Characterization and Reclamation Assessment for the Central Shops Diesel Storage Facility at Savannah River Site^(U)

MASTER

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

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Characterization and Reclamation Assessment of the Central Shops Diesel Storage Facility at the Savannah River Site (U)

C. B. Fliermans, T. C. Hazen, and H. W. Bledsoe

Abstract

The contamination of subsurface terrestrial environments by organic contaminants is a global phenomenon. The remediation of such environments requires innovative assessment techniques and strategies for successful cleanups. Using innovative approaches, the Central Shops Diesel Storage Facility at the Savannah River Site (SRS) was characterized to determine the extent of subsurface diesel fuel contamination. Effective bioremediation techniques for cleaning up of the contaminant plume were established.

1.0 Introduction

This report summarizes the environmental characterization data and a bioreclamation feasibility assessment for the Central Shops Diesel Storage Area at the Savannah River Site (SRS) in Aiken, South Carolina, and it is a part of a remedial action investigation of the contaminated soils and sediments at the Central Shops Diesel Storage Area.

1.1 Background

Groundwater and vadose zone sediments throughout the world have become contaminated with industrial and agricultural wastes over the centuries. Abelson (1989) tried to place the problem in perspective in that as many as 375,000 underground storage tanks in the United States have leaked and endangered groundwater systems. The problem is far more extensive than underground storage tanks and the North American continent. The problem is not unique to American soils; Poland, for example, reported that during the last 20 years approximately 40,000 tons of highly toxic agricultural wastes have been buried in Poland. Such estimates appear highly underestimated and the real volumes are likely to be as much as 100% higher (Amador 1992).

Abelson also pointed out that the cleanup of groundwater contamination often requires 20–40 years, costing over \$500 billion using the current cost-effective technologies. A technology that promises to reduce these costs, yet provide an effective cleanup, is bioremediation, the use of indigenous biological processes to destroy or immobilize

contaminants. Traditionally, scientists have underestimated the power, capabilities, and diversity of the subsurface microbial communities. The usefulness of indigenous microorganisms for *in situ* bioremediation of groundwater and sediment pollutants was documented in Integrated Demonstration Program at SRS (Hazen 1991) and provides new mechanisms for remediating subsurface environments contaminated with organic wastes.

Underground storage tanks at the Central Shops Diesel Storage Facility (CSDSF) at SRS (Figures 1 and 2) were installed in 1955. The tank farm contained 10 underground carbon steel storage tanks, each holding 15,000 gallons. The facility was used to store diesel fuels and occasionally gasoline. In December 1987, water that leaked from an underground water line near the CSDSF contained petroleum hydrocarbons. The contamination was presumed to be from handling and storing diesel fuel, although other contamination sources were in this area. Tanks suspected of leaking were taken out of service and a soil gas survey was conducted to determine whether hydrocarbons had leaked into the surrounding soil (Looney et al. 1988). The soil gas survey detected high concentrations of volatile components in diesel fuel. Large amounts of methane were also being produced (Figure 3), indicating biological degradation of the diesel fuel in the soils.

The characterization study for the CSDSF began in November 1988 and consisted of sampling and analyzing the shallow soils, sediments, and groundwater to determine the extent, both vertical and horizontal, of the diesel

fuel contamination. The feasibility of bioremediation as an option for remediating the site was then be determined from this characterization study.

1.2 Program Overview

The remediation goal for the CSDSF is to cost effectively reduce the contamination levels of petroleum hydrocarbons in the subsurface environment to levels that are acceptable to both SRS and regulatory agencies. This will be accomplished in a stepped approach initiated by extensive site characterization and feasibility investigations for possible remediation technologies.

The assessment portion of the investigation was separated into two sets of drilling and analyses operations. Initially, 29 boreholes were drilled from the surface to the water table (60 feet) while sampling at three-foot intervals using both split-spoon sampling technologies for sediments and Hydropunch® technology (Manchon 1992) to collect groundwater samples. The location of each of these boreholes is given in Figure 2. Total petroleum hydrocarbons (TPH), total bacterial densities, indigenous microbiological degraders of diesel fuel, and selected inorganic compounds were measured. Nine boreholes (CSD-1D, CSD-2D, CSD-4, CSD-8D, CSD-9D-CSD-13D) were continuously cored and lithologically described. Monitoring wells were then installed at each of these boreholes and the geology and hydrology of the sediments and aquifer were defined. The data for each of these wells were published in Fliermans et al. (1993). Nutrient optimization investigations were conducted to determine the following:

- the best nutrients to stimulate the indigenous microbial populations
- whether such additions were compatible with sediments at the CSDSF

2.0 Material and Methods

2.1 Site Geological Description

The Savannah River Site is located approximately 40 km from the upper (landward) margin of the Atlantic Coastal Plain and approximately 120 km from the current ocean margin. The elevation of the land's surface at SRS ranges from 25 to 125 m above mean sea level. The wedge of sediments beneath SRS ranges from approximately 200 m in thickness at the northern boundary to approximately 400 m at the southern boundary. A generalized stratigraphic section appears in Figure 4. The geology of the site was described by Sargent and Fliermans (1989).

2.2 Geology and Hydrology of Diesel Storage Facility Site

The CSDSF site contains 4–6 feet of topsoil, which is generally underlain by 15 feet of mottled clay or sandy clay. Poorly sorted and tightly packed sands and clayey sands with numerous small silty clay seams are beneath the clay layer. The sands become more cross-bedded with depth and generally contain less clay. A perched groundwater table was encountered in several borings at approximately 25 feet below land surface at the top of a sandy clay interval.

The mineral composition of three sediment samples from CSD-9D was determined by x-ray diffraction analyses. Two samples, from 62 to 64 feet and 66 to 67 feet respectively, were predominantly quartz sand with a small amount of kaolinite. The third sample (67–68 feet) was a mixture of quartz with minor amounts of hornblende, kaolinite, and aragonite. The grain-size distribution is given in Table 1.

2.3 Sediment Analyses

Based on data from the soil gas survey (Looney et al. 1988), a drilling program, designed to characterize both the lateral and vertical extent of the diesel contamination in the soil, was conducted from December 1988 through January 1989. All soil samples were collected from the first 13 boreholes (see Figure 1), analyzed for TPH by extraction with EPA Methods 3540 and 9071, and quantified using EPA Method 418.1. EPA Method 3540 was a soxhlet extraction with freon, while EPA 418.1 involved cleaning up the freon extract with silica gel to remove non-hydrocarbon components and quantifying the TPHs by infrared analyses (FTIR). The minimum detectable limit for laboratory analysis was 1 mg/kg; however, all values less than 5 mg/kg were considered below detectable limits. Spiked recoveries for the assays averaged 80%. All groundwater samples were below detectable limits of less than 1.0 ppm for TPHs (Table 2). (The U.S. Army Corp of Engineers performed cone penetrometer investigations using fiber optic hardware to confirm, in real time, the concentrations of TPH and at which depth and to identify additional contamination, if present.)

The concentrations of selected inorganic nutrients in the groundwater was also determined by inductively coupled plasma emission spectrometry for selected metals and anions. Specific attention was given to lead concentrations since the storage tanks at the facility had occasionally contained leaded gasoline. Total lead analyses of the

sediments and water were conducted using EPA Method 239.2 protocol with laboratory control standards within the control limits of 80–120% recovery. All water samples were processed within the holding times required by 40 CFR 136 (EPA), although holding times for soil and sediment samples have not been promulgated by EPA at this time. The data in Table 3 indicate the concentration of lead in the sediments for the boreholes, while the data in Table 4 shows the concentration of lead in the groundwater for screened wells along with maximum concentration of lead found in the sediments of a given borehole.

Dissolved aluminum was detected in the groundwater and ranged in concentration from 1.2 to 4.6 mg/L. The only other metals found above the detection level were zinc at 0.06 mg/L in CSD-4D and iron at 1.26 mg/L in CSD-13D and 3.95 mg/L in CSD-11D. The presence of dissolved iron in the groundwater at moderate concentrations may make it difficult to add oxygen to the system because of the fouling by iron oxidized floc if *in situ* bioreclamation is chosen as the remedial alternative. Well CSD-4D contained higher levels of calcium, sodium, and potassium than the other two wells. Most inorganic nutrients required for microbial growth were present, although probably not at levels necessary for maximum growth and biodegradation of the organic contaminants. Nitrogen, as nitrate, was also present in the groundwater, ranging from 0.6 to 1.6 mg/L. Nitrite was not detected. Ortho-phosphate levels were below 5 mg/L. Other minerals required for microbial growth such as magnesium, manganese, potassium, sodium, chloride, and sulfate were found in low quantities in almost all of the samples.

2.4 Microbiological Methods

Sediment samples were collected for microbial investigations as previously described (Phelps et al. 1989), and density and physiological characteristics of the indigenous microbial populations were determined. Biological activity, as measured by colony-forming units (CFUs), was conducted on the soil, sediment, and groundwater samples using standard microbiological plating techniques. The total heterotrophic microbial population was enumerated on Difco® (Detroit, MI, U.S.A.) nutrient agar using the pour plate techniques. Bacterial populations capable of using hydrocarbons were plated on a mineral salts medium with diesel fuel hydrocarbons as the sole carbon source. The mineral salts medium contained washed agar and essential inorganic nutrients. Three drops of the diesel fuel were placed on a filter paper in the inverted lid of the petri dish; the diesel vapors provided the carbon for growth of the hydrocarbon-utilizing microorganisms. Groundwater

from the site was filter-sterilized and used as the dilutant. All samples were plated within 24 to 36 hours of collection. Total heterotrophic bacteria populations were enumerated after a seven-day incubation period at 20°C, and the hydrocarbon utilizers were counted after 26 days. Microbial counts for both the heterotrophic populations grown on plate count agar and diesel-utilizing (DU) bacteria are presented in Table 5.

