS2DS- | 4 | 6'-10' | ND |
| 36AS2DS- | 7 | 12'-14' | ND |
| 36AS2DS- | 8 | 14'-16' | ND |
| 36AS2DS- | 9 | 16'-20' | ND |
| 36AS2DS- | 11 | 20'-22' | ND |
| 36AS2DS- | 12 | 22'-24' | ND |
| 36AS2DS- | 13 | 24'-26' | ND |
| 36AS2DS- | 14 | 26'-28' | ND |
| 36AS2DS- | 15 | 28'-30' | ND |
| 36AS2DS- | 16 | 30'-32' | ND |
| 36AS2DS- | 17 | 32'-34' | ND |
| 36AS2DS- | 18 | 34'-36' | ND |
| 36AS2DS- | 19 | 36'-38' | ND |
| 36AS2DS- | 20 | 38'-40' | ND |
| 47AS3DS | 7 | 12'-16' | ND |
| 47AS3DS | 7 | 12'-16' | ND |
| 47AS3DS- | 9 | 16'-18' | ND |
| 47AS3DS- | 9 | 16'-18' | ND |
| 47AS3DS- | 10 | 18'-20' | ND |
| 47AS3DS- | 10 | 18'-20' | ND |
| 47AS3DS- | 11 | 20'-22' | ND |
| 47AS3DS- | 11 | 20'-22' | ND |
| 47AS3DS- | 12 | 22'-24' | ND |
| 47AS3DS- | 12 | 22'-24' | ND |
| 47AS3DS- | 13 | 24'-26' | ND |
| 47AS3DS- | 13 | 24'-26' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 47AS3DS- | 14 | 26'-28' | ND |
| 47AS3DS- | 14 | 26'-28' | ND |
| 47AS3DS- | 15 | 28'-30' | ND |
| 47AS3DS- | 15 | 28'-30' | ND |
| 47AS3DS- | 16 | 30'-32' | ND |
| 47AS3DS- | 16 | 30'-32' | ND |
| 47AS3DS- | 17 | 32'-34' | ND |
| 47AS3DS- | 17 | 32'-34' | ND |
| 47AS3DS- | 18 | 34'-36' | ND |
| 47AS3DS- | 18 | 34'-36' | ND |
| 47AS3DS- | 19 | 36'-38' | ND |
| 47AS3DS- | 19 | 36'-38' | ND |
| 47AS3DS- | 20 | 38'-40' | ND |
| 47AS3DS- | 20 | 38'-40' | ND |
| 47AS3DS- | 21 | 40'-42' | ND |
| 47AS3DS- | 21 | 40'-42' | ND |
| 47AS3DS- | 22 | 42'-44' | ND |
| 47AS3DS- | 22 | 42'-44' | ND |
| 47AS3DS- | 23 | 44'-46' | ND |
| 47AS3DS- | 23 | 44'-46' | ND |
| 47AS3DS- | 24 | 46'-48' | ND |
| 47AS3DS- | 24 | 46'-48' | ND |
| 47AS3DS- | 25 | 48'-50' | ND |
| 47AS3DS- | 26 | 50'-52' | ND |
| 47AS3DS- | 26 | 50'-52' | ND |
| 47AS3DS- | 27 | 52'-54' | ND |
| 47AS3DS- | 27 | 52'-54' | ND |
| 47AS3DS- | 28 | 54'-56' | ND |
| 47AS3DS- | 28 | 54'-56' | ND |
| 47AS3DS- | 29 | 56'-58' | ND |
| 47AS3DS- | 29 | 56'-58' | ND |
| 47AS3DS- | 25 | 48'-50' | ND |
| 47AS3DS- | 30 | 58'-60' | ND |
| 47AS3DS- | 30 | 58'-60' | ND |
| 47AS3DS- | 31 | 60'-62' | ND |
| 47AS3DS- | 31 | 60'-62' | ND |
| 47AS3DS- | 32 | 62'-64' | ND |
| 47AS3DS- | 32 | 62'-64' | ND |
| 47AS3DS- | 33 | 64'-66' | ND |
| 47AS3DS- | 33 | 64'-66' | ND |
| 47AS3DS- | 34 | 66'-68' | ND |
| 47AS3DS- | 34 | 66'-68' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 56S3NDS- | 1 | 1.5-2.0' | ND |
