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## **ENHANCED BIODEGRADATION THROUGH SOIL VENTING**

**ROBERT E. HINCHEE  
BATTELLE MEMORIAL INSTITUTE  
505 KING AVENUE  
COLUMBUS OH 43201**

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**AIR FORCE RESEARCH LABORATORY  
MATERIALS & MANUFACTURING DIRECTORATE  
AIRBASE & ENVIRONMENTAL TECHNOLOGY DIVISION  
TYNDALL AFB FL 32403-5323**

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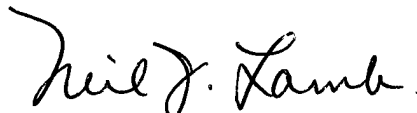
**TIMOTHY G WILEY, Maj, USAF, BSC**  
Biosystems Area Manager



**CHRISTINE WAGENER-HULME, LtCol, USAF**  
Chief, Environmental Technology Development Branch



**ANDREW D. POULIS**  
Scientific & Technical Info Prog Mgr



**NEIL J. LAMB, Col, USAF, BSC**  
Chief, Airbase & Environmental Technology Division

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**13. ABSTRACT (Maximum 200 words)**

The objective of this report was to investigate the potential for enhanced biodegradation of JP-4 jet fuel in the vadose zone by providing O<sub>2</sub> through soil venting with added moisture and nutrients. Two treatment and two background plots were used, with different combinations of venting, moisture and nutrient additions at each one. Biodegradation rates varied from 2 to 20 mg/kg/day, with an average of 5 mg/(kg day). Moisture and nutrient addition had no apparent effect on biodegradation rates. The effects of soil temperature on biodegradation rates were shown to approximate effects predicted by the Van't Hoff-Arrhenius equation. In one treatment cell, approximately 26 kg of hydrocarbons/contaminants were volatilized and 32 kg were biodegraded. Although this equates to 55 percent of the total removal attributed to biodegradation, a series of flow rate tests showed that removal due to biodegradation could be increased to 85 percent by simply managing the air flow rates. Proper design and air flow management could result in complete biological mineralization of jet fuel, thereby reducing remediation costs.

**14. SUBJECT TERMS**

In situ biodegradation, JP-4 jet fuel, bioventing, vadose zone, nutrient and moisture addition, petroleum hydrocarbons, temperature

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## EXECUTIVE SUMMARY

### A. OBJECTIVE

The objective of this project was to investigate the potential for enhanced biodegradation of JP-4 jet fuel in the vadose zone by providing oxygen through soil venting, combined with the addition of moisture and nutrients. This project was a field evaluation and demonstration of this in situ technology. Specific objectives of the research were as follows:

1. To evaluate the potential for enhanced biodegradation of JP-4 in the vadose zone through soil venting and to evaluate the incremental effectiveness of adding nutrients and moisture
2. To evaluate the relationships among air flow rate, biodegradation, and volatilization to determine minimal aeration rates required to maintain aerobic conditions for maximizing biodegradation and minimizing volatilization
3. To evaluate the potential for biodegradation of hydrocarbon vapors (off-gas) in uncontaminated or less contaminated vadose zone soil as an alternative to expensive aboveground off-gas treatment.

The intended result is to develop sufficient information to allow the U.S. Air Force or other large users of similar fuel mixtures to progress to full-scale implementation of the technology.

### B. BACKGROUND

Every year the U.S. Air Force stores and transfers more than 3 billion gallons of JP-4 jet fuel. Fuel leaks and spills are the most frequent sources of soil and groundwater contamination on Air Force installations. An estimated 1,500 fuel spills have been identified during Phase II investigations of the Air Force Installation Restoration Program (IRP). The volume of these spills ranges from tens of gallons to 125,000 gallons of JP-4 jet fuel. The number of spill sites could increase as underground storage tanks are more closely inspected.

Soil venting is effective for physical removal of volatile hydrocarbons from unsaturated soils, but in some cases is also more effective than water/hydrogen peroxide as a source of oxygen for biological mineralization of the volatile and nonvolatile fractions. Treatment of soil venting off-gas is

expensive, constituting a minimum of 50 percent of soil venting remediation costs. This research investigated methods for enhancing biological mineralization through soil venting, with the goal of eliminating the need for expensive off-gas treatment.

### C. SCOPE

Building on earlier research conducted by the U.S. Air Force Engineering and Services Center, a field investigation was conducted at Tyndall Air Force Base (AFB), Florida, where past jet fuel storage had resulted in contaminated sandy soils. The scope of work comprised three tasks: initial site characterization, test plan preparation, and field testing.

Initial site characterization activities included (a) determining the location of test plots for treatment; (b) determining contaminant levels and distribution in groundwater, soil, and soil gas; (c) determining the distribution of total and hydrocarbon-degrading bacteria in the soils; (d) determining soil texture and soil organic matter content; (e) installation of permanent soil gas probes and monitoring wells; and (f) determining soil gas permeability.

A test plan was then prepared describing the results of the site characterization and outlining experiments to be performed in the field, along with the appropriate instrumentation and analytical methods to be employed.

Test plots were then constructed and air and water/nutrient delivery systems were installed. These systems were tested and modified as necessary before the field test start-up on October 4, 1989, and operated through April 24, 1990, with final sampling in May 1990.

### D. METHODOLOGY

The study combined field evaluation and demonstration with laboratory analysis. Two treatment plots and two background plots were constructed and operated in the following manner:

- a. Contaminated Treatment Plot 1--Venting only for approximately 8 weeks, followed by moisture addition for approximately 14 weeks, followed by moisture and nutrient addition for approximately 7 weeks.
- b. Contaminated Treatment Plot 2--Venting coupled with moisture and nutrient addition for 29 weeks.

- c. Background Plot 3--Venting with moisture and nutrient addition at rates similar to Plot 2, with injection of hydrocarbon-contaminated off-gas from Plot 1.
- d. Background Plot 4--Venting with moisture and nutrient addition at rates similar to Vent 2.

Soil, water, and soil gas samples were collected in the field using properly calibrated instruments. These samples were then analyzed in the laboratory according to specific protocols.