2.4.1 Nutrient Treatability Study

To achieve maximum rates of biodegradation within a sediment and aquifer ecosystem, both inorganic nutrients and oxygen may be required as nutritional additives. Since each ecological habitat has different microbial consortia, the combination of inorganic nutrients necessary for maximum growth is specific for each site. A total of 34 combinations of inorganic nutrients were examined to determine which combination would give the maximum stimulation of the microbial population. Aliquots (50 mL) of the mixture of groundwater from three wells (CSD-4D, CSD-11D, and CSD-13D) were placed in 500-mL reaction vessels. The appropriate combinations of stock solutions of inorganic nutrients (Table 6) were added to each bottle, along with 50 µL of diesel fuel to serve as the sole organic carbon source. Negative controls did not contain the diesel fuel. An additional 50 µL of diesel fuel was added after the first week. At the end of the two-week incubation period, the vessels were acidified to dissolve any precipitates and to stop microbial growth, and the cell yield was gravimetrically determined.

2.4.2 Nutrient Stability Tests

Investigations were conducted to determine whether the introducing the most effective nutrient solution would affect the soil permeability. The interaction between the soil and nutrient solution was determined using columns packed with the site soil and treated consecutively with the groundwater, nutrient solution in groundwater, and an oxygen source (hydrogen peroxide). The nutrient stability tests were also used to determine the interaction between hydrogen peroxide and the soil.

2.4.3 Biodegradability Studies

Biodegradation studies determined the ability of the diesel contaminants to be removed biologically. Sediment samples were collected from boring CSD-13 (Figure 2) at 17 feet and used in the mineralization study of the diesel contaminants. The sediment samples were predominantly clay and contained approximately 432 ppm of total petroleum hydrocarbon. The volatile fraction of diesel and dodecane

was followed by headspace gas chromatography analyses using a Perkin-Elmer Model 8320 gas chromatograph equipped with a Model HS-6 headspace analyzer. These analyses were used to demonstrate a reduction in the overall concentration of diesel fuel.

Calibration curves for the total volatile fraction were prepared by peak area analyses. The concentration of dodecane was determined from the peak area matching the retention time of dodecane standards. Other compounds may have co-eluted with the dodecane and prevented an accurate determination of the dodecane concentration.

The four perturbation treatments for the biodegradation studies included the following:

- a nutrient-amended series
- an unamended series
- a nutrient-amended control series
- an unamended series.

A series of positive nutrient-amended controls and a series of unamended negative controls were included. Negative controls accounted for losses from the system other than those due to microbial activity. Two-hundred fifty grams of sediment from boring CSD-13 were placed in a large beaker and thoroughly mixed. Ten-gram aliquots of the sediment were placed in sterile, 70-mL serum bottles for the TPH test series and 1-gram subsamples were placed in sterile, 9-mL vials for the volatile test series.

The first perturbation treatment was prepared with 100 mL of groundwater amended with 687 mg/L phosphate, 160 mg/L potassium, 336 mg/L ammonia, 57 mg/L carbonate, 3.6 mg/L calcium, 19.5 mg/L magnesium, 4 mg/L manganese, 1 mg/L iron, 87 mg/L sulfate, 670 mg/L chloride, and 172 mg/L sodium. Ten milliliters of the groundwater nutrient solution were added to each serum bottle, in the TPH series and 1 mL into the volatile series. The second perturbation treatment received only groundwater, and the groundwater used in the third perturbation treatment was amended with the same combination of inorganic nutrients as the first series, but also received 4 mL of sulfuric acid, a poisoned control agent. The fourth perturbation treatment was prepared with 100 mL of groundwater and 4 mL of sulfuric acid. Each serum bottle was sealed with a sterile teflon-lined rubber septa and mixed with a vortex mixer. All of the serum bottles were incubated at 22°C.

An additional biodegradation test was performed to determine whether the contaminated sediments could be treated with a vacuum system (i.e., providing the oxygen necessary for biodegradation of the diesel fuel while removing

the volatile diesel fraction). A glass column was packed with 100 grams of contaminated sediment from CSD-13D. The sediment was periodically moistened with a nutrient amended groundwater as described in Table 6. A vacuum of 200 mm Hg was placed on the bottom of the column and air was drawn through the column. Samples were removed periodically and analyzed for TPH as previously described.

2.4.4 Two- and Three-Dimensional Visualization

A two-dimensional contour mapping program Mac-Gridzo® (RockWare, Wheat Ridge, CO) for the Macintosh computer was used to prepare maps of the distribution of TPH concentration from discrete, 10-foot-thick sediment intervals. The plots are shown in Figures 6-9. These maps suggest that the TPH plume has moved in a southwesterly direction following the land surface topography. Because of the extensive clay deposits in the vadose zone, horizontal migration has greatly exceeded vertical migration. In fact, more than 80% of the contamination appears to be confined to the upper 20 feet of the soil column.

To better visualize the distribution of contamination, three-dimensional (3-D) images were prepared using a 3-D modeling software package (Interactive Volume Modeling™ [IVM], version 5.0, Dynamic Graphics, Alameda, CA). These models were created from irregularly spaced data values specified by x, y, and z coordinates and a property value. Using a bicubic spline algorithm, the data values were transformed into a regularly spaced 3-D grid with a minimum tension gridding technique. Display files were created from the grid by specifying a series of concentration surfaces to be contoured. The display files were interactively viewed from numerous angles, layers, and sections were removed, and selected concentration zones were interpreted and analyzed.

The resulting 3-D grid files were used to create the displays shown in Figures 10-13. Surfaces were used to define the boundaries for the 3-D grids.

3.0 Results and Discussion

3.1 Sediment Analyses

The concentration of TPHs in individual soil and sediment samples is given in Table 2. Sediment borings in the fuel storage area (CSD-3D, -4D, and -5D) had an average of 256 ppm in the 0-15-foot zone. Isolated zones showed contaminant concentrations of less than 160 ppm in the

sediments from 15 to 82 feet in CSD-4D. CSD-6D, located to the north of the diesel fuel storage area, had a concentration of 5040 ppm at the 10–12-foot interval below land surface. Sediments from CSD-7D showed contamination above the detection limits only at 6 feet below land surface. CSD-8D appeared to be clean except for one sample at 41–43 feet that showed a very low level of contamination. Contaminant levels above 100 ppm were found in CSD-9D at depths down to 72 feet. Sediments from CSD-10D and CSD-12D did not show (PAHs) above detectable limits and appeared to be outside the plume of contamination. Sediments from CSD-11D and -13D revealed relatively high levels of contamination in the surface soils. CSD-11D did not show any contamination below 15 feet, but CSD-13D showed contamination extending to 57 feet. The contaminants found in CSD-9D, -11D, and -13D indicated that the plume is quite extensive.

The TPH analysis revealed values from 4.1 to 5040 mg/kg of sediment. Analyses of groundwater collected with HydroPunch® sampling demonstrated undetectable concentrations of TPH in the groundwater, even though sediment concentrations in the unsaturated zone were often high. The TPH analysis of sediments indicated that the absolute extent of contamination has not yet been determined on the western-most boundary of the area. However, because the highest TPH concentrations at the boundaries were just above detection limits and coincided with the calculated outer edge of the contamination, we believe that the zone of contamination has been adequately defined.

The monitoring wells have not shown detectable levels of dissolved hydrocarbons (Fliermans et al. 1993). Analysis of the groundwater for volatile organic compounds (VOCs) showed no VOCs at levels above the limit of detection ($< 5\text{--}10$ ppb) for the method. The field and trip blanks contained no VOCs except for methylene chloride, which was found in all samples, including the method blank, indicating that it is most likely laboratory contaminant.

3.2 Two- and Three-Dimensional Visualization

The TPH assessment program revealed widespread contamination of the soils and sediments. The majority of the contaminants was found between 0–15 feet. Sediment borings to the east of the underground fuel storage area did not show detectable concentrations of TPH in the intervals that were sampled. Plume analyses, as depicted in Figures 10-13, indicate that the plume is primarily associated with

the top 15 feet of soil and sediments. Deep but small pockets of petroleum hydrocarbons were observed in CSD-9 and CSD-23 at depths of greater than 60 feet.

The results from the 3-D imaging data are shown in Figures 10-13 and indicate that the bulk of the contamination lies in a region that corresponds to a low spot in the terrain and may represent a sink for the TPH. The TPH distribution suggests that very little extends beyond the area already investigated. The hydrology, geology, topography, and nature of the contaminant suggest that the diesel fuel contaminating the sediments in this area is moving very slowly or not at all and has not impacted the groundwater in the area.

3.3 Bacteriological Analyses

Bacterial densities in the soils and sediments were generally quite low (Fliermans et al. 1993). Most of the samples contained fewer than 100 CFUs per gram of sediments for the total bacterial counts and 200 CFUs per gram of sediments for the hydrocarbon-utilizing bacteria. These limits of detection represent the minimum number of microorganisms that can be counted by the procedures used in the tests. In the surface soils from 0 to 15 feet, elevated total microbial counts were found for borings 3, 4, 5, and 6, which are in the vicinity of the tank storage area. However, only boring 5 had elevated hydrocarbon-utilizing bacterial counts. Elevated bacterial counts were found in only a few instances in sediment samples deeper than 15 feet, although boring 10 had elevated counts in the 45 to 60-foot range.

The groundwater bacterial counts were somewhat higher than the sediments for two of the three wells (Fliermans et al. 1993). Total plate counts ranged from 3.6×10^3 to 4.4×10^4 , while hydrocarbon utilizers ranged from 4.2×10^3 to 1.48×10^4 per mL. Aseptic control conditions were maintained during processing and shipping of samples as shown by the field and trip control blanks ranging from 10–20 CFU/mL of sample. Mineral medium plates spread with 0.1 mL of groundwater but not incubated under diesel vapors contained an average of 90 organisms per mL. The data showed that greater densities of the acclimated microbiological population was achieved in diesel vapors.

Direct bacterial counts (AODC) showed higher densities than those found for viable plate counts. In some cases, such as CSD-4D, no viable plate counts were recorded, demonstrating that although there may be organisms present in the groundwater, they are unable to grow on the media used for the viable enumerations.