| 56S3NDS- | 2 | 2'-3' | ND |
| 56S3NDS- | 12 | 21'-23' | ND |
| 56S3NDS- | 13 | 23'-25' | ND |
| 56S3NDS- | 14 | 25'-27' | ND |
| 56S3NDS- | 15 | 27'-29' | 0.6 |
| 56S3NDS- | 16 | 29'-31' | ND |
| 56S3NDS- | 18 | 33'-35' | ND |
| 56S3NDS- | 19 | 35'-37' | 0.1 |
| 56S3NDS- | 20 | 37'-39' | ND |
| 56S3NDS- | 21 | 39'-41' | ND |
| 56S3NDS- | 22 | 41'-43' | ND |
| 56S3NDS- | 23 | 43'-45' | ND |
| 56S3NDS- | 24 | 45'-47' | ND |
| 56S3NSS- | 1 | 0.0'-0.5' | ND |
| 56S3NSS- | 2 | 0.5'-1.0' | ND |
| 67AS4-3S- | 9 | 16'-20' | ND |
| 67AS4-3S- | 11 | 20'-22' | ND |
| 67AS4-3S- | 12 | 22'-24' | ND |
| 67AS4-3S- | 13 | 24'-26' | ND |
| 67AS4-3S- | 14 | 26'-28' | ND |
| 67AS4-3S- | 15 | 28'-30' | ND |
| 67AS4-3S- | 16 | 30'-32' | ND |
| 67AS4-3S- | 17 | 32'-34' | ND |
| 67AS4-3S- | 17-R | | ND |
| 67AS4-3S- | 18 | 34'-36' | ND |
| 67AS4-3S- | 19 | 36'-38' | ND |
| 67AS4-3S- | 20 | 38'-40' | ND |
| 67AS4-3S- | 21 | 40'-42' | ND |
| 67AS4-3S- | 26 | 50'-52' | ND |
| 67AS4-3S- | 22 | 42'-44' | ND |
| 67AS4-3S- | 23 | 44'-46' | ND |
| 67AS4-3S- | 24 | 46'-48' | ND |
| 67AS4-3S- | 25 | 48'-50' | ND |
| 67AS4-3S-3W- | 9 | 16'-18' | ND |
| 67AS4-3S-3W- | 10 | 18'-20' | ND |
| 67AS4-3S-3W- | 11 | 20'-22' | ND |
| 67AS4-3S-3W- | 12 | 22'-24' | 0.2 |
| 67AS4-3S-3W- | 13 | 24'-26' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 3W- | | | |
| 67AS4-3S-3W- | 14 | 26'-28' | ND |
| 67AS4-3S-3W- | 15 | 28'-30' | ND |
| 67AS4-3S-3W- | 16 | 30'-32' | ND |
| 67AS4-3S-3W- | 17 | 32'-34' | ND |
| 67AS4-3S-3W- | 18 | 34'-36' | ND |
| 67AS4-3S-3W- | 19 | 36'-38' | ND |
| 67AS4-3S-3W- | 20 | 38'-40' | ND |
| 67AS4-3S-3W- | 21 | 40'-42' | ND |
| 67AS4-3S-3W- | 22 | 42'-44' | ND |
| 67AS4-3S-3W- | 23 | 44'-46' | ND |
| 67AS4-3S-3W- | 24 | 46'-48' | ND |
| 67AS4-3S-3W- | 25 | 48'-50' | ND |
| 67AS4-3S-3W- | 26 | 50'-52' | 0.3 |
| 67AS4DS- | 1 | 1.5'-2.0' | 6.3 |
| 67AS4DS- | 2 | 2'-4' | 7.7 |
| 67AS4DS- | 3 | 4'-6' | 1.3 |
| 67AS4DS- | 5 | 8'-10' | 0.8 |
| 67AS4DS- | 6 | 10'-12' | ND |
| 67AS4DS- | 7 | 12'-14' | ND |
| 67AS4DS- | 8 | 14'-16' | ND |
| 67AS4DS- | 9 | 16'-18' | 83.9 |
| 67AS4DS- | 09a | 16'-20' | ND |
| 67AS4DS- | 11a | 20'-22' | 1122 |
| 67AS4DS- | 12a-R | 22'-24' | 784 |
| 67AS4DS- | 12a | 22'-24' | 796 |
| 67AS4DS- | 13a-R | 24'-26' | 426 |
| 67AS4DS- | 13a | 24'-26' | 433 |
| 67AS4DS- | 14a-R | 26'-28' | 87.3 |