#### E. TEST DESCRIPTION

Nine soil gas monitoring probes and two groundwater monitoring wells were installed in each plot. In situ soil and vented off-gases were monitored twice weekly for oxygen, carbon dioxide, and total hydrocarbon concentrations. The venting system was shut down periodically and the oxygen uptake and carbon dioxide production levels were measured to determine the in situ biodegradation rates. The test plots were operated with and without nutrient and moisture addition to determine the effect of these parameters on biodegradation rates. The venting system air flow rate was varied to determine the effect on the proportion of hydrocarbon removal by biodegradation.

#### F. RESULTS

Measured biodegradation rates varied from 2 to 20 mg/kg/day. Moisture addition had no significant effect on soil moisture content or biodegradation rate. Soil moisture content ranged from 6.5 to 9.8 percent, by weight, throughout the field test. Nutrient addition had no statistically significant effect on biodegradation rate. Temperature did have a significant effect, with higher biodegradation being measured at higher temperatures. Initial soil samples indicated that naturally occurring nutrients were adequate for the amount of biodegradation observed. Acetylene reduction studies revealed an organic nitrogen fixation potential capable of fixing the observed organic nitrogen, under anaerobic conditions, in as little as 60 days.

In one treatment cell, approximately 26 kg of hydrocarbons volatilized and 32 kg biodegraded. Although this equates to 55 percent removal attributed



to biodegradation, a series of flow rate tests showed that biodegradation could be increased to 85 percent by simply managing the air flow rate. Off-gas from one treatment cell was injected into clean soil to assess the potential for complete biological remediation. Based on the data collected at this field site, a soil volume ratio of approximately 4 to 1, uncontaminated to contaminated soil, would be required to biodegrade the off-gas completely from a similarly operated bioventing system.

#### G. CONCLUSIONS

This field-scale investigation has demonstrated that soil venting is an effective source of oxygen for enhanced aerobic biodegradation of petroleum hydrocarbons (jet fuel) in the vadose zone. Operational data and in situ respiration tests indicated that moisture (6.5-9.8 percent) and nutrients were not a limiting factor in hydrocarbon biodegradation or, if limiting, did not stimulate hydrocarbon biodegradation in the field plots.

This research indicates that proper design and air flow management could result in complete biological mineralization of jet fuel, thereby substantially reducing remediation costs. Moreover, this research has provided adequate design parameters for a full-scale remediation project using enhanced biodegradation through soil venting. A full-scale project should attempt to biodegrade all contamination including any generated off-gas.

#### H. RECOMMENDATIONS

A configuration is presented that may successfully remediate the contaminated site and the generated off-gas. An air extraction well is drilled in uncontaminated soil at a distance from the contaminated site that will provide adequate uncontaminated soil volume (4:1) to treat generated off-gas. Air injection wells are drilled, as needed, into and on the opposite side of the contaminated area in a manner that will provide a relatively even distribution of air to the contaminated soil. Soil gas monitoring wells are installed in the contaminated area and, in the uncontaminated area, used as an off-gas treatment reactor to monitor total hydrocarbons, carbon dioxide, and oxygen. Air flows are adjusted to assure aerobic conditions in the contaminated and off-gas treatment areas while ensuring that only carbon

dioxide, not hydrocarbons, are emitted from the blower. A strategy for design should include as a minimum the following:

1. In addition to a conventional site investigation, initial soil samples should be collected to determine the volume of contaminated soil, the total hydrocarbon, total organic nitrogen (TKN), and total phosphorus concentrations.
2. Initial soil gas analyses should be conducted to delineate hydrocarbon, O<sub>2</sub>, and CO<sub>2</sub> distributions.
3. Field treatability tests to determine in situ respiration rates and gas permeability levels should be conducted to demonstrate biodegradation and to determine rates for design.
4. C:N:P ratios should be determined assuming no nutrient recycle, a C:N:P ratio of 300:10:1 should be adequate, realizing that only one-third of the hydrocarbons are converted to cell mass and two-thirds to carbon dioxide. Wider C:N:P ratios should not eliminate the site as a potential candidate for this technology.
5. Based upon the field treatability tests, an air delivery system should be designed to provide sufficient, but not excess, air to the site.
6. Soil gas should be monitored and adjusted to assure minimum air flow rates to maintain aerobic conditions (2-4 percent O<sub>2</sub>) and minimize or eliminate hydrocarbons in the blower discharge.
7. Add moisture only if moisture is significantly less than required for biodegradation. Add nutrients only if C:N:P ratios are not satisfied and biodegradation rates are significantly less than reported in this research and if nutrients appear to be limiting. If nitrogen is limiting, consideration may be given to shutting down the air delivery system temporarily and enhancing anaerobic nitrogen fixation.
8. Depending on seasonal temperature fluctuations, operation during periods of maximum soil temperature may be optimum.
9. Manipulate the water table as required for air/contaminant contact.

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## PREFACE

This report was prepared by Battelle Memorial Institute, 505 King Avenue, Columbus, OH 43201, USAF Contract No. F08635-85-C-0122, for the US Air Force Research Laboratory, Materials and Manufacturing Directorate, Airbase and Environmental Technology Division (AFRL/MLQE), Suite 2, 139 Barnes Drive, Tyndall Air Force Base, Florida 32403-5323. AFRL/MLQE was formally known as the US Air Force Armstrong Laboratory (AL/EQ).

This final report investigates the potential for enhanced biodegradation of JP-4 in the vadose zone by providing oxygen through soil venting with added moisture and nutrients. Two treatment and two background plots were used, with different combinations of venting, moisture, and nutrient addition. Biodegradation rates varied from 2 to 20 mg/kg/day. Moisture and nutrient addition had no apparent effect on the biodegradation rates. A total of 55 percent of the hydrocarbons were removed due to volatilization and biodegradation, with potential of increasing to 85 percent with air flow management. Proper design and air flow management could result in complete biological mineralization of jet fuel, thereby reducing remediation costs.

The work was performed between June 1990 and August 1990. The AL/EQ project officer were Doug Downey and Catherine Vogel.