3.4 Nutrient Treatability Study

The nutrient stimulation investigations demonstrated the presence of microbial populations capable of degrading the diesel contamination. The data in Table 7 show the cell yields for the nutrient study. Cell yields of greater than 15 times background were obtained during the nutrient optimization study when the systems were supplied with the necessary inorganic nutrients. Minimal growth was achieved in the system without additional inorganic nutrients (test 2), while the additions of both ammonia and phosphate increased cell yields by 5-6 fold (tests 5 and 6). The greatest cell yield (nearly 16 fold) occurred in test 27, which received all of the inorganic nutrients except carbonate. The second highest yield, test 28, contained ammonia, phosphate, carbonate, magnesium, manganese, and iron, while the third highest yield was for test 9 and contained magnesium in addition to ammonia and phosphate. The tests with the best yields appeared to contain ammonia, phosphate, and magnesium and generally manganese and iron.

Bacterial cell biomass used up to 23% of the added diesel fuel, with much of the remaining fuel being converted to carbon dioxide and water. Growth occurred with the groundwater microbial consortia using the added diesel as the sole carbon and energy source, even though there was no apparent diesel contamination in the groundwater samples. Such data demonstrates that the indigenous microorganisms from both the sediments and groundwater can acclimate to biodegrade the diesel when supplied with the necessary oxygen and inorganic nutrients.

During the nutrient-amended treatments, biodegradation studies of the volatile fraction of diesel fuel indicated that this fraction was reduced by 67% within 35 days when the sediments and groundwater samples were supplemented with the necessary inorganic nutrients (Figure 14). Treatment #2-UT, which did not receive any nutrients, showed that total VOCs were reduced only 18%. The data indicated that adding inorganic nutrients enhanced the biological removal of the volatile fraction of the diesel fuel over adding oxygen. There was no reduction in the volatile fraction in the nutrient-amended controls (treatment #3-AC) or unamended controls (treatment #4-UC), although there was some variability in the measured concentrations of volatiles. Phosphate may sorb to the soil and not be available for the microorganisms. While adding nutrient solution may enhance diesel fuel degradation, reaction with the minerals in the groundwater (particularly iron, magnesium, and calcium) may cause a precipitate to form.

Excessive precipitation of the nutrient solution will likely clog the soil pores, resulting in a decrease in the soil permeability and formation blockage.

To enhance TPH oxidation, additional oxygen sources are often provided. One such source is hydrogen peroxide, which decomposes water and oxygen. Hydrogen peroxide provides a much greater quantity of oxygen to the subsurface than air, or compressed or liquid oxygen, which are other common methods of oxygen addition. Experiments were conducted to determine the rate of hydrogen peroxide decomposition in CSDSF sediments. If the hydrogen peroxide decomposed rapidly, the subsurface environment may require treatment with phosphate or other agents to stabilize the decomposition rate before hydrogen peroxide can be introduced. Additionally, phosphate may sorb to the soil particles and become unavailable to the microbial population. On the other hand, if the hydrogen peroxide is readily decomposed in the formation, then the rate of oxygen production may be too slow to support maximal aerobic microbial growth. Thus a nutrient balance with oxygenation is sought.

The results of the phosphate sorption and hydrogen-peroxide stability test are expressed in Table 8. Two sediment samples with high TPH concentrations were used in the test. The first test used 20 grams of sediment collected from borehole CSD-13D at a depth interval of 5-7 feet along with 100 mL of groundwater spiked with 81 ppm phosphate and 150 ppm hydrogen peroxide. The second test employed sediment from boring CSD-6D at a depth interval of 10-12 feet along with 100 mL of groundwater amended with 280 mg/L of phosphate and 265 mg/L of hydrogen peroxide. Samples were taken periodically from the liquid above the sediment, centrifuged to separate sediments from groundwater, and checked for the remaining concentrations of phosphate and hydrogen peroxide. Phosphate was measured colorimetrically with ammonium molybdate and ascorbic acid. Hydrogen-peroxide concentrations were determined colorimetrically with titanium sulfate.

Phosphate sorption to the CSD-13D sediment sample was relatively rapid (Table 8) in that the phosphate levels were reduced by more than half within 2 hours and by 90% after 5 hours. When additional phosphate was added, the concentration in solution was reduced by 30% within 4 hours and by 67% within the next 20 hours. The phosphate demand for this sediment was high at approximately 2.3 pounds per cubic yard. The sample from CSD-6D showed

less phosphate adsorption (Table 8), in that the phosphate concentration was reduced by 50% after 8 hours. The phosphate sorption for this sample amounted to 1.7 pounds per cubic yard.

The hydrogen peroxide concentrations dropped rapidly from 150 mg/L down to 9 mg/L within 21 hours in the sediment sample from CSD-13D (Table 8). A similar rate of hydrogen peroxide breakdown was observed after adding more hydrogen peroxide and phosphate to the soil and groundwater solution. The stability of the hydrogen peroxide in the CSD-6D sample was improved in that the concentration of hydrogen peroxide decreased by just over 25% within 8 hours (Table 8). Based on the stability of the peroxide, it appears that for these particular sediments hydrogen peroxide can be used as the oxygen source if the phosphate demand were satisfied and the other site conditions were favorable for the use of *in situ* bioreclamation.

Column sediment tests were established to determine the affect of the nutrient amendments on the infiltration rate. These data are given in Table 9. Two columns were prepared—one with 40 grams of a sediment from soil boring CSD-6D at a depth of 10–12 feet, and the second with 40 grams of a sediment from boring CSD-13D at a depth of 5–7 feet. The columns were moistened with 200 mL of groundwater, and the time was recorded for 50 mL of the groundwater plus amendments to pass through the column. Reasonable rates of infiltration were achieved initially in both columns for the passage of groundwater (i.e., 13 mL/min for CSD-13D sediments and 18 mL/min for CSD-6D sediments [Table 9]). However, the sediments plugged when inorganic nutrients were added. The addition of hydrogen peroxide resulted in decreased flow for both columns. Sediments from CSD-13D became fully plugged, and the flow through the CSD-6D column was reduced to 1 mL/min. The high clay content of the sediment samples seemed to prevent nutrient additions since CSD-13D consisted of sand with clay and silt with an estimated 25% clay and 15% silt. The sample from CSD-6D consisted of cohesive, medium plasticity clay with approximately 15% sand.

3.5 Biodegradability Studies

Experiments were also conducted to demonstrate the biotransformation and complete mineralization of dodecane, one of the components of diesel fuel, to carbon dioxide and water. Mineralization studies were conducted with soils from CSD-13D at a depth of 2–4 feet and with

sediments from depths of 6–19 feet. Dodecane biotransformation experiments were also conducted with sediments from CSD-13D at a depth of 17 feet. Up to 4.4% of the added carbon-14 label was mineralized in the soil from CSD-13D (2–4 feet) when amended with 80 ppm phosphate and 50 ppm ammonia. Some mineralization of dodecane occurred with addition of phosphate by itself, but not for ammonia alone. No more than 7.6% of the label was mineralized in these studies. The high concentrations of other biodegradable contaminants and the location of the carbon-14 label on only the first carbon of dodecane contributed to the apparent low percentage conversion of the dodecane to carbon dioxide.

In the biotransformation experiment, 80% of the dodecane was removed in 35 days when the soils were amended with ammonia, phosphate, and other inorganic nutrients and incubated under aerobic conditions. Without any additional nutrients, 69% of the dodecane were biotransformed. Approximately 50% of the dodecane was lost in the nutrient-amended and unamended controls. These losses may be a result of interaction between the acid used as a biological inhibitor and the dodecane. The following may have contributed to the higher percentage of dodecane removal in the biotransformation experiment than seen in the mineralization experiment:

1. The biotransformation experiment only followed the loss of the parent compound and not complete conversion to carbon dioxide.
2. The headspace quantification method may be subject to interferences with compounds that have similar retention times to that of dodecane.
3. The biotransformation experiment was carried out for a longer period.
4. The mineralization experiments were carried out with dodecane, which was only labeled on the first carbon.

The TPH levels were reduced from 467 ppm down to 70 ppm after 24 days (Figure 16). Some removal was probably resulted from volatilization of the lighter fraction of diesel. While this technique was successful in the laboratory, it may be difficult to apply in the field. The clayey soils found throughout much of the CSDSF site will make it difficult to draw the nutrients and air through the contaminated zone.

4.0 Conclusions and Recommendations

The hydrology, geology, topography, and the nature of the contaminant suggest that the diesel fuel contaminating the sediments in this area is moving very slowly or not at all. Additionally, impacts to the groundwater have not been observed. Small areas of perched water found at depths of approximately 25 feet below ground surface were overlying a low permeability sandy clay unit of limited extent. The static water table across the site is between 238 to 244 feet mean sea level (approximately 45 to 75 feet below ground surface) as shown in Figure 5. Directions of groundwater flow vary depending on location; however, the dominant direction is to the west in the direction of the lowest topographical elevation (Figure 5).

In situ bioreclamation was chosen as one of the remediation alternatives for further investigation, since bioremediation is effective in degrading TPHs. Conventional treatment relies on liquid additions circulating through the contaminated soils via horizontal or injection wells, infiltration galleries, and withdrawal wells to supply the necessary nutrients to the subsurface environments. To determine if *in situ* bioreclamation was an appropriate cleanup technology for this site soil, sediment and groundwater samples were collected for laboratory analyses. The studies involved determining the microbial distribution of both the total bacterial and hydrocarbon-utilizing populations, the nutrient requirements for maximum growth rate, the rate and extent of biodegradation of the organic contaminants, and compatibility of the nutrient mixture with the subsurface soils.

The Bioreclamation Feasibility Assessment Study revealed that indigenous microorganisms that degrade diesel fuel were present in the soil and sediments at the Central Shop Diesel Storage Facility site. A nutrient mix to stimulate the indigenous microorganisms was tested on sediment core samples, and optimum concentrations were established to yield the most microbial cells.