| 67AS4DS- | 14a | 26'-28' | 88 |
| 67AS4DS- | 15a | 28'-30' | 21.3 |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 67AS4DS- | 17a | 32'-34' | 22.9 |
| 67AS4DS- | 18a | 34'-36' | ND |
| 67AS4DS- | 19a | 36'-38' | 1.9 |
| 67AS4DS- | 20a | 38'-40' | ND |
| 67AS4DS- | 21a | 40'-44' | 4.8 |
| 67AS4DS- | 23a | 44'-46' | 19.9 |
| 67AS4DS- | 24a | 46'-48' | ND |
| 67AS4DS- | 25a | 48'-50' | 15.9 |
| 67AS4DS- | 26a | 50'-52' | ND |
| 67AS4DS- | 27a | 52'-54' | ND |
| 67AS4DS- | 28a | 54'-56' | ND |
| 67AS4SS- | 1 | 0'-0.5' | 10.7 |
| 67AS4SS- | 2 | 0.5'-1.0' | 6 |
| 67AS4SS- | 3 | 1.0'-1.5' | 5.6 |
| 77S4SDS- | 10 | 18'-20' | 2854 |
| 77S4SDS- | 11 | 20'-24' | 804 |
| 77S4SDS- | 11-R | 20'-24' | 821 |
| 77S4SDS- | 13 | 24'-26' | 226 |
| 77S4SDS- | 15 | 28'-30' | 191 |
| 77S4SDS- | 16 | 30'-32' | 0.6 |
| 77S4SDS- | 18 | 34'-36' | ND |
| 77S4SDS- | 20 | 38'-40' | ND |
| 77S4SDS- | 21 | 40'-42' | 2.9 |
| 77S4SDS- | 22 | 42'-44' | ND |
| 77S4SDS- | 23 | 44'-46' | 7.4 |
| 77S4SDS- | 24 | 46'-48' | ND |
| 77S4SDS- | 25 | 48'-50' | 8.1 |
| 77S4SDS- | 26 | 50'-52' | ND |
| 77S4SDS- | 27 | 52'-54' | 7 |
| 77S4SDS- | 28 | 54'-56' | ND |
| 77S4SDS- | 29 | 56'-58' | 47.2 |
| 77S4SDS- | 30 | 58'-60' | ND |
| 77S4SDS- | 31 | 60'-62' | 1.1 |
| 77S4SDS- | 32 | 62'-64' | ND |
| 77S4SDS- | 33 | 64'-66' | 4.4 |
| 77S4SDS- | 34 | 66'-68' | ND |
| 77S4SSS- | 1 | 0.0'-0.5' | 10.6 |
| 77S4SSS- | 2 | 0.5'-1.0' | 13.9 |
| 77S4SSS- | 3 | 1.0'-1.5' | 10.5 |
| 41NBEDS- | 1 | 1.5'-2.0' | ND |
| 41NBEDS- | 1 | 1.5'-2.0' | ND |
| 41NBEDS- | 2 | 2'-4' | 0.2 |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 41NBEDS- | 2 | 2'-4' | 0.2 |
| 41NBEDS- | 3 | 4'-6' | ND |
| 41NBEDS- | 3 | 4'-6' | ND |
| 41NBEDS- | 16 | 30'-34' | 58.3 |
| 41NBEDS- | 18 | 34'-36' | 146 |
| 41NBEDS- | 19 | 36'-38' | ND |
| 41NBEDS- | 20 | 38'-40' | 17.5 |
| 41NBEDS- | 21 | 40'-42' | ND |
| 41NBEDS- | 22 | 42'-44' | 13.7 |
| 41NBEDS- | 23 | 44'-46' | ND |
| 41NBEDS- | 24 | 46'-48' | ND |
| 41NBEDS- | 25 | 48'-50' | ND |
| 41NBEDS- | 26 | 50'-52' | 4.3 |
| 41NBEDS- | 27 | 52'-54' | 0.3 |
| 41NBESS- | 1 | 0.0'-0.5' | ND |
| 41NBESS- | 1 | 0.0'-0.5' | ND |
| 41NBESS- | 2 | 0.5'-1.0' | ND |
| 41NBESS- | 2 | 0.5'-1.0' | ND |
| 41NBESS- | 3 | 1.0'-1.5' | ND |
| 41NBESS- | 3 | 1.0'-1.5' | ND |
| 41NBWCC- | 1 | 0.0'-0.5' | ND |