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SECTION I  
INTRODUCTION

A. OBJECTIVE

This research, funded by the Environics Division of the U.S. Air Force Engineering and Services Center (AFESC), builds upon earlier AFESC work with enhanced bioreclamation. Two field projects that evaluated conventional hydrogen-peroxide-enhanced bioreclamation technology (1,2) led to the conclusion that this process was very inefficient. Based upon these apparent failures, Battelle recommended evaluating the soil venting approach to aeration of contaminated soils. AFESC therefore supported a project to evaluate biodegradation associated with conventional soil venting (3) and, based upon the results of that study, initiated the research reported here.

The objective of this project was to investigate the potential for enhanced biodegradation of JP-4 jet fuel in the vadose zone by providing oxygen through soil venting, combined with the addition of moisture and nutrients. This project was a field evaluation and demonstration of this in situ technology. Specific objectives of the research were

1. To evaluate the potential for enhanced biodegradation of JP-4 in the vadose zone through soil venting and to evaluate the incremental effectiveness of adding nutrients and moisture
2. To evaluate the relationships among air flow rate, biodegradation, and volatilization to determine minimal aeration rates required to maintain aerobic conditions for maximizing biodegradation and minimizing volatilization
3. To evaluate the potential for biodegradation of hydrocarbon vapors (off-gas) in uncontaminated or less contaminated vadose zone soil as an alternative to expensive aboveground off-gas treatment.

The intended result is to develop sufficient information to allow the Air Force or other large users of similar fuel mixtures to progress to full-scale implementation of the technology.

## B. BACKGROUND

Every year the U.S. Air Force stores and transfers more than 3 billion gallons of JP-4 jet fuel. Fuel leaks and spills are the most frequent sources of soil and groundwater contamination on Air Force installations. An estimated 1,500 fuel spills have been identified during Phase II investigations of the Air Force Installation Restoration Program (IRP). The volume of these spills ranges from tens of gallons to 125,00 gallons of JP-4 jet fuel. The number of spill sites could increase as underground storage tanks are more closely inspected.

The Environics Division of AFESC, Tyndall Air Force Base (AFB), develops and tests new technologies that can remediate jet fuel contamination in both soil and groundwater. Sampling data have shown that the majority of spilled fuel will remain in the vadose zone, adsorbed or occluded in the soil matrix. Air Force researchers have been investigating technologies for enhancing the natural biodegradation of fuel residuals in the vadose zone.

In 1986, AFESC initiated a full-scale in situ soil venting test. The field site chosen was a contamination site at Hill AFB, Utah, where 27,000 gallons of JP-4 jet fuel were accidentally released in 1985. Field studies were conducted to document the amount of JP-4 being biodegraded in the vadose zone during the soil venting test. Laboratory treatability studies were also conducted to determine the feasibility of increasing the rate of in situ biodegradation of the jet fuel components.

The field studies showed that approximately 25 percent of the total amount of the hydrocarbons removed was due to in situ biodegradation. The laboratory studies indicated that the amount of hydrocarbon removal due to biodegradation could be increased by amending the unsaturated zone with nutrients and additional moisture.

## C. SCOPE/APPROACH

In 1989, a pilot-scale bioventing project was initiated at a JP-4 contamination site at Tyndall AFB. The objective of this project was to build upon our earlier soil venting work at Hill AFB and to optimize the biodegradation component of soil venting.

The site chosen for this study was an old JP-4 jet fuel storage area at Tyndall AFB. Fuels that had been stored there and may have potentially

contributed to the contamination include JP-4 jet fuel, diesel fuel Number 2, and motor gasoline. The soil in the area of the spill site consists of very fine to fine unconsolidated quartz sands with trace occurrences of organic material. The groundwater table lies approximately 3-5 feet below the ground surface in the contaminated area.

Initial site characterization showed total hydrocarbon concentrations ranging from 40 to 27,000 ppm in the soil gas. Oxygen concentrations were as low as 2.5 percent and carbon dioxide levels as high as 20 percent in the soil gas. This was a good indication that biodegradation of the hydrocarbon contaminants was already taking place.

Prior to constructing the test cells, a dewatering system was installed to lower the water table in the contaminated area to approximately 5 feet. This extended the smear zone and increased the volume of contaminated soil that we attempted to treat. The test cells were constructed by isolating a volume of contaminated soil in situ using tongue and groove plywood boards, plastic on four sides, and the water table as a bottom seal. A venting system was installed in each test plot. This system consisted of a central vacuum well with air entering the subsurface passively from either end of the cell. Additional moisture and nutrients were added via perforated polyvinyl chloride (PVC) pipes laid in shallow gravel trenches at the surface of the cell.

Nine soil gas monitoring probes and two groundwater monitoring wells were installed in each plot. In situ soil and vented off-gases were monitored twice weekly for oxygen, carbon dioxide, and total hydrocarbon concentrations. The venting system was shut down periodically and the oxygen uptake and carbon dioxide production levels measured to determine the in situ biodegradation rates. The test plots were operated with and without nutrient and moisture addition to determine the effect of these parameters on biodegradation rates. The venting system air flow rate was varied to determine the effect on the proportion of hydrocarbon removal by biodegradation.

## SECTION II

### LITERATURE REVIEW

This literature review briefly addresses technologies for in situ remediation of fuel hydrocarbon contamination in the vadose zone including soil washing, radio-frequency (RF) heating of soil, soil venting, and microbial degradation. Soil washing and RF heating are only briefly addressed as they do not directly apply to this research. However, they are included to provide an overview of vadose zone in situ treatment alternatives. A review of soil venting literature was conducted to identify costs, efficiencies, and any connections between soil venting and biodegradation. Although aerobic and anaerobic biodegradation of hydrocarbons is well documented, sufficient literature is cited here to provide a working knowledge of applicable terms and mechanisms. Literature addressing conventional enhanced biodegradation is reviewed as an introduction and justification for enhanced biodegradation through soil venting.