Problems arose when the inorganic nutrients and oxygen were added to the Central Shops Diesel Storage Facility soils and sediments. There is a relatively high phosphate demand by the soils, ranging from 1.7 pounds to 2.3 pounds per cubic yard, which must be met before an oxygen source such as hydrogen peroxide can be added to the soil without creating plugging problems. The rate of hydrogen peroxide decomposition in the presence of the soils was reasonable. When nutrients are added to the groundwater, they appear to release fines from the soil,

which plug the formation. Even with pretreating the soils with the nutrient solution, groundwater flow through the soil columns was restricted when hydrogen peroxide was added.

However, soil column studies suggested that injecting this nutrient mix would plug the soil, through microbial biomass and/or inorganic precipitates from chemical reactions. This formation plugging seriously limits using conventional liquid nutrient infiltration galleries to enhance indigenous microbial populations in these soils. The location of most of the diesel contaminants in the unsaturated soil above the groundwater table, the relatively low permeability of the soils, and the problems with adding hydrogen peroxide and nutrients to the soils will probably preclude using conventional *in situ* bioreclamation for the site. Thus, conventional *in situ* biodegradation through injection of liquid nutrients via infiltration galleries may not be appropriate. However, if plume containment was desirable, these studies indicated that biomass plugging of the soil could inhibit subsurface water flow and may be appropriate as a method of containment.

The investigation that allowed the removal of the total petroleum hydrocarbon by vacuum extraction and enhanced biodegradation through bioventing indicated that this method may be useful. It will probably not be difficult to draw the necessary oxygen and nitrogen through the clayey soils using pressurized air. The nitrogen present in the compressed air will serve as a nutrient source for the microbial consortia present in the soils. Field-scale demonstrations of the vacuum-extraction, enhanced-bioventing biodegradation processes have been accomplished for TCE-contaminated soils at M Area and are expected to be work favorably at the Central Shops Diesel Storage Facility (Eddy et al., 1991; Looney et al., 1991).

The most economical and technically feasible option to clean up the diesel contaminated soil at the Central Shops Diesel Storage Facility can be approached in two ways. Initially, small vertical injection and vacuum extraction wells would be inserted into the most contaminated and shallowest areas of the plume to biovent and bioremediate the plume. This would allow the bioremediation of the greatest concentration of the TPHs with the least cost. Since the contamination has not entered the groundwater, an immediate bioventing procedure would enhance the degradation without excavation. This phase of the bioremediation may well continue for 12-18 months followed by an evaluation of the residual plume. Core samples would be collected for comparison of the bioremediated plume with the initial conditions.

Since these studies indicated that the CSDSF site may not be suitable for some conventional types of *in situ* bioremediation, a second approach is to excavate the shallow contaminated soils and treat them. A prepared bed treatment facility (soils facility) for all oil-contaminated soils at SRS has been constructed at D Area. Because the majority of contamination at CSDSF is shallow, much of the contaminated soil from the Central Shops Diesel Storage Facility would be excavated and treated in this facility. The excavated material would be mixed with nutrients at the controlled site (soils facility) and brought to acceptable levels of TPH by the indigenous microflora in a rapid and cost-effective manner. The facility is used to treat all petroleum-contaminated surface soil at SRS now and in the future. The clayey nature of much of the sediments will not restrict land farming because the nutrients can be added directly to soils and mixed manually. Whereas the bulk of the contaminated soils is confined to a narrow and shallow depth (< 20 ft), removing the highly contaminated material may be the most effective remediation of the site. Microbial populations that are acclimated to the diesel contaminants or can become acclimated to diesel once the proper inorganic nutrients are available are present at the contaminated site.

The small pools of deeper contamination (> 30 feet) will require more innovative treatment (e.g., bioventing). Bioremediation would be achieved by placing vertical wells into the most heavily contaminated area. Vacuum extraction could remove the volatile portion of the TPH and also establish a bioventing regime where the indigenous microbial populations would be stimulated to degrade the TPHs *in situ*.

Since this plume has probably existed for more than 20 years at this site and there is no evidence of immediate danger to groundwater supplies in the area, we propose using this site to test innovative technologies for *in situ* bioremediation. These studies could significantly improve our ability to cleanup similar sites by decreasing remediation time and costs and improving terminal destruction of the contaminants with minimal environmental disturbance.

5.0 References

- Abelson, P., 1989, "Cleaning Hazardous Waste Sites", *Science* 246:1097.
- Amador, Alphons and A. C. Uijtewaal, 1992, "Buried Pesticide Waste Hazard to Poland", *Waste Management & Research* 10: 387-398.
- Eddy, C. A., B. B. Looney, J. M. Dougherty, T. C. Hazen, and D. S. Kaback, 1991, *Characterization of the Geology, Geochemistry, Hydrology and Microbiology of the In Situ Air Stripping Demonstration Site at the Savannah River Site*. WSRC-RP-93-0369, Westinghouse Savannah River Company, Aiken, SC 29808.
- Fliermans, C. B., H. W. Bledsoe, and T. C. Hazen, 1993, *Characterization and Reclamation Assessment for the Central Shops Diesel Storage Facility, Savannah River Site, Aiken, SC*, WSRC-MS-93-039, Westinghouse Savannah River Company, Aiken, SC 29808.
- Hazen, T. C., 1991, *Test Plan for In Situ Bioremediation Demonstration of the Savannah River Integrated Demonstration Project*, DOE/OTD TTP No.: SR 0566-01.
- Looney, B. B., V. Price, D. J. Masdea, and C. A. Boe, 1988, *Soil Gas and Soil Plug Survey at the Central Shops Diesel Storage Facility (8318)*, DPST-88-829. E. I. duPont de Nemours & Co. Savannah River Laboratory, Aiken, SC 29808.
- Looney, B. B., T. C. Hazen, D. S. Kaback, and C. A. Eddy, 1991, *Full Scale Field Test of the In Situ Air Stripping Process at the Savannah River Integrated Demonstration Test Site*, WSRC-RD-91-22, Westinghouse Savannah River Company, Aiken, SC 29808.
- Manchon, Bruce, 1992, "Cone Penetrometer Testing, Hydropunch®, and Borehole Geophysics Applications for Environmental Investigations", *Journal of Soil Contamination*, 1(4):321-338.
- Phelps, T. J., C. B. Fliermans, T. Garland, S. M. Pfiffner, and D. C. White, 1989, "Recovery of Deep Subsurface Material for Microbiological Studies," *Journal of Microbiological Methods* 9: 267-279.
- Sargent, K. A. and C. B. Fliermans, 1989, "Microbiology and Geological Comparisons of the Terrestrial Deep Subsurface", *Geomicrobiology Journal* 7: 1-11.

Table 1. Grain-size Distribution for Sediments Collected at Selected Intervals at the CSDSF Site (expressed in percent)

Depth (ft)	% Coarse Sands	% Medium Sands	% Fine Sands	% Very Fine Sands
62-64	30	50	20	0
66-67	5	27	0	68
67-68	15	52	0	33

Table 2. Concentration of Petroleum Hydrocarbons at Depth

Well	All Depths	0-19 ft	20-39 ft	40-59 ft	> 60 ft
CSD-1D	50	0	0	50	0
CSD-2D	50	0	50	50	0
CSD-3D	665	665	0	0	0
CSD-4D	887	887	156	50	87
CSD-5D	603	603	0	0	0
CSD-6D	5040	5040	0	0	0
CSD-7D	273	273	0	0	0
CSD-8D	57	0	50	57	50
CSD-9D	384	383	265	269	384
CSD-10D	50	0	50	50	50
CSD-11D	2413	2413	50	50	50
CSD-12D	50	0	50	50	50
CSD-13D	4377	4377	492	94	50
CSD-15D	85	85	4.7	4.7	4.8
CSD-16D	6.7	5.8	6.7	4.7	4.8
CSD-17D	1700	1700	8.2	4.7	6.1
CSD-18D	34	11	34	8.5	0
CSD-19D	69	69	7.1	4.8	0
CSD-20D	65	65	7.5	4.9	0
CSD-21D	1000	1000	58	14	0
CSD-22D	1500	1500	43	89	0
CSD-23D	2600	2600	510	110	0
CSD-24D	5.1	5.1	4.8	4.8	0
CSD-25D	5	4.9	5	4.9	0
CSD-26D	840	840	5	4.9	0
CSD-27D	230	230	5.5	5	0
CSD-28D	32	32	5.1	5.1	0
CSD-29D	170	170	4.9	5	0
Maximum		5040			
Minimum		4.1			

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Table 3. Concentration of Lead at Depth in the Sediments of Central Shops Diesel Storage Facility

Well ID	Depth (ft)	Concentration	Detection Limit
CS-15D	3-5	5.7 mg/Kg	0.68
CS-15D	8-10	3.8 mg/Kg	0.71
CS-15D	13-15	20.9 mg/Kg	2.90
CS-15D	18-20	19.3 mg/Kg	2.80
CS-15D	23-25	7.7 mg/Kg	0.68
CS-15D	28-30	5.0 mg/Kg	0.67
CS-15D	33-35	4.6 mg/Kg	0.68
CS-15D	38-40	15.5 mg/Kg	2.80
CS-15D	43-45	5.0 mg/Kg	0.74
CS-15D	48-50	5.8 mg/Kg	0.73
CS-15D	53-55	8.9 mg/Kg	0.72
CS-15D	58-60	9.2 mg/Kg	0.69
CS-15D	63-65	4.0 mg/Kg	0.67
CS-15D	68-70	4.7 mg/Kg	0.65
CS-15D	73-75	3.8 mg/Kg	0.70
CS-15D	78-80	2.1 mg/Kg	0.71
CS-16D	3-5	17.5 mg/Kg	2.90
CS-16D	8-10	3.2 mg/Kg	0.69
CS-16D	13-15	9.7 mg/Kg	0.72
CS-16D	18-20	10.2 mg/Kg	0.72
CS-16D	23-25	11.1 mg/Kg	0.72
CS-16D	28-30	3.3 mg/Kg	0.66
CS-16D	33-35	7.4 mg/Kg	0.69
CS-16D	38-40	5.6 mg/Kg	0.70
CS-16D	43-45	6.7 mg/Kg	0.71
CS-16D	48-50	3.1 mg/Kg	0.68
CS-16D	53-55	4.3 mg/Kg	0.67
CS-16D	58-60	2.2 mg/Kg	0.66
CS-16D	63-65	1.6 mg/Kg	0.69
CS-16D	68-70	3.2 mg/Kg	0.73
CS-17D	3-5	6.1 mg/Kg	0.68
CS-17D	8-10	4.2 mg/Kg	0.72
CS-17D	13-15	6.3 mg/Kg	0.72
CS-17D	18-20	8.4 mg/Kg	0.70
CS-17D	23-25	5.5 mg/Kg	0.68