| 41NBWDS- | 1 | 1.5'-2.0' | ND |
| 41NBWDS- | 2 | 2'-4' | ND |
| 41NBWDS- | 3 | 4'-6' | ND |
| 41NBWDS- | 19 | 36-38' | ND |
| 41NBWDS- | 20 | 38'-40' | 1.9 |
| 41NBWDS- | 20-R | 38'-40' | 1.9 |
| 41NBWDS- | 21 | 40'-42' | ND |
| 41NBWDS- | 22 | 42'-44' | 1.6 |
| 41NBWDS- | 23 | 44'-46' | ND |
| 41NBWDS- | 24 | 46'-48' | 1.2 |
| 41NBWDS- | 25 | 48'-50' | ND |
| 41NBWDS- | 26 | 50'-52' | 1.2 |
| 41NBWDS- | 27 | 52'-54' | ND |
| 41NBWDS- | 28 | 54'-56' | ND |
| 41NBWDS- | 29 | 56'-58' | ND |
| 41NBWDS- | 30 | 58'-60' | 1.1 |
| 41NBWDS- | 31 | 60'-62' | ND |
| 41NBWSS- | 1 | 0.0'-0.5' | ND |
| 41NBWSS- | 2 | 0.5'-1.0' | ND |
| 41NBWSS- | 3 | 1.0'-1.5' | ND |
| 43N1SDS | 11 | 20'-22' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 43N1SDS | 12 | 22'-24' | ND |
| 43N1SDS | 13-14 | 24'-28' | ND |
| 43N1SDS | 15 | 28'-30' | ND |
| 43N1SDS | 16 | 30'-32' | ND |
| 43N1SDS | 17 | 32'-34' | ND |
| 43N1SDS | 18 | 34'-36' | ND |
| 43N1SDS | 19 | 36'-38' | ND |
| 43N1SDS | 20 | 38'-40' | ND |
| 43N1SDS | 21 | 40'-42' | ND |
| 43N1SDS | 22 | 42'-44' | ND |
| 43N1SDS | 23 | 44'-46' | ND |
| 43N1SDS | 24 | 46'-48' | ND |
| 43N1SDS | 25 | 48'-50' | ND |
| 43N1SDS | 26 | 50'-52' | ND |
| 43N1SDS | 27 | 52'-54' | ND |
| 43N1SDS | 28 | 54'-56' | ND |
| 43N1SDS | 29 | 56'-58' | ND |
| 43N1SDS | 30 | 58'-60' | ND |
| 43N1SDS | 31 | 60'-62' | ND |
| 43N1SDS | 32 | 62'-64' | ND |
| 43NISSS- | 01-R | 0.0'-0.5' | 1.2 |
| 43NISSS- | 1 | 0.0'-0.5' | 1.3 |
| 43NISSS- | 2 | 0.5'-1.0' | 0.5 |
| 43NISSS- | 3 | 1.0'-1.5' | 1 |
| 51ANBDS | 2 | 2'-6' | ND |
| 51ANBDS | 04a | 6'-10' | ND |
| 51ANBDS | 06a | 10'-14' | ND |
| 51ANBDS- | 1 | 1.5'-2.0' | ND |
| 51ANBDS- | 01R | 1.5'-2.0' | ND |
| 51ANBDS- | 08b-R | 14'-16' | ND |
| 51ANBDS- | 08b | 14'-16' | ND |
| 51ANBDS- | 09b | 16'-18' | ND |
| 51ANBDS- | 09b-R | 16'-18' | ND |
| 51ANBDS- | 10b-R | 18'-20' | ND |
| 51ANBDS- | 10b | 18'-20' | ND |
| 51ANBDS- | 11b | 20'-22' | ND |
| 51ANBDS- | 11b-R | 20'-22' | ND |
| 51ANBDS- | 12b-R | 22'-24' | ND |
| 51ANBDS- | 12b | 22'-24' | ND |
| 51ANBDS- | 13b-R | 24'-26' | ND |
| 51ANBDS- | 13b | 24'-26' | ND |
| 51ANBDS- | 13E | 24'-28' | 13.1 |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 51ANBDS- | 14b-R2 | 26-28' | 8000 |
| 51ANBDS- | 14b | 26-28' | 12300 |
| 51ANBDS- | 16D | 28'-29' | 21100 |
| 51ANBDS- | 15C | 28'-30' | 39400 |