The realization that contaminated soil, is a long-term source of groundwater contamination has shifted the focus of remediation from treating contaminated groundwater (pump and treat) to treating the source of the contamination in the vadose zone (4). The initial remediation method employed by consulting firms was excavation of contaminated soil with placement in landfills or for use in asphalt plants.

Fuel-contaminated soil is not listed or normally characterized as hazardous waste, and disposal in sanitary landfills is often recommended to reduce disposal costs (5). This is frequently the least expensive means of disposal; however, excavation and transport costs may be high and sanitary landfill space may not be available. Moreover, increased restrictions on landfilling and the risk of being identified as a potentially responsible party (PRP) in a hazardous waste or sanitary landfill cleanup project have led to the emergence of excavation, coupled with incineration as a remediation technology. However, because this technology is relatively expensive at \$1,000 to \$2,000 per cubic yard, it is cost prohibitive for large volumes of contaminated soil (6). A less expensive means of treating excavated soil contaminated with JP-4 is low-temperature desorption. Costs for this technique reportedly range from \$100 to \$200 per cubic yard (7).

Excavation is expensive, and may be impossible if contamination extends beneath buildings or across property lines. If contamination is deep, the size of safe excavations may be prohibitive (8). Numerous failures at hazardous waste landfills, together with the inability to excavate many sites, have prompted increased emphasis on on-site cleanup technologies. If feasible, this approach is usually preferred. On-site treatment has often proven less expensive than off-site alternatives and is therefore being applied more frequently. Technologies for in situ remediation of fuel hydrocarbon contamination in the vadose zone include soil washing, RF heating of the soil, soil venting, and enhanced microbial degradation.

Soil venting has been proven effective for the physical removal of volatile compounds such as gasoline and trichloroethylene (TCE) from the unsaturated zone. However, soil venting produces an effluent that may require expensive treatment before discharge.

This off-gas treatment step frequently constitutes a minimum of 50 percent of the total remediation costs. In addition, volatilization of contaminants through soil venting alone is not effective in removing nonvolatile or low volatility compounds such as fuel oil and jet fuel. This research explores the possibility of eliminating or reducing expensive off-gas treatment, while remediating low volatility jet fuel contamination of vadose zone soils.

#### A. SOIL WASHING

Soil washing is the flushing of contaminants from the vadose zone combined with pump and treat technology. Although this method may be successful for water-soluble compounds, it is of limited value for water-insoluble material. Fuel typically has a low aqueous solubility and, although the benzene, toluene, ethylbenzene, and xylenes (BTEX) fraction is more soluble, removal depends on partitioning from the low solubility or oily fraction of the fuel into the water. Surfactants and solvents have been used successfully to flush contaminants from the soil, but their use has been hindered by the toxicity of commercially available products. Also, this technology is hindered by the inability to trap hydraulically and pump all of the solubilized contaminant and solvent (9). It has been estimated that flushing with surfactants requires 30 to 40 pore volume exchanges of water to extract contaminants (6).



Column studies using a 4 percent surfactant solution resulted in 86 and 98 percent removal of crude oil and polychlorinated biphenyls (PCBs), respectively, after passing 10 pore volumes through the soil (10). However, AFESC-supported, field-scale research at Volk Field Air National Guard Base, Camp Douglas, Wisconsin, showed no significant removal of oil and grease after passing 14 pore volumes of surfactant solution through the soil (10). Because of the problems described, in situ soil washing has received less attention for fuel hydrocarbon remediation than either soil venting or microbial degradation.

## B. SOIL VENTING

Soil venting is the process whereby a vacuum is applied to a well or wells installed in the vadose zone in an area contaminated with volatile organics. Clean air is drawn through the subsurface along natural flow lines from the surface or through wells installed to allow preferential introduction or forced injection. The technology reduces organic vapor concentrations within the vadose zone while also accelerating evaporation and removal of volatile organic materials. This discussion is intended as an overview of soil venting; for a more complete review, see Reference 11.

Early work on soil venting was accomplished in 1980 by the Texas Research Institute (12) under contract to the American Petroleum Institute (API). Four experiments were conducted to examine forced venting of air through the soil above a gasoline spill in a model aquifer. Various flow rates and geometries for the venting plumbing were used to determine the most cost efficient method of (a) removing gasoline from the underground environment and (b) lowering gasoline vapor concentrations in the unsaturated zone above the spill. This laboratory research concluded that forced venting was a worthwhile technique to investigate in the field. Possible techniques for optimizing field use were suggested (12). This research also investigated microbial degradation resulting from oxygen supplied by soil venting. Researchers concluded that biodegradation was insignificant (12).

Work by the Texas Research Institute suggested soil venting as a viable in situ technology, but did not address mechanisms of removal or prediction of removal rates. Marley and Hoag (13) used column studies to measure evaporation rates of more than 50 compounds found in gasoline. The effects of soil density, moisture content, particle size, and induced air flow were

determined. The researchers demonstrated that 99 percent recovery of gasoline was possible using soil venting. A model based on Dalton's and Raoult's laws demonstrated excellent agreement between predicted and observed mass loss rates (13, 14). Additional laboratory research was conducted by Clarke (6) to evaluate the effectiveness of soil venting as a function of contaminant and soil type using column studies. Models were developed to assess feasibility and define parameters that would optimize field-scale studies.

Numerous field demonstration and full-scale remediation projects involving fuel hydrocarbons have demonstrated the efficacy of the technology. These projects have demonstrated that in situ treatment of volatile hydrocarbons by soil venting is not only effective, but much less expensive than traditional excavation/reburial or excavation/incineration technologies. A soil venting field demonstration was conducted at a spill site in Granger, Indiana. A ruptured valve at a petroleum fuels marketing terminal resulted in a release of 380,000 liters (100,000 gallons) of gasoline. A substantial amount of the gasoline was recovered, but the actual amount was not reported. Much of the unrecovered product had migrated 7.6 meters (25 feet) to the water table where 50 centimeters (cm) (1.6 feet) of floating product was measured in the monitoring wells. Two parallel test cells were constructed, each with one extraction well and two injection wells. After approximately 40 days of operational testing, 700 liters (186 gallons) of product had been removed and vapor concentrations had been reduced 99.2 percent at 30 cm (1 foot) above the capillary zone (15).