Table 3. Concentration of Lead at Depth in the Sediments of Central Shops Diesel Storage Facility (Contd)

Well ID	Depth (ft)	Concentration	Detection Limit
CS-17D	28-30	2.9 mg/Kg	0.71
CS-17D	33-35	3.1 mg/Kg	0.68
CS-17D	38-40	2.9 mg/Kg	0.71
CS-17D	43-45	12.8 mg/Kg	1.40
CS-17D	48-50	5.4 mg/Kg	0.67
CS-17D	53-55	4.6 mg/Kg	0.73
CS-17D	58-60	2.8 mg/Kg	0.71
CS-17D	63-65	136 mg/Kg	14.2
CS-17D	68-70	4.7 mg/Kg	0.71
CS-17D	73-75	4.2 mg/Kg	0.72
CS-17D	78-80	2.1 mg/Kg	0.69
CS-17D	83-85	4.9 mg/Kg	0.72
CS-17D	88-90	5.8 mg/Kg	0.71
CS-18D	3-5	6.5 mg/Kg	0.67
CS-18D	8-10	9.3 mg/Kg	0.66
CS-18D	13-15	8.9 mg/Kg	0.71
CS-18D	18-20	5.9 mg/Kg	0.70
CS-18D	23-25	5.6 mg/Kg	0.69
CS-18D	28-30	6.6 mg/Kg	0.65
CS-18D	33-35	5.3 mg/Kg	0.66
CS-18D	38-40	3.6 mg/Kg	0.68
CS-18D	43-45	1.4 mg/Kg	0.65
CS-18D	48-50	3.0 mg/Kg	0.71
CS-18D	53-55	3.1 Mg/Kg	0.62
CS-19D	3-5	7.4 mg/Kg	0.71
CS-19D	8-10	6.4 mg/Kg	0.69
CS-19D	13-15	10.8 mg/Kg	0.74
CS-19D	18-20	10.0 mg/Kg	0.72
CS-19D	23-25	7.2 mg/Kg	0.67
CS-19D	28-30	16.2 mg/Kg	1.30
CS-19D	33-35	4.2 mg/Kg	0.64
CS-19D	38-40	4.4 mg/Kg	0.68
CS-19D	43-45	4.0 mg/Kg	0.68
CS-19D	48-50	6.3 mg/Kg	0.67
CS-19D	53-55	2.7 mg/Kg	0.71
CS-20D	3-5	5.2 mg/Kg	0.71

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Table 3. Concentration of Lead at Depth in the Sediments of Central Shops Diesel Storage Facility (Contd)

Well ID	Depth (ft)	Concentration	Detection Limit
CS-20D	8-10	4.6 mg/Kg	0.71
CS-20D	13-15	5.3 mg/Kg	0.72
CS-20D	18-20	4.6 mg/Kg	0.68
CS-20D	23-25	8.3 mg/Kg	0.68
CS-20D	28-30	6.4 mg/Kg	0.69
CS-20D	33-35	4.6 mg/Kg	0.68
CS-20D	38-40	5.0 mg/Kg	0.68
CS-20D	43-45	6.0 mg/Kg	0.68
CS-20D	48-50	5.5 mg/Kg	0.69
CS-20D	53-55	2.7 mg/Kg	0.73
CS-21D	3-5	7.1 mg/Kg	0.67
CS-21D	8-10	10.4 mg/Kg	0.74
CS-21D	13-15	6.2 mg/Kg	0.71
CS-21D	18-20	5.4 mg/Kg	0.71
CS-21D	23-25	10.1 mg/Kg	0.70
CS-21D	28-30	30.9 mg/Kg	6.80
CS-21D	33-35	8.2 mg/Kg	0.69
CS-21D	38-40	4.0 mg/Kg	0.66
CS-21D	43-45	6.3 mg/Kg	0.69
CS-21D	48-50	5.1 mg/Kg	0.71
CS-21D	53-55	4.5 mg/Kg	0.73
CS-21D	58-60	4.8 mg/Kg	0.73
CS-22D	3-5	7.1 mg/Kg	0.71
CS-22D	6-8	9.7 mg/Kg	1.60
CS-22D	9-11	5.0 mg/Kg	1.40
CS-22D	12-14	7.0 mg/Kg	1.40
CS-22D	15-17	15.0 mg/Kg	1.40
CS-22D	18-20	10.2 mg/Kg	1.50
CS-22D	21-23	12.3 mg/Kg	1.40
CS-22D	28-30	5.5 mg/Kg	1.40
CS-22D	33-35	11.1 mg/Kg	1.40
CS-22D	38-40	7.1 mg/Kg	1.40
CS-22D	43-45	4.3 mg/Kg	1.40
CS-23D	3-5	4.0 mg/Kg	0.67
CS-23D	8-10	9.1 mg/Kg	0.71
CS-23D	13-15	13.1 mg/Kg	1.40

Table 3. Concentration of Lead at Depth in the Sediments of Central Shops Diesel Storage Facility (Contd)

Well ID	Depth (ft)	Concentration	Detection Limit
CS-23D	18-20	6.2 mg/Kg	0.70
CS-23D	23-25	5.4 mg/Kg	0.70
CS-23D	28-30	8.8 mg/Kg	0.70
CS-23D	33-35	5.6 mg/Kg	0.72
CS-23D	38-40	5.0 mg/Kg	0.72
CS-23D	43-45	11.0 mg/Kg	0.72
CS-23D	48-50	7.4 mg/Kg	0.76
CS-24D	3-5	6.6 mg/Kg	1.40
CS-24D	8-10	7.7 mg/Kg	1.30
CS-24D	13-15	11.6 mg/Kg	1.40
CS-24D	18-20	4.7 mg/Kg	1.40
CS-24D	23-25	7.2 mg/Kg	1.40
CS-24D	28-30	4.9 mg/Kg	0.70
CS-24D	33-35	3.8 mg/Kg	0.70
CS-24D	38-40	4.3 mg/Kg	0.70
CS-24D	43-45	3.2 mg/Kg	0.71
CS-24D	48-50	4.2 mg/Kg	0.72
CS-25D	3-5	6.3 mg/Kg	0.67
CS-25D	8-10	17.0 mg/Kg	1.50
CS-25D	13-15	5.3 mg/Kg	0.73
CS-25D	18-20	5.1 mg/Kg	0.68
CS-25D	23-25	9.0 mg/Kg	0.67
CS-25D	28-30	9.8 mg/Kg	0.95
CS-25D	33-35	13.5 mg/Kg	1.40
CS-25D	38-40	4.5 mg/Kg	0.68
CS-25D	43-45	10.1 mg/Kg	0.72
CS-25D	48-50	5.0 mg/Kg	0.72
CS-26D	3-5	12.6 mg/Kg	1.40
CS-26D	8-10	6.6 mg/Kg	0.74
CS-26D	13-15	5.9 mg/Kg	0.72
CS-26D	18-20	6.8 mg/Kg	0.71
CS-26D	23-25	5.4 mg/Kg	0.72
CS-26D	28-30	5.0 mg/Kg	0.71
CS-26D	33-35	11.1 mg/Kg	0.70
CS-26D	38-40	3.9 mg/Kg	0.68
CS-26D	43-45	6.2 mg/Kg	0.69

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Table 3. Concentration of Lead at Depth in the Sediments of Central Shops Diesel Storage Facility (Contd)

Well ID	Depth (ft)	Concentration	Detection Limit
CS-26D	48-50	5.0 mg/Kg	0.73
CS-27D	3-5	10.9 mg/Kg	0.70
CS-27D	8-10	6.0 mg/Kg	0.72
CS-27D	13-15	5.6 mg/Kg	0.70
CS-27D	18-20	1.7 mg/Kg	0.69
CS-27D	23-25	5.3 mg/Kg	0.74
CS-27D	28-30	5.0 mg/Kg	0.69
CS-27D	33-35	3.6 mg/Kg	0.74
CS-27D	38-40	2.9 mg/Kg	0.71
CS-27D	43-45	4.1 mg/Kg	0.70
CS-27D	48-50	7.0 mg/Kg	0.77
CS-28D	3-5	6.0 mg/Kg	0.66
CS-28D	8-10	7.8 mg/Kg	0.70
CS-28D	13-15	6.9 mg/Kg	0.69
CS-28D	18-20	5.2 mg/Kg	0.70
CS-28D	23-25	7.6 mg/Kg	0.71
CS-28D	28-30	8.5 mg/Kg	0.70
CS-28D	33-35	5.6 mg/Kg	0.70
CS-28D	38-40	5.4 mg/Kg	0.74
CS-28D	43-45	10.7 mg/Kg	0.75
CS-28D	48-50	5.1 mg/Kg	0.73
CS-28D	53-55	5.6 mg/Kg	0.75
CS-29D	3-5	8.7 mg/Kg	0.71
CS-29D	8-10	8.4 mg/Kg	0.70
CS-29D	13-15	6.9 mg/Kg	0.72
CS-29D	18-20	4.2 mg/Kg	0.71
CS-29D	23-25	5.2 mg/Kg	0.72
CS-29D	28-30	4.5 mg/Kg	0.70
CS-29D	33-35	7.2 mg/Kg	0.73
CS-29D	38-40	5.8 mg/Kg	0.75
CS-29D	43-45	6.1 mg/Kg	0.75
CS-29D	48-50	8.1 mg/Kg	0.76

mean=7.49

stdev=10.49

Table 4. Maximum Concentration of Lead in the Groundwater and Sediments of Central Shops Storage Facility Well