| 51ANBDS- | 15E | 28'-32' | 5.3 |
| 51ANBDS- | 16E | 32' | 10100 |
| 51ANBDS- | 17F | 32'-34' | 17050 |
| 51ANBDS- | 18F | 34'-36' | 10300 |
| 51ANBDS- | 19E-R | 36'-38' | 675 |
| 51ANBDS- | 19E | 36'-38' | 676 |
| 51ANBDS- | 20E | 38'-40' | 2.4 |
| 51ANBDS- | 21E | 40'-42' | 8.9 |
| 51ANBDS- | 22E | 42'-44' | ND |
| 51ANBDS- | 23E | 44'-46' | 2.1 |
| 51ANBDS- | 24E | 46'-48' | ND |
| 51ANBDS- | 25E | 48'-50' | 6 |
| 51ANBDS- | 26E | 50'-52' | ND |
| 51ANBSS- | 1 | 0.0'-0.5' | ND |
| 51ANBSS- | 2 | 0.5'-1.0' | ND |
| 51ANBSS- | 3 | 1.0'-1.5' | ND |
| 52ANB1DS- | 1 | 1.5'-2.0' | ND |
| 52ANB1DS- | 2 | 2'-4' | ND |
| 52ANB1DS- | 3 | 4'-6' | ND |
| 52ANB1DS- | 4 | 6'-10' | ND |
| 52ANB1DS- | 6 | 10'-14' | ND |
| 52ANB1DS- | 8 | 14'-18' | ND |
| 52ANB1DS- | 10 | 18'-20' | ND |
| 52ANB1DS- | 11S | 20'-22' | ND |
| 52ANB1DS- | 11 | 20'-22' | ND |
| 52ANB1DS- | 12 | 22'-23' | ND |
| 52ANB1DS- | 12a | 22'-24' | 8.2 |
| 52ANB1DS- | 12a-R | 22'-24' | 10.6 |
| 52ANB1DS- | 13a | 24'-28' | 2.1 |
| 52ANB1DS- | 15a | 28'-32' | ND |
| 52ANB1DS- | 19a | 36'-40' | ND |
| 52ANB1DS- | 21a | 40'-42' | ND |
| 52ANB1DS- | 23a | 44'-48' | ND |
| 52ANB1SS- | 01R | 0.0'-0.5' | 1.7 |
| 52ANB1SS- | 1 | 0.0'-0.5' | 2.2 |
| 52ANB1SS- | 2 | 0.5'-1.0' | ND |
| 52ANB1SS- | 3 | 1.0'-1.5' | ND |
| 53AN1DS- | 2 | 2'-4' | 0.4 |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 53AN1DS- | 03-R | 4-8' | 1.2 |
| 53AN1DS- | 3 | 4-8' | 1.3 |
| 53AN1DS- | 5 | 8'-12' | 0.5 |
| 53AN1DS- | 7 | 12'-16' | 0.3 |
| 53AN1DS- | 9 | 16'-18' | ND |
| 53AN1DS- | 10 | 18'-20' | ND |
| 53AN1DS- | 11 | 20'-22' | ND |
| 53AN1DS- | 12 | 22'-24' | ND |
| 53AN1DS- | 14 | 26'-28' | 0.5 |
| 53AN1DS- | 15 | 28'-30' | ND |
| 53AN1DS- | 16 | 30'-32' | ND |
| 53AN1DS- | 17 | 32'-34' | ND |
| 53AN1DS- | 13 | 24'-26' | ND |
| 53AN1DS- | 18 | 34'-36' | ND |
| 53AN1SS- | 1 | 0.0'-0.5' | ND |
| 53AN1SS- | 2 | 0.5'-1.0' | 0.6 |
| 53AN2DS- | 1 | 1.5'-2.0' | ND |
| 53AN2DS- | 2 | 2'-4' | 0.5 |
| 53AN2DS- | 3 | 4'-8' | ND |
| 53AN2DS- | 7 | 12'-16' | 0.1 |
| 53AN2DS- | 9 | 16'-20' | ND |
| 53AN2DS- | 11 | 20'-22' | ND |
| 53AN2DS- | 12 | 22'-24' | ND |
| 53AN2DS- | 13 | 24'-26' | ND |
| 53AN2DS- | 14 | 26'-28' | ND |
| 53AN2DS- | 15 | 28'-30' | 0.5 |
| 53AN2DS- | 16 | 30'-32' | ND |
| 53AN2DS- | 17 | 32'-34' | ND |
| 53AN2DS- | 18 | 34'-36' | ND |
| 53AN2DS- | 19 | 36'-38' | ND |