A pilot soil-venting test at a Bellview, Florida, site measured initial extraction rates ranging from 150 to 980 liters (39 to 260 gallons) per day. After 123 days of operation, a total of 11,120 liters (2,937 gallons) of the estimated 38,000 liter (10,000 gallon) release had been extracted from the site (16).

Explosive vapors discovered in a manhole by an electrical utility company led to the discovery of a long-term leak at a gasoline station. Soil venting at this site was shown to remove 730 kilograms (kg) (1,600 pounds) of gasoline hydrocarbons from contaminated soil, reducing soil vapor concentrations from the explosive range to less than 5 percent of the lower explosive limit (LEL). Concentrations remained below 5 percent LEL following a shutdown period of 1 week. During the 8 weeks of soil venting, all traces of free product

[originally measured up to 15 cm (6 inches)] were removed from the shallow water table. Groundwater hydrocarbon concentrations were also reduced more than 98 percent (17). It is not clear whether groundwater movement or soil venting was responsible for apparent cleanup of the groundwater. Investigators at another gasoline station spill site reported a removal rate of 15 kg (33.5 pounds) of total gasoline hydrocarbons per day. Regulators are allowing direct emission of volatilized hydrocarbon vapor at this site based on a risk assessment utilizing downwind dispersion modeling (18).

Soil venting systems are not always vertical and can be modified to match site characteristics. A horizontal soil venting system was designed and operated at a gasoline-contaminated site underlain by a shallow water table (19). Treatment for the evaporated gasoline was carbon adsorption with steam regeneration. The steam generator required 3.8 - 4.9 liters (1 - 1.3 gallons) of fuel oil per 3.8 liters (1 gallon) of gasoline removed. The extraction system was constructed on 6 meter (20 foot) centers, 1.2 - 1.4 meters (4 - 4.5 feet) deep. Injection trenches were later placed between extraction pipes to enhance removal. Investigators found that a polyethylene cover reduced short circuiting and improved removal efficiency. Investigators also found that most fuel was in the area of the fluctuating water table, and they considered dewatering to allow cleanup of this zone during winter months when the water table was high. It was concluded that soil venting reduced the concentration of contaminant in the groundwater as well as in the soil. They estimate a total cleanup cost of \$144,000 compared with \$560,000 for excavation (19).

One of the largest and most thoroughly documented fuel hydrocarbon soil venting projects was supported by AFESC at Hill AFB, Utah. In January 1985, an estimated 100,000 liters (27,000 gallons) of JP-4 jet fuel was released when an automatic shutoff device for a large fuel storage tank failed. An estimated 14,000 m<sup>3</sup> (18,000 yd<sup>3</sup>) of soil were unevenly contaminated to a depth of 15 meters (50 feet). The formation is composed of sand and gravel with occasional clay stringers. A slight amount of perched but discontinuous groundwater was found under the site. This demonstration project was designed to test soil venting as a potential remediation technology for JP-4 and to produce a design manual for future remediation projects (20). Soil venting was initiated on December 18, 1988, and, after 9 months of operation,

approximately 51,950 kg (114,400 pounds) or 68,000 liters (18,000 gallons) of JP-4 had been removed (21, 22). Off-gas was initially treated by both fluidized and fixed bed catalytic incineration during the first year of operation. A change in operation modes has allowed the direct discharge of low hydrocarbon concentration off-gas during the second year of the operating period. A final project report is expected in June 1991. Microbial degradation has also been observed and measured at this site.

In addition to fuel hydrocarbon remediation, soil venting is being successfully applied to the physical removal of chlorinated hydrocarbons from soil. A field demonstration project, designed to determine parameters for TCE soil venting technology, demonstrated cleanup of soils by three orders of magnitude at an estimated cost of \$19 - \$26 per  $m^3$  (\$15 - \$20 per  $yd^3$ ) (23). Perchloroethylene (PCE) was found in groundwater near Stevensville, Michigan, at concentrations ranging from 100 to 800 micrograms per liter ( $\mu g/L$ ). The source was surface disposal of PCE tank sludge that had contaminated 800 - 1600  $m^3$  (1000 - 2000  $yd^3$ ) of soil. After 45 days of soil venting, PCE concentrations declined to 10 milligrams per cubic meter ( $mg/m^3$ ) in extracted air and less than 1  $mg/kg$  in soil. Operational costs were estimated at less than 20 percent of projected excavation costs (15).

The Twin Cities Army Munitions plant is successfully remediating a site contaminated with TCE and 1,1,1-trichloroethane (TCA) using soil venting technology. Treatment of the gas stream is by carbon adsorption. Regulators are allowing total saturation of carbon or 100 percent breakthrough. As of September 1988, 28,600 kg (63,000 pounds) of volatile organics had been extracted from the soil and collected on 105,300 kg (232,000 pounds) of carbon (27 percent by weight). A major complaint has been noise generated by the extraction blowers and noise control measures have been implemented (24). TCE was also the subject of a case study in California. After 440 days of operation at an air extraction rate of 2.8  $m^3/minute$ , the vacuum extraction system had removed 30 kg of the 32 kg of TCE in the soil. Carbon adsorption was used for off-gas treatment. To satisfy a 10 gallon/day emission limit, 180 kg of activated carbon were used for the removal of 25 kg of TCE (14 percent by weight) (25).

The Verona well field supplies drinking water to 50,000 residents of Battle Creek, Michigan. Ten of the city's 30 production wells were

contaminated with chlorinated hydrocarbons, aromatics, and ketones traced to the Thomas Solvent Company. Soil venting was selected for site remediation with treatment of the off-gas by carbon adsorption. The project is currently ongoing and costs are projected at \$50 - \$60/m<sup>3</sup> (\$60 - \$70/yd<sup>3</sup>) with off-gas treatment, and \$20/m<sup>3</sup> (\$25/yd<sup>3</sup>) without off-gas treatment (26).