Well No.	Screen Depth (ft)	Maximum Lead Concentration Water(ug/L)	Maximum Lead Concentration in Sediments (ug/Kg)	Detection Limits (ug/L)
CS-15D	83-84	780.0	126	300.0
CS-16D	73-74	15.4	89.1	3.0
CS-17D	ND	ND	222.7	ND
CS-18D	58-59	4.4	59.2	4.4
CS-19D	58-59	13.6	79.6	3.0
CS-20D	54-55	30.0	58.2	30.0
CS-21D	64-65	11.7	103	3.0
CS-22D	50-51	600.0	94.3	300.0
CS-23D	ND	86.0	75.6	30.0
CS-24D	54-55	4.7	58.2	3.0
CS-25D	54-55	3.0	85.6	3.0
CS-26D	52-53	120.0	68.5	30.0
CS-27D	53-54	40.0	52.1	30.0
CS-28D	58-59	84.0	74.4	12.0
CS-29D	53-54	26.1	65.1	3.0
Mean		137.91	87.44	
Standard deviation		242.54	42.31	
ND		No Data		

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Table 5. Densities of Total Heterotrophic and Diesel Utilizing Bacteria in Sediments Containing Total Petroleum Hydrocarbons from Central Shops Diesel Fuel Facility with Respect to TPH Concentrations

TPH Concentration in Sediments (ppm/gdw)	Total Heterotrophs (cfu/gdw)	Diesel Utilizers (cfu/gdw)
665	2,800	200
75	1000	200
887	1000	200
74	100	200
156	100	200
91	100	200
132	100	200
87	100	200
70	400	200
76	100	200
603	520,000	22,400
5,040	100	200
273	100	200
57	100	200
383	200	200
229	100	200
265	100	200
269	1000	400
384	300	200
301	100	200
79	100	200
2,413	300	200
468	100	200
4,377	300	200
475	100	200
965	600	200
492	200	1,000
136	100	200
392	100	200
101	100	200
69	100	200
84	100	200
94	100	200

Table 6. Amendments and Concentrations Used in Biodegradability Investigations

Amendments	Concentrations (mg/L)
phosphate	687
potassium	160
ammonia	336
carbonate	57
calcium	3.6
magnesium	19.5
manganese	4
iron	1
sulfate	87
chloride	670
sodium	172

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Table 7. Cell Yields (mg/L) for Combinations of Inorganic Nutrients

Test #	PO ₄	NH ₄	CO ₃	Ca	Mg	Mn	Fe	Diesel Fuel	Cell Yield (mg/l)
1									24
2								+	26
3	+							+	38
4		+						+	42
5	+	+						+	170
6	+	+						+	158
7	+	+	+					+	178
8	+	+		+				+	154
9	+	+			+			+	268
10	+	+				+		+	218
11	+	+					+	+	94
12	+	+	+	+				+	142
13	+	+	+		+			+	132
14	+	+	+			+		+	78
15	+	+	+				+	+	100
16	+	+		+	+			+	132
17	+	+		+		+		+	98
18	+	+		+			+	+	60
19	+	+			+	+		+	158
20	+	+			+		+	+	224
21	+	+				+	+	+	162
22	+	+	+	+	+			+	52
23	+	+	+	+	+	+		+	116
24	+	+	+	+	+	+	+	+	122
25	+	+	+	+	+	+	+	+	152
26	+	+	+	+	+	+	+	+	262
27	+	+		+	+	+	+	+	396
28	+	+	+		+	+	+	+	288
29	+	+	+	+		+	+	+	166
30	+	+	+	+	+		+	+	188
31	+	+			+	+	+	+	254
32	+	+		+		+	+	+	218
33	+	+		+	+		+	+	234
34	+	+		+	+	+		+	240
35	+	+	+				+	+	196
36	+	+	+		+		+	+	206
37	+	+	+		+	+		+	214
38	+	+	+	+			+	+	134

Table 8. Nutrient Stability Tests for Borings CSD 13 (5-7 feet) and CSD 6 (10-12 feet)

Borehole	Time (hr)	Phosphate (mg/L)	Hydrogen Peroxide (mg/L)
CSD-13D	0	81	150
CSD-13D	0.5	59	105
CSD-13D	1	28	130
CSD-13D	3	14	95
CSD-13D	5	9	85
CSD-13D	21	4	< 1
**CSD-13D	21	140	150
CSD-13D	25	90	100
CSD-13D	43	44	25
CSD-6D	0	280	265
CSD-6D	4	195	230
CSD-6D	8	150	109

**Additional phosphate and hydrogen peroxide added.

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Table 9. Column Investigations of Groundwater Flow Rate through Columns Packed with CSD-13D and CSD-6D Soils, Respectively

Borehole	Treatment	Flow Rate (mL/min)
CSD-13D	1	17
CSD-13D	2	15
CSD-13D	3	14
CSD-13D	4	11
CSD-13D	5	11
CSD-13D	6	10
*CSD-13D	7	22
		(soil fines in effluent)
CSD-13D	8	10
CSD-13D	9	4
CSD-13D	10	2
CSD-13D	11	1
**CSD-13D	12	1
CSD-13D	13	1.4
CSD-13D	14	Plugged
CSD-6D	1	18
CSD-6D	2	18
CSD-6D	3	17
CSD-6D	4	46
CSD-6D	5	21
CSD-6D	6	13
CSD-6D	7	12
CSD-6D	8	10
		(soil fines in effluent)
CSD-6D	9	10
***CSD-6D	10	4
CSD-6D	11	2
CSD-6D	12	1
CSD-6D	13	1

*PO₄+NH₄+Ca+Mg+Mn+CO₃+Fe

**PO₄+NH₄+Ca+Mg+Mn+CO₃+Fe+160 ppm H₂O₂

***PO₄+NH₄+Ca+Mg+Mn+CO₃+Fe+210 ppm H₂O₂

Figure 1. Location of the Central Shops Diesel Storage Facility

Characterization and Reclamation for the Central Shops Diesel Storage Facility at the Savannah River Site

Figure 2. Characterization Area at Central Shops Diesel Storage Facility

Figure 3. Concentration of Methane in Soil Gas (expressed in percentage)

Characterization and Reclamation for the Central Shops Diesel
Storage Facility at the Savannah River Site

Figure 2. Generalized stratigraphic section at the Savannah River Site.

93X1564

Figure 4. Generalized Stratigraphic Section at the Savannah River Site

94X03960.FMK

Characterization and Reclamation for the Central Shops Diesel
Storage Facility at the Savannah River Site

Figure 6. Two-Dimensional Contour Mapping of Maximum Total Petroleum Hydrocarbons at 100 ppm Intervals for Sediments 0 to 19 feet below the Soil Surface

Figure 7. Two-Dimensional Contour Mapping of Maximum Total Petroleum Hydrocarbons at 100 ppm Intervals for Sediments 20 to 39 feet below the Soil Surface

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Figure 8. Two-Dimensional Contour Mapping of Maximum Total Petroleum at 100 ppm Intervals for Sediments 40 to 59 Feet below the Soil Surface

Figure 9. Two-Dimensional Contour Mapping of Maximum Total Petroleum Hydrocarbons at 100 ppm Intervals for Sediments Greater than 60 Feet below the Soil Surface

Figure 10. Three-Dimensional Contour Mapping of Maximum Total Petroleum Hydrocarbons at 100 ppm Intervals for Sediments at Depth below the Soil Surface

Figure 11. Three-Dimensional Contour Mapping of Maximum Total Petroleum Hydrocarbons at 100 ppm Intervals for Sediments at Depth below the Soil Surface (b)

Figure 12. Three-Dimensional Contour Mapping of Maximum Total Petroleum Hydrocarbons at 100 ppm Intervals for Sediments at Depth below the Soil Surface (c)

Figure 13. Three-Dimensional Contour Mapping of Maximum Total Petroleum Hydrocarbons at 100 ppm Intervals for Sediments at Depth below the Soil Surface (d)

93X2164.02.AIL

Figure 14. Biological Degradation of Volatile TPH in Laboratory Microcosms with a Variety of Amendments

93X2164.03.AIL

Figure 15. Biological Degradation of TPH in Laboratory Microorganisms with a Variety of Amendments

93X2164.04.AIL

Figure 16. Vacuum Extraction of CSD-13D Soils Containing TPH

Appendix I
Lancaster Laboratories, Inc. Analysis Reports of Water Samples

Well Number: CSD-13D
LLI Sample Number: WW 1376373
Water Sample: #856
Collected on: April 5, 1989

Table 1. Lancaster Laboratories, Inc. Analysis Report of Water Samples from CSD-13D

Acid Extractables	Result as Received	Limit of Quantitation	Lab Code
2-Chlorophenol	< 20. ug/l	20.	064600000N
Phenol	< 20. ug/l	20.	065500000N
2-Nitrophenol	< 20. ug/l	20.	065100000N
2,4-Dimethylphenol	< 20. ug/l	20.	064800000N
2,4-Dichlorophenol	< 20. ug/l	20.	064700000N
4-Chloro-3-methylphenol	< 20. ug/l	20.	065300000N
2,4,6-Trichlorophenol	< 20. ug/l	20.	065600000N
2,4-Dinitrophenol	< 50. ug/l	50.	065000000N
4-Nitrophenol	< 50. ug/l	50.	065200000N
2-Methyl-4,6-dinitrophenol	< 50. ug/l	50.	064900000N
Pentachlorophenol	< 50. ug/l	50.	065400000N

Well Number: CSD-13D
Water Sample Number: #856
Collected on: April 5, 1989

Table 2. Lancaster Laboratories, Inc. Analysis Report of Water Samples from CSD-13D

Base Neutrals	Result as Received	Limit of Quantitation	Lab Code
Anthracene	< 20. ug/l	20.	065900000N
1-n-butyl phthalate	< 20. ug/l	20.	068200000N
Fluoranthene	< 20. ug/l	20.	068700000N
Pyrene	< 20. ug/l	20.	070100000N
Benzidine	< 50. ug/l	50.	066000000N
Benzyl phthalate	< 20. ug/l	20.	067100000N
Benzo (α) anthracene	< 20. ug/l	20.	066100000N
Chrysene	< 20. ug/l	20.	067400000N
1,3 Dichlorobenzidine	< 50. ug/l	50.	067900000N
*Cis (2-ethylhexyl) phthalate	2,630. ug/l	20.	066900000N
Di-n-octyl phthalate	< 20. ug/l	20.	068500000N
Benzo (β) fluoranthene	< 20. ug/l	20.	066300000N
Benzo (K) fluoranthene	< 20. ug/l	20.	066500000N
Benzo (α) pyrene	< 20. ug/l	20.	066200000N
Indeno (1,2,3-cd) pyrene	< 20. ug/l	20.	069300000N
Dibenzo (a,h) anthracene	< 20. ug/l	20.	067500000N
Benzo (ghi) perylene	< 20. ug/l	20.	066400000N

*Due to suspected contamination, this sample was re-extracted and re-analyzed for bis (2-ethylhexyl) phthalate. The result from the re-analysis for this compound is 50. ug/l. The detection limit for this compound in the re-extract is 40. ug/l (increased due to limited volume for re-analysis). Since the holding time had been exceeded, data from both extractions is reported.