| 53AN2DS- | 20 | 38'-40' | ND |
| 53AN2DS- | 21 | 40'-42' | ND |
| 53AN2DS- | 22 | 42'-44' | ND |
| 53AN2SS- | 1 | 0.0'-0.5' | ND |
| 53AN2SS- | 2 | 0.5'-1.0' | 1.1 |
| 53AN2SS- | 3 | 1.0'-1.5' | 1.5 |
| 54N2NDS- | 01R | 1.5-2.0' | 1.4 |
| 54N2NDS- | 1 | 1.5-2.0' | 1.5 |
| 54N2NDS- | 13 | 23'-25' | ND |
| 54N2NDS- | 14 | 25'-27' | ND |
| 54N2NDS- | 16 | 29'-31' | ND |
| 54N2NDS- | 17 | 31-33' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 54N2NDS- | 18 | 33-35' | ND |
| 54N2NDS- | 20 | 37-39' | ND |
| 54N2NDS- | 21 | 39'-41' | ND |
| 54N2NDS- | 22 | 41-43' | ND |
| 54N2NDS- | 23 | 43-45' | ND |
| 54N2NDS- | 24 | 45-47' | ND |
| 54N2NDS- | 25 | 47-49' | ND |
| 54N2NDS- | 26 | 49-51' | ND |
| 54N2NDS- | 27 | 51-53' | ND |
| 54N2NDS- | 28 | 53-55' | ND |
| 54N2NDS- | 29 | 55-59' | ND |
| 54N2NDS- | 31 | 59-61' | ND |
| 54N2NDS- | 32 | 61-63' | ND |
| 54N2NSS- | 2 | 0.5'-1.0' | 2.2 |
| 74AN3DS- | 1 | 1.5'-2.0' | ND |
| 74AN3DS- | 3 | 4'-6' | ND |
| 74AN3DS- | 4 | 6'-8' | ND |
| 74AN3DS- | 5 | 8'-10' | ND |
| 74AN3DS- | 6 | 10'-12' | ND |
| 74AN3DS- | 7 | 12'-14' | ND |
| 74AN3DS- | 8 | 14'-16' | ND |
| 74AN3DS- | 9 | 16'-18' | ND |
| 74AN3DS- | 10 | 18'-20' | ND |
| 74AN3DS- | 11 | 20'-22' | ND |
| 74AN3DS- | 12 | 22'-24' | ND |
| 74AN3DS- | 13 | 24'-26' | ND |
| 74AN3DS- | 14 | 26'-28' | ND |
| 74AN3DS- | 15 | 28'-30' | ND |
| 74AN3DS- | 16 | 30'-32' | 0.3 |
| 74AN3DS- | 17 | 32'-34' | ND |
| 74AN3DS- | 18 | 34'-36' | ND |
| 74AN3DS- | 19 | 36'-38' | ND |
| 74AN3DS- | 20 | 38'-40' | ND |
| 74AN3DS- | 21 | 40'-42' | ND |
| 74AN3DS- | 22 | 42'-44' | ND |
| 74AN3DS- | 23 | 44'-46' | ND |
| 74AN3DS- | 24 | 46'-48' | ND |
| 74AN3DS- | 25 | 48'-50' | ND |
| 74AN3DS- | 26 | 50'-52' | ND |
| 74AN3DS- | 27 | 52'-54' | ND |
| 74AN3DS- | 28 | 54'-56' | ND |
| 74AN3DS- | 29 | 56'-60' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 74AN3DS- | 31 | 60'-62' | ND |
| 74AN3DS- | 32 | 62'-64' | ND |
| 74AN3DS- | 33 | 64'-66' | ND |
| 74AN3DS- | 34 | 66'-68' | ND |
| 74AN3SS- | 1 | 0.0'-0.5' | 0.8 |
| 74AN3SS- | 2 | 0.5'-1.0' | 1 |
| 74AN3SS- | 3 | 1.0'-1.5' | 0.6 |
| 75N4NDS- | 1 | 1.5'-2.0' | 7.7 |
| 75N4NDS- | 11R | 20'-24' | 66 |
| 75N4NDS- | 14 | 26'-28' | ND |
| 75N4NDS- | 16 | 30'-32' | ND |
| 75N4NDS- | 17 | 32'-34' | 6.1 |
| 75N4NDS- | 18 | 34'-36' | ND |
| 75N4NDS- | 19 | 36'-38' | 0.7 |