An overturned Southern Pacific rail car near Benson, Arizona, resulted in a spill of 68,000 kg (150,000 pounds) of 1,3-dichloropropene. At the time of cleanup, it was estimated that 20,000 - 41,000 kg (45,000 - 90,000 pounds) remained, contaminating approximately 460 m<sup>3</sup> (600 yd<sup>3</sup>) of soil. The balance of the spilled product had already volatilized prior to project initiation. Over a period of 7 months, 6,500 kg (14,300 pounds) were extracted at a capital cost of \$25,000 and operational cost of \$50,000. Treatment of the off-gas was not required. Cost of the project was \$1,150/m<sup>3</sup> (\$875/yd<sup>3</sup>) which is in the range of costs for excavation/incineration (15). Operational costs for this project were high because of the remote location and the need to provide power generation.

A soil venting enhancement that could allow removal of higher molecular weight organics is soil heating. Emerging technologies for soil heating include steam injection, direct current, and RF heating. AFESC is supporting research in RF Heating.

RF heating involves heating soil by radio frequency energy emitted through a network of soil probes. Absorbed RF energy can heat soil to a range of 150 - 400°C (302 - 752°F). The high temperature effectively drives off contaminants because of their substantially increased vapor pressures. Vapors are collected at the surface or through vented electrodes that are also used for heating.

An AFESC-supported field demonstration project of this technology was conducted at Volk Air National Guard Base. Fourteen cubic meters (m<sup>3</sup>), which is equivalent to 500 cubic feet (ft<sup>3</sup>), of soil were heated for 12.5 days with maximum temperatures reaching 150 - 160°C (302 - 320°F). Ninety-nine percent of volatile and semivolatile aromatics and volatile aliphatics, and 94 percent of semivolatile aliphatics were removed (27). This technology is just emerging and little published literature is available. A full-scale demonstration project has not yet been conducted, however one sponsored by AFESC is currently planned for Kelly AFB, Texas.

### C. MICROBIAL DEGRADATION

The microbial degradation of petroleum hydrocarbons has been extensively studied and well documented in the literature. A review of one computer database (Life Sciences Collection), from January 1978 to June 1989, revealed more than 700 citations for the microbiological decomposition of hazardous materials. The compounds described in the literature are primarily saturated and substituted hydrocarbons. Early research into biodegradation of hydrocarbons in soil systems can be traced to the agricultural literature where modified hydrocarbons have been used extensively for pest control. Decomposition of herbicides, insecticides, and fungicides depends on both biotic and abiotic reactions, and the rate of these reactions determines the required frequency of application. The high cost of pest control has been the motivation for conducting research concerning degradation mechanisms and degradation rates for these applied pesticides.

Researchers have long understood mechanisms and even microbial populations responsible for biodegradation of hydrocarbons (28, 29, 30, 31). Genera of hydrocarbon-degrading organisms isolated from soil include 22 strains of bacteria and 31 strains of fungi (30). A number of strains of hydrocarbon-degrading actinomycetes have also been isolated, but do not seem to compete as well as other microorganisms in hydrocarbon-contaminated soils. The most commonly isolated species of hydrocarbon-degrading bacteria, in decreasing order, include Pseudomonas, Arthrobacter, Alcaligenes, Corynebacterium, Flavobacterium, Achromobacter, Micrococcus, Nocardia, and Mycobacterium. The most commonly isolated hydrocarbon-degrading fungi, in decreasing order, include Trichoderma, Penicillium, Aspergillus, and Mortierella (30).

Researchers have studied in great detail the relationship between chemical structure and biodegradation. Petroleum hydrocarbons are comprised primarily of alkanes, alkylaromatics, and aromatics. The n-alkanes, n-alkylaromatics, and aromatics in the C<sub>10</sub> to C<sub>22</sub> range are the hydrocarbons least toxic to organisms and the most biodegradable. The n-alkanes, alkylaromatic, and aromatic hydrocarbons in the C<sub>5</sub> to C<sub>9</sub> range are biodegradable by a narrower species of microorganisms and at lower concentrations (30). In most soil systems, compounds in the C<sub>5</sub> to C<sub>9</sub> range are removed to a greater extent by volatilization than by biodegradation. The

species range of hydrocarbon degraders responsible for the degradation of the gaseous compounds (n-alkanes  $C_1$  to  $C_4$ ) is even narrower, although biodegradation of these materials has been documented. Volatilization in this range is more important than biodegradation in typical soil environments. Branched alkanes and cycloalkanes in the  $C_{10}$  to  $C_{22}$  are less degradable than n-alkanes and aromatics of equivalent size. Branching hinders beta-oxidation, the primary mechanism in the degradation of straight chain hydrocarbons, and cycloalkane degradation requires the presence of two or more species for complete metabolism to take place (30).

Liebig's Law of the Minimum states that the rate of biological processes, such as growth and metabolism, is limited by the factor present at its minimal level (30). In uncontaminated subsurface soil, microbial growth is limited by the absence of an available source of energy. Since most soil microorganisms are heterotrophs, the limiting factor is a source of readily degradable carbon. Soil microbiologists have observed an abundant population of microorganisms whenever an abundant source of carbon was present (30). However, the attention of the microbiologist has usually focused on agricultural surface soils because the relationships among the microflora and higher plants are most important in the A horizon where populations and nutrients are most abundant (28). Because of the focus on the A horizon, it was generally accepted that microorganisms were not available for biodegradation of organic chemicals in deeper soils. Recent research has dispelled this theory. Microbial characterization of soil samples collected before venting at the Hill AFB project (3) revealed large numbers of hydrocarbon degraders at depths up to 20 meters (65 feet). Concentrations generally ranged from  $10^3$  to  $10^6$  colony forming units (CFU) per gram dry weight. Samples taken during construction of a background well in uncontaminated soil also revealed the presence of hydrocarbon degraders in the upper 20 feet of a 50-foot profile. Concentrations ranged from three to six orders of magnitude less in background samples than in contaminated samples, however.