Well Number: CSD-13D
 Water Sample Number: #856
 Collected on: April 5, 1989

Table 3. Lancaster Laboratories, Inc. Analysis Report of Water Samples from CSD-13D

Base Neutrals	Result as Received	Limit of Quantitation	Lab Code
N-Nitrosodimethylamine	< 20. ug/l	20.	069700000N
cis (2-chloroethyl) ether	< 20. ug/l	20.	066700000N
1,3-Dichlorobenzene	< 20. ug/l	20.	067700000N
1,4-Dichlorobenzene	< 20. ug/l	20.	067800000N
1,2-Dichlorobenzene	< 20. ug/l	20.	067600000N
cis (2-chloroisopropyl) ether	< 20. ug/l	20.	066800000N
Hexachloroethane	< 20. ug/l	20.	069200000N
N-nitrosodi-n-propylamine	< 20. ug/l	20.	069800000N
Nitrobenzene	< 20. ug/l	20.	069600000N
Isophorone	< 20. ug/l	20.	069400000N
Bis (2-chloroethoxy) methane	< 20. ug/l	20.	066600000N
1,2,4-Trichlorobenzene	< 20. ug/l	20.	070200000N
Naphthalene	< 20. ug/l	20.	069500000N
Hexachlorobutadiene	< 20. ug/l	20.	069000000N
Hexachlorocyclopentadiene	< 20. ug/l	20.	069100000N
2-Chloronaphthalene	< 20. ug/l	20.	067200000N
Acenaphthylene	< 20. ug/l	20.	065800000N
Dimethyl phthalate	< 20. ug/l	20.	068100000N
2,6-Dinitrotoluene	< 20. ug/l	20.	068400000N
Acenaphthene	< 20. ug/l	20.	065700000N
2,4-Dinitrotoluene	< 20. ug/l	20.	068300000N
Fluorene	< 20. ug/l	20.	068800000N
4-Chlorophenyl phenyl ether	< 20. ug/l	20.	067300000N
Diethyl phthalate	< 20. ug/l	20.	068000000N
1,2-Diphenylhydrazine	< 20. ug/l	20.	068600000N
N-Nitrosodiphenylamine	< 20. ug/l	20.	069900000N
4-Bromophenyl phenyl ether	< 20. ug/l	20.	067000000N
Hexachlorobenzene	< 20. ug/l	20.	068900000N
Phenanthrene	< 20. ug/l	20.	070000000N

Date: April 28, 1989
 Well Number: CSD-13D
 Laboratory Number: M856
 Sample Description: Water Sample
 Date Received: March 28, 1989

Table 4. Lancaster Laboratories, Inc. Analysis Report of Water Samples from CSD-13D

Compound	Concentration µg/l	Limit of Detection µg/l
Chloromethane	< 10	10
Bromomethane	< 10	10
Vinyl chloride	< 10	10
Chloroethane	< 10	10
Methylene chloride	7 (B=2)	5
1,1-Dichloroethene	< 5	5
1,1-Dichloroethane	< 5	5
Trans-1,2-dichloroethene	1 (J)	5
Chloroform	< 5	5
1,2-Dichloroethane	< 5	5
1,1,1-Trichloroethane	1 (J)	5
Carbon Tetrachloride	< 5	5
Bromodichloromethane	< 5	5
1,2-Dichloropropane	< 5	5
cis-1,3-dichloropropene	< 5	5
Trichloroethene	3 (J)	5
Dibromochloromethane	< 5	5
1,1,2-Trichloroethane	< 5	5
Benzene	5	5
2-Chloroethylvinylether	< 10	10
Trans-1,3-dichloropropene	< 5	5
Bromoform	< 5	5
Tetrachloroethene	< 5	5
1,1,2,2-Tetrachloroethane	< 5	5
Toluene	< 5	5
Chlorobenzene	< 5	5
Ethylbenzene	< 5	5
Total xylenes	< 5	5

J = Below detection limit

B = Found in method blank at level indicated

Method of Analysis: EPA Method 624 + Xylenes using HP Gas Chromatograph/Mass Spectrometer

Date: April 25, 1989
 Well Number: Field Blank
 Laboratory Number: M857
 Sample Description: Water Sample
 Date Received: March 28, 1989

Table 5. Lancaster Laboratories, Inc. Analysis Report of Water Samples from the Well Blank

Compound	Concentration µg/l	Limit of Detection µg/l
Chloromethane	< 10	10
Bromomethane	< 10	10
Vinyl chloride	< 10	10
Chloroethane	< 10	10
Methylene chloride	2 (J, B = 2)	5
1,1-Dichloroethene	< 5	5
1,1-Dichloroethane	< 5	5
trans-1,2-dichloroethene	< 5	5
Chloroform	< 5	5
1,2-Dichloroethane	< 5	5
1,1,1-Trichloroethane	< 5	5
Carbon tetrachloride	< 5	5
Bromodichloromethane	< 5	5
1,2-Dichloropropane	< 5	5
cis-1,3-dichloropropene	< 5	5
Trichloroethene	< 5	5
Dibromochloromethane	< 5	5
1,1,2-Trichloroethane	< 5	5
Benzene	5	5
2-Chloroethylvinylether	< 10	10
trans-1,3-dichloropropene	< 5	5
Bromoform	< 5	5
Tetrachloroethene	< 5	5
1,1,2,2-Tetrachloroethane	< 5	5
Toluene	< 5	5
Chlorobenzene	< 5	5
Ethylbenzene	< 5	5
Total xylenes	< 5	5

J = Below detection limit

B = Found in method blank at level indicated

Method of Analysis: EPA Method 624 + Xylenes using HP5970 Gas Chromatograph/Mass Spectrometer

Date: April 28, 1989
 Well Number: CSD-11D
 Laboratory Number: M858
 Sample Description: Water Sample
 Date Received: March 28, 1989

Table 6. Lancaster Laboratories, Inc. Analysis Report of Water Samples from CSD-11D

Compound	Concentration µg/l	Limit of Detection µg/l
Chloromethane	< 10	10
Bromomethane	< 10	10
Vinyl chloride	< 10	10
Chloroethane	< 10	10
Methylene chloride	15 (B = 2)	5
1,1-Dichloroethene	< 5	5
1,1-Dichloroethane	< 5	5
Trans-1,2-dichloroethene	< 5	5
Chloroform	< 5	5
1,2-Dichloroethane	< 5	5
1,1,1-Trichloroethane	3 (J)	5
Carbon tetrachloride	< 5	5
Bromodichloromethane	< 5	5
1,2-Dichloropropane	< 5	5
cis-1,3-dichloropropene	< 5	5
Trichloroethene	2 (J)	5
Dibromochloromethane	< 5	5
1,1,2-Trichloroethane	< 5	5
Benzene	< 5	5
2-chloroethylvinylether	< 10	10
Trans-1,3-dichloropropene	< 5	5
Bromoform	< 5	5
Tetrachloroethene	< 5	5
1,1,2,2-Tetrachloroethane	< 5	5
Toluene	< 5	5
Chlorobenzene	< 5	5
Ethylbenzene	< 5	5
Total xylenes	< 5	5

J = Below detection limit

B = Found in method blank at level indicated

Method of Analysis: EPA Method 624 + Xylenes using HP 5970 Gas Chromatograph/Mass Spectrometer

Date: April 28, 1989
 Well Number: CSD-4D
 Laboratory Number: M859
 Sample Description: Water Sample
 Date Received: March 28, 1989

Table 7. Lancaster Laboratories, Inc. Analysis Report of Water Samples from CSD-4D

Compound	Concentration µg/l	Limit of Detection µg/l
Chloromethane	< 10	10
Bromomethane	< 10	10
Vinyl chloride	< 10	10
Chloroethane	< 10	10
Methylene chloride	1 (J, B = 2)	5
1,1-Dichloroethene	< 5	5
1,1-Dichloroethane	< 5	5
trans-1,2-dichloroethene	< 5	5
Chloroform	< 5	5
1,2-Dichloroethane	< 5	5
1,1,1-Trichloroethane	< 5	5
Carbon tetrachloride	< 5	5
Bromodichloromethane	< 5	5
1,2-Dichloropropane	< 5	5
cis-1,3-dichloropropene	< 8	5
Trichloroethene	< 8	5
Dibromochloromethane	< 5	5
1,1,2-Trichloroethane	< 5	5
Benzene	< 5	5
Trans-1,3-dichloropropene	< 10	10
2-Chloroethylvinylether	< 5	5
Bromoform	< 5	5
Tetrachloroethene	3 (J)	5
1,1,2,2-Tetrachloroethane	< 5	5
Toluene	< 5	5
Chlorobenzene	< 5	5
Ethylbenzene	< 5	5
Total xylenes	< 5	5

J = Below detection limit

B = Found in method blank at level indicated

Method of Analysis: EPA Method 624 + Xylenes using HP 5970 Gas Chromatograph/Mass Spectrometer