| 75N4NDS- | 20 | 38'-40' | ND |
| 75N4NDS- | 21 | 40'-42' | 0.7 |
| 75N4NDS- | 22 | 42'-44' | ND |
| 75N4NDS- | 23 | 44'-46' | 5.6 |
| 75N4NDS- | 24 | 46'-48' | ND |
| 75N4NDS- | 25 | 48'-50' | 2.4 |
| 75N4NDS- | 26 | 50'-52' | 1.1 |
| 75N4NSS- | 1 | 0.0'-0.5' | 12.2 |
| 75N4NSS- | 2 | 0.5'-1.0' | 2.8 |
| 75N4NSS- | 3 | 1.0'-1.5' | 9.5 |
| 84AN4DS- | 1 | 1.5'-2.0' | 2 |
| 84AN4DS- | 2 | 2'-4' | ND |
| 84AN4DS- | 3 | 4'-6' | ND |
| 84AN4DS- | 4 | 6'-8' | ND |
| 84AN4DS- | 5 | 8'-10' | ND |
| 84AN4DS- | 6 | 10'-12' | ND |
| 84AN4DS- | 7 | 12'-14' | ND |
| 84AN4DS- | 8 | 14'-18' | 2.1 |
| 84AN4DS- | 10 | 18'-20' | 0.7 |
| 84AN4DS- | 11 | 20'-22' | ND |
| 84AN4DS- | 12 | 22'-24' | ND |
| 84AN4DS- | 13 | 24'-26' | 1.3 |
| 84AN4DS- | 14 | 26'-28' | 4.2 |
| 84AN4DS- | 15 | 28'-30' | 4.1 |
| 84AN4DS- | 16 | 30'-34' | ND |
| 84AN4DS- | 18 | 34'-36' | ND |
| 84AN4DS- | 19 | 36'-38' | ND |
| 84AN4DS- | 20 | 38'-42' | ND |

| Sample ID | | Depth | Cs-137 |
|---|---|---|---|
| 84AN4DS- | 22 | 42'-44' | ND |
| 84AN4DS- | 23 | 44'-46' | ND |
| 84AN4DS- | 24 | 46'-48' | 1 |
| 84AN4DS- | 25 | 48'-50' | 0.4 |
| 84AN4SS- | 1 | 0.0'-0.5' | 7.7 |
| 84AN4SS- | 2 | 0.5'-1.0' | 5.5 |
| 84AN4SS- | 3 | 1.0'-1.5' | 1.5 |
| 84ANB2DS- | 04R | 6'-8' | ND |
| 84ANB2DS- | 4 | 6'-8' | ND |
| 84ANB2DS- | 5 | 8'-10' | ND |
| 84ANB2DS- | 6 | 10'-14' | ND |
| 84ANB2DS- | 8 | 14'-18' | ND |
| 84ANB2DS- | 10 | 18'-20' | ND |
| 84ANB2DS- | 11 | 20'-22' | ND |
| 84ANB2DS- | 12 | 22'-24' | ND |
| 84ANB2DS- | 13 | 24'-26' | ND |
| 84ANB2DS- | 14 | 26'-28' | ND |
| 84ANB2DS- | 15 | 28'-30' | ND |
| 84ANB2DS- | 16 | 30'-32' | ND |
| 84ANB2DS- | 17 | 32'-34' | ND |
| 84ANB2DS- | 18 | 34'-36' | ND |
| 84ANB2DS- | 19 | 36'-38' | ND |
| 84ANB2DS- | 20 | 38'-40' | ND |
| 84ANB2DS- | 22 | 42'-46' | ND |
| 84ANB2DS- | 26 | 50'-54' | ND |
| 84ANB2SS- | 1 | 0.0'-0.5' | 0.8 |
| 84ANB2SS- | 2 | 0.5'-1.0' | ND |
| 84ANB2SS- | 3 | 1.0'-1.5' | ND |
| 84ANB2SS- | 1 | 1.5'-2.0' | ND |
| 84ANB2SS- | 2 | 2'-4' | ND |
| 84ANB2SS- | 3 | 4'-6' | ND |
| 84ASB2DS- | 21 | 40'-42' | ND |
| ANB-3E- | 18-19 | 34-38' | 67 |
| ANB-3E- | 18-19-R | 34-38' | 67.5 |
| ANB-3S- | 16-17 | 30-34' | 0.2 |
| ANB-3S- | 18 | 34-36' | 1686 |
| ANB-3S- | 19 | 36-38' | 1.7 |
| ANB3E-3E- | 19 | 36-38 | 40.4 |