In addition to a source of carbon, the biodegradation process is dependent on soil factors including pH, soil moisture, temperature, and presence of available inorganic nutrients (30). Most microorganisms function best in a pH range of 6 - 8 with the optimum being slightly above 7 (30). A

shift in pH generally results in a shift of microbial population because of the ability of certain species to survive a wider range in pH. For example, an acidic environment may contain a proportionately larger fungi population, not because fungi prefer a low pH, but because fewer bacteria and actinomycetes survive in that environment (28).

Soil microorganisms require soil moisture for metabolic processes and for solubilization of energy and nutrient supplies. A study of polyaromatic hydrocarbon (PAH) biodegradation in the vadose zone concluded that the solubility of PAHs was the growth limiting factor for microbial populations. A decline in the number of organisms was shown to follow a decline in PAH concentration in the aqueous phase. Researchers increased the solubility of PAHs by adding acetone, and organism counts increased dramatically. The organisms were not inhibited by the acetone nor were they able to degrade it. A conclusion of the study is that the major objective in bioremediation of contaminated soil is to release organics bound to soil, thereby increasing solubility and biodegradation (32). A review of 23 in situ bioremediation projects concluded that biodegradation depends entirely on contact between contaminants in the water phase and the microorganisms (33).

The effect of soil moisture as it relates to microbial activity and crop production has been addressed in the literature. However, there is less information on the relationship between the requisite amount of soil moisture and biodegradation of organic chemicals (30). Column studies on soils from Hill AFB yielded insignificant increases in microbial activity with increasing soil moisture without nutrient addition. However, following nutrient addition, respiration increased significantly with increased soil moisture. After 48 days CO<sub>2</sub> evolution showed 3-, 3.5-, and 4.5-fold increases at 25, 50, and 75 percent of field capacity, respectively. These data suggest that microorganisms in the Hill AFB soil were either nutrient- and/or moisture-limited (3). The soil columns in this study were dosed with approximately 1000 mg/kg JP-4 and oxygen was supplied by a constant flow of air.

Since liquid water is required for microbial activity, the minimum temperature required for biodegradation is probably close to freezing. The upper temperature limit is thought to be approximately 50°C (122°F) because essential microbial enzymes are denatured above this temperature (30). As



with pH, populations vary with changes in temperature. Optimum temperature for soil microbial reactions is in the range of 30 - 35°C (86 - 95°F).

Cell growth and maintenance requires a number of nutrients in addition to a source of available carbon. At a minimum, the following nutrients must be available in the proper form and amount for microbial proliferation: nitrogen, phosphorus, potassium, sodium, sulfur, calcium, magnesium, iron, manganese, zinc, copper, cobalt, and molybdenum (28). In general, nitrogen and phosphorus can be considered macronutrients because they are required in the largest quantities. The remaining compounds are considered micronutrients because they are required in minute quantities, which are usually naturally available in excess in the soil (30).

If nutrient addition is required, it is usually limited to nitrogen and phosphorus. Microbial cells contain 5 - 15 parts of carbon to 1 part of nitrogen, but 10:1 is a reasonable average for aerobic flora (28). The generally accepted C:N ratio of aquatic flora in domestic wastewater is 4.3:1 based on the experimentally derived formula ( $C_5H_9O_{2.5}N$ ) for cell protoplasm (34). The apparent difference in soil and wastewater flora may be due to differing species in soil and domestic wastewater or the higher availability of nitrogen in domestic wastewater. A carbon, nitrogen, phosphorus (C:N:P) ratio of 250:10:3 is considered optimum for biodegradation in soil, but 100:10:2 has been used in some applications (33). In general, one unit of nitrogen assimilated into cell material is accompanied by 10 units of carbon assimilated and 20 units of carbon respired as  $CO_2$  (28). The 100:10:2 ratio is conservative because it assumes all carbon is assimilated into cell mass. The 250:10:3 ratio is probably also conservative because, although it is closer to the combined assimilation/volatilization ratio, it does not consider recycling of the organic nitrogen or phosphorus. In determining the appropriate ratio, one must also consider the delivery efficiency which explains why the most conservative value is often used.

Uncontaminated soils with low natural organic carbon content are frequently aerobic to substantial depths because diffusion of atmospheric oxygen exceeds microbial respiration (35, 3). However, microbial activity in soils heavily contaminated with petroleum hydrocarbons is usually limited by oxygen because respiration rates and evolution of  $CO_2$  exceed diffusion rates of atmospheric oxygen. For this reason, biodegradation research has focused

first on methods of supplying oxygen or some other terminal electron acceptor, and second on supplying nutrients to indigenous populations.

#### D. CONVENTIONAL ENHANCED BIODEGRADATION

Biodegradation of contaminants in aquifers has been studied for at least two decades (36). Original research focused on biologically treating groundwater rather than the source, usually located in the unsaturated zone. Since groundwater is typically the exposure route of most concern, it is only natural that this was the target of early research (4). This research focused on methods of providing oxygen and nutrients to the indigenous microbial population to stimulate biodegradation of contaminants in groundwater.

Many contaminants, including fuels, are highly insoluble and hydrophobic. These compounds tend to partition into the soil and are solubilized slowly by water in the soil, thus contaminating the groundwater for many years. Hincbee et al. (4) provided a hypothetical case for fuels where a typical 1,000 gallon spill would be distributed with 50 liters (13 gallons) in groundwater, 3,650 liters (962 gallons) in soil, and 100 liters (25 gallons) in soil vapor. Understanding the phenomenon of partitioning, combined with the high cost of pump and treat technology, has redirected research toward the source of contamination in the unsaturated zone.

Although the focus is now on the source of contamination rather than the contaminated groundwater, the objective of providing oxygen and nutrients remains. Using conventional bioreclamation, oxygen and nutrients are typically carried to the organisms by water. Stoichiometry for typical aerobic biodegradation to mineralization of benzene and hexane follows:



Oxygen saturation in water, following air sparging, is temperature dependent and ranges from 8 to 12 mg/L (36). Assuming an aqueous solubility of 9 mg/L, 110 liters of water are required to deliver 1 gram of O<sub>2</sub> to the

subsurface. This equates to 390 liter of water to provide enough  $O_2$  to mineralize 1 gram of hexane.