Date: April 28, 1989
 Well Number: Trip Blank
 Laboratory Number: M860
 Sample Description: Water Sample
 Date Received: March 28, 1989

Table 8. Lancaster Laboratories, Inc. Analysis Report of Water Samples from the Trip Blank

Compound	Concentration µg/l	Limit of Detection µg/l
Chloromethane	< F10	10
Bromomethane	< 10	10
Vinyl chloride	< 10	10
Chloroethane	< 10	10
Methylene chloride	3 (J, B = 2)	5
1,1-Dichloroethene	< 5	5
1,1-Dichloroethane	< 5	5
trans-1,2-dichloroethene	< 5	5
Chloroform	< 5	5
1,2-Dichloroethane	< 5	5
1,1,1-Trichloroethane	< 5	5
Carbon tetrachloride	< 5	5
Bromodichloromethane	< 5	5
1,2-Dichloropropane	< 5	5
cis-1,3-dichloropropene	< 5	5
Trichloroethene	< 5	5
Dibromochloromethane	< 5	5
1,1,2-Trichloroethane	< 5	5
Benzene	< 5	5
trans-1,3-dichloropropene	< 10	10
2-Chloroethylvinylether	< 5	5
Bromoform	< 5	5
Tetrachloroethene	< 5	5
1,1,2,2-Tetrachloroethane	< 5	5
Toluene	< 5	5
Chlorobenzene	< 5	5
Ethylbenzene	< 5	5
Total xylenes	< 5	5

J = Below detection limit

B = Found in method blank at level indicated

Method of Analysis: EPA Method 624 + Xylenes using HP 5970 Gas Chromatograph/Mass Spectrometer

Appendix II
Soil Microbiology Counts

Date: February 2, 1989

Laboratory Number: 038035 and 038037 - M506 to M543

Samples Description: Core Samples

Date Received: December 20, 21, and 22, 1988

Sample From: Savannah River Plant, Aiken SC

Table 1. Analysis Report

Log #	Core #	Depth Feet	CFU/g	
			Total Counts *	Diesel Utilizers **
534	1-1	47	< 100	< 200
535	1-2	50	< 100	< 200
536	1-3	52	< 100	< 200
537	1-4	55	100	< 200
538	1-5	61	< 100	< 200
538D	1-5	61	< 100	< 200
539	2-1	27	1400	< 200
540	2-2	30	1200	< 200
541	2-3	31	500	< 200
542	2-4	36	< 100	< 200
543	2-5	46	200	< 200
543D	2-5	46	100	< 200
506	3-1	3	2800	200
507	3-2	7	1000	< 200
508	3-3	12	< 100	2200

*100 is the minimum number of total bacteria that can be counted by this procedure

**200 is the minimum of diesel utilizers that can be counted by this procedure

"D" indicates laboratory duplicate

Date: February 1, 1989
 Laboratory Number: 38036 - M509 to M533
 Sample Description: Core Samples
 Date Received: December 17, 1988
 Sample From: Savannah River Plant, Aiken SC
 Chain of Custody: Yes

Table 2. Analysis Report

Log #	Core #	Depth Feet	CFU/g	
			Total Counts *	Diesel Utilizers **
509	4-1	2.5	4600	< 200
510	4-2	4	1000	< 200
511	4-3	12	< 100	200
512	4-4	17	< 100	200
513	4-5	22	< 100	200
514	4-6	25	< 100	< 200
515	4-7	28	< 100	200
516	4-8	31	< 100	200
517	4-9	34	< 100	200
518	4-10	37	< 100	200
519	4-11	40	< 100	< 200
520	4-12	43	100	< 200
521	4-13	46	< 100	< 200
522	4-14	48	< 100	< 200
523	4-15	52	< 100	< 200
524	4-16	55	< 100	< 200
525	4-17	58	< 100	< 200
526	4-18	61	100	< 200
527	4-19	64	400	< 200
528	4-20	67	< 100	< 200
529	4-21	70	< 100	< 200
530	4-22	73	< 100	< 200
531	4-23	76	< 100	200
532	4-24	79	< 100	< 200
533	4-25	82	< 100	< 200

*100 is the minimum number of total bacteria that can be counted by this procedure
 **200 is the minimum number of diesel utilizers that can be counted by this procedure

Date: January 31, 1989

Laboratory Number: 038035 and 036038 - M496 to M569

Sample Description: Core Samples

Date Received: December 15, 16, 1988 and January 4, 1989

Sample From: Savannah River Plant, Aiken SC

Chain of Custody: Yes

Table 3. Analysis Report

Log #	Core #	Depth Feet	CFU/g	
			Total Counts *	Diesel Utilizers **
496	5-1	1-3	2800	200
497	5-2	3	520,000	22,400
498	5-2	7-9	400	< 200
499	5-3	10-12	1000	< 200
500	6-1	2.5	1500	< 200
501	6-2	7	4000	< 200
502	6-3	12	< 100	< 200
503	7-1	4	< 100	< 200
504	7-2	8	< 100	< 200
505	7-3	12	< 100	400
562	8-1	27	2000	800
563	8-2	32	< 100	< 200
564	8-3	37	100	< 200
565	8-4	42	< 100	< 200
566	8-5	57	< 100	< 200
567	8-6	67	< 100	< 200
567D	8-6	67	< 100	< 200
569	8-7	77	< 100	< 200

*100 is the minimum number of total bacteria that can be counted by this procedure

**200 is the minimum of diesel utilizers that can be counted by this procedure

"D" indicates laboratory duplicate

Date: February 16, 1989
 Laboratory Number: 038038 and 038046 - M570 to M586
 Sample Description: Core Samples
 Date Received: January 6, 9, and 11, 1989
 Sample From: Savannah River Plant, Aiken SC
 Chain of Custody: Yes

Table 4. Analysis Report

Log #	Core #	Depth Feet	CFU/g	
			Total Counts *	Diesel Utilizers **
M576	9-1	8	200	200
M577	9-2	20	< 100	< 200
M578	9-3	30	< 100	< 200
M579	9-4	38	< 100	< 200
M580	9-5	50	100	< 200
M581	9-6	56	1000	400
M582	9-7	60	100	< 200
M583	9-8	66	300	200
M584	9-9	72	< 100	200
M585	9-10	76	< 100	< 200
M586	9-11	80	100	< 200
570	10-1	32	< 100	< 200
571	10-2	42	< 100	< 200
572	10-3	52	100	< 200
573	10-4	57	4200	3800
574	10-5	62	< 100	600
575	10-6	67	< 100	< 200

*100 is the minimum number of total bacteria that can be counted by this procedure

** 200 is the minimum number of diesel utilizers that can be counted by this procedure

Date: February 16, 1989
 Laboratory Number: 038047 - M593 to M603
 Sample Description: Core Samples
 Date Received: January 12, 1989
 Sample From: Savannah River Plant, Aiken SC
 Chain of Custody: Yes

Table 5. Analysis Report

Log #	Core #	Depth Feet	CFU/g	
			Total Counts *	Diesel Utilizers **
M593	11-1	6	300	< 200
M594	11-2	10	< 100	< 200
M595	11-3	16	100	< 200
M596	11-4	24	< 100	200
M597	11-5	30	< 100	2400
M598	11-6	36	< 100	200
M599	11-7	42	< 100	200
M600	11-8	48	< 100	< 200
M601	11-9	54	100	< 200
M602	11-10	62	< 100	< 200
M603	11-11	70	100	< 200

* 100 is the minimum number of total bacteria that can be counted by this procedure

**200 is the minimum number of diesel utilizers that can be counted by this procedure

Date: February 2, 1989
 Laboratory Number: 038037 and 038038 - M544 to M561
 Sample Description: Core Samples
 Date Received: December 23, 1988 and January 4, 1989
 Sample From: Savannah River Plant, Aiken SC
 Chain of Custody: Yes

Table 6. Analysis Report

Log #	Core #	Depth Feet	CFU/g	
			Total Counts *	Diesel Utilizers **
556	12-1	32	< 100	< 200
557	12-2	37	< 100	< 200
558	12-3	42	< 100	200
559	12-4	47	300	< 200
560	12-5	60	100	200
561	12-6	65	< 100	200
544	13-1	7	300	< 200
545	13-2	12	< 100	200
546	13-3	17	600	200
547	13-4	22	200	1000
548	13-5	27	< 100	< 200
549	13-6	32	< 100	< 200
550	13-7	37	100	< 200
551	13-8	42	< 100	< 200
552	13-9	47	100	< 200
553	13-10	52	< 100	< 200
554	13-11	57	< 100	< 200
555	13-12	62	< 100	< 200

* 100 is the minimum number of total bacteria that can be counted by this procedure

**200 is the minimum number of diesel utilizers that can be counted by this procedure

Date: May 23, 1989
Laboratory Number: 038089 - M856 to M860
Sample Description: Water Samples
Date Received: March 28, 1989
Sample From: Savannah River Plant, Aiken SC
Chain of Custody: Yes

Table 7. Analysis Report

Log #	Well #	Total Counts	Diesel Utilizers
M856	13	3600	4200
M857	FB*	9	20
M858	11	44000	14800
M859	4	0	< 10 ¹
M859D	4	0	< 10
M860	TB*	0	< 10

Standard Dilution Method

¹ Minimum number of diesel utilizer which can be counted by this procedure is 10 organisms per milliliter

*FB = Field Blank

*TB = Trip Blank

Date: May 23, 1989
Laboratory Number: 038089 - M856 to M860
Sample Description: Water Samples
Date Received: March 28, 1989
Sample From: Savannah River Plant, Aiken SC
Chain of Custody: Yes

Table 8. Analysis Report

Log #	Well #	Direct Counts
M856	13	11,498
M857	FB*	< 40 ¹
M858	11	5970
M859	4	5105
M859D	4	9894
M860	TB*	< 40

Cells stained with acridine orange, collected on a 0.45 um Erglan black prestained filter, and counted by epifluorescent microscopy.

¹Minimum number of direct counts which can be made by this procedure is 40 organisms per milliliter

* FB = Field Blank

* TB = Trip Blank