# REFERENCES


1. Draft Below-Ground Ducts Engineering Evaulation/Cost Analysis, Brookhaven Graphite Research Reactor Decommissioning Project, Brookhaven Nation laboratory, January 30, 2002, BGRR-050, Rev. D.

2. Historical Site Assessment for Brookhaven Graphite Research Reactor Complex and Pile Fan Sump Soils (Excluding Building 702), BGRR-009, BNL Internal Report, October 1999.

3. J. HEISER and B.P. DWYER, "Summary Report on Close-Coupled Subsurface Barrier Technology - Initial Field Trials to Full-Scale Demonstration", Brookhaven National Laboratory, Upton, New York, September 1997, BNL-52531, (1997).

4. T.M. SULLIVAN, J. HEISER, A. GARD, and G. SENUM, "Monitoring Subsurface Barrier Integrity Using Perfluorocarbon Tracers", ASCE Journal of Environmental Engineering, Vol. 124, No. 6, (1998).

5. T.W. D'OTTAVIO and R.N. DIETZ, "Radon Source Rate Measurements using Perfluorocarbon Tracers", Indoor Air '87, 4th International Conference on Indoor Air Quality and Climate, Berlin, Germany, (1987).

6. E.G. HORN, R.N. DIETZ, R.M. ALDOUS, G.A. LEADON, J.J. HONAN, and K.K. SEIFFERT, EPRI 1991 PCB Seminar, Baltimore, MD, Electric Power Research Institute (1991).

7. J. HEISER, T.M. SULLIVAN, "Using Perfluorocarbon Tracers For Verification Of Cap And Cover Systems Performance", Brookhaven National Laboratory, Upton, New York, November 2001, BNL-52647, (2001).

8. J. HEISER, T.M. SULLIVAN, P. KALB, L. MILIAN, C. NEWSON and M. LILIMPAKIS, "Characterization of Leak Pathways in Below Grade Ducts of the BGRR Using Perfluorocarbon Tracers", Brookhaven National Laboratory, Upton, New York, April 2001, BNL-52629, (2001).

9. P. Kalb, L. Luckett, K. Miller, C. Gogolak, and L. Milian, "Accelerated Site Technology Deployment, Cost and Performance Report, Comparability of ISOCS Instrument in Radionuclide Characterization at the Brookhaven National Laboratory", Brookhaven National Laboratory, Upton, New York, March 2001, BNL-52607-01/04-Rev, (2001).

10. P.D. Kalb, L. Milian, L. Luckett, D. Watters, K. M. Miller and C. Gogolak, Deployment of Innovative Characterization Technologies and Implementation of the MARSSIM Process at Radiologically Contaminated Sites, FY2000 Program Document Compilation, Brookhaven National Laboratory, Upton, New York, May 2001, BNL-52633.

11. BGRR Characterization Report for the Below Grade Ducts, Brookhaven National Laboratory Internal Report, 1/31/02.