A typical  $1 \text{ m}^3$  of dry sand (40 percent porosity and a density of  $1,600 \text{ kg/m}^3$ ) contaminated with  $10,000 \text{ mg/kg}$  of hexane contains  $16 \text{ kg}$  of hexane. Therefore,  $6.2$  million liters or  $15,500$  pore volumes of water are required to aerate with saturated water each  $\text{m}^3$  of contaminated soil. A pore volume is defined as the unit volume of voids per unit volume of soil (porosity). A relatively small  $3,800$ -liters ( $1,000$ -gallon) hexane spill would require  $980$  million liters ( $260$  million gallons) of water to provide adequate oxygen for complete mineralization (assuming a density of  $0.66$ ). Wilson and Ward (37) indicate that  $32,000$  pore volumes of air sparged water are required at hydrocarbon saturation levels, which are assumed to be about 2 percent ( $20,000 \text{ mg/kg}$ ) hydrocarbons by weight.

Researchers realized that providing extremely large volumes of water was not only expensive, but may require ten to thousands of years to deliver in lower permeability soils. Emphasis has moved toward increasing the  $O_2$  concentration in water, thereby reducing required water volumes. Sources of  $O_2$  investigated include pure oxygen, hydrogen peroxide, and ozone. Sparging with pure  $O_2$  provides dissolved  $O_2$  concentrations of  $40 - 50 \text{ mg/L}$  (35).

A number of studies have investigated hydrogen peroxide ( $H_2O_2$ ) as a source of dissolved  $O_2$  in water. Most researchers conclude that  $500 \text{ mg/L}$  of  $H_2O_2$  is the maximum allowable concentration based on toxicity to microbial populations and rapid breakdown that causes bubble formation and reduced permeability (36). One  $\text{mol/L}$  of  $H_2O_2$  provides approximately  $0.5 \text{ mol/L}$  ( $235 \text{ mg/L}$ ) of dissolved  $O_2$  as illustrated by Equation (3).



Therefore, in a soil contaminated at  $10,000 \text{ mg/kg}$  hexane,  $6.2$  million liters of air-sparged water,  $1.2$  million liters of pure oxygen-sparged water, or  $220,000$  liters of water containing  $500 \text{ mg/L}$   $H_2O_2$  are required for each  $\text{m}^3$  of soil. Under the best conditions (100 percent utilization), a  $3,800$ -liter ( $1,000$ -gallon) hexane spill would require  $35$  million liters ( $8.5$  million gallons) of water containing  $500 \text{ mg/L}$   $H_2O_2$  to provide the necessary  $O_2$  for aerobic biodegradation. This analysis assumes complete mineralization of

hexane to  $\text{CO}_2$  and water. Since a portion of available hydrocarbon is converted to cell mass, oxygen requirements may be proportionately less. However, the analysis is valid for comparative purposes.

Lee et al. (36) describe a number of projects using  $\text{H}_2\text{O}_2$  as a source of  $\text{O}_2$ , with various degrees of success. In 1984, AFESC sponsored  $\text{H}_2\text{O}_2$  research at a JP-4-contaminated site at Kelly AFB, Texas. Severe problems with soil permeability were encountered, reducing the delivery of  $\text{O}_2$  and nutrients. Permeability reductions were attributed to silt and clay soils, together with precipitation of calcium phosphates formed by the reaction of injected phosphates and calcium in the soil. Little biodegradation was observed at the site because of the inability to deliver  $\text{O}_2$  and nutrients (38). A second site at Eglin AFB, Florida, was selected in an attempt to study hydrogen peroxide technology under ideal soil conditions. Bench-scale microcosm studies conducted prior to field research confirmed that existing microbial populations could degrade soluble aromatic compounds in less than 2 weeks under enriched oxygen and nutrient conditions (10). Hydrogen peroxide was injected into approximately 16 million gallons of groundwater, which were delivered to the JP-4-contaminated field site by spray irrigation, infiltration galleries, and injection wells. Rapid peroxide destabilization and oxygen loss at the point of injection severely limited the amount of oxygen delivered and resulted in low rates of hydrocarbon mineralization. Researchers concluded that  $\text{H}_2\text{O}_2$  decomposition rates were higher than  $\text{O}_2$  utilization rates and that most of the  $\text{H}_2\text{O}_2$  decomposed and was lost to the atmosphere. A review of the literature led researchers to believe that similar problems occurred at other bioremediation sites, and that unless  $\text{H}_2\text{O}_2$  decomposition rates were substantially lowered,  $\text{H}_2\text{O}_2$  was not an economical source of  $\text{O}_2$  (39). This research, coupled with the soil washing experiments described above, illustrate the need for field research to prove the efficacy of remediation technologies demonstrated in the laboratory (10).

Laboratory and field hydrogen peroxide research was conducted by the U.S. Environmental Protection Agency (EPA) on aviation gasoline-contaminated aquifer material from Traverse City, Michigan (40). Fifty-four percent of the initial mass of aviation gasoline in columns degraded; however, it was not possible to distinguish between abiotic and biotic degradation. Researchers concluded that at a hydrogen peroxide concentration of 100 mg/L, oxygen gas

production far exceeded the oxygen demand and that 45 percent of the available oxygen was transferred to the gaseous phase. In addition, the rate of oxygen consumption decreased, indicating that inhibition of microbial populations may have occurred. The field study conducted at Traverse City supported observations from the laboratory study. Hydrogen peroxide decomposed rapidly even though precautions were taken to minimize iron-driven decomposition reactions. It was concluded that decomposition resulted from enzymatic catalysts. Neither an oxygen nor hydrocarbon mass balance was possible at field scale. Researchers were only able to conclude that hydrogen peroxide successfully increased the concentration of available oxygen in down-gradient groundwater (40).

#### E. ENHANCED BIODEGRADATION THROUGH SOIL VENTING

Soil venting technology, as discussed above, provides large volumes of air to the vadose zone. Table 1 compares the  $O_2$  carrying capacity of water and air for the theoretical biodegradation of hexane.

Table 1 illustrates that air has a much greater potential than water for delivering  $O_2$  to the vadose zone, on both a mass/mass and volume /mass basis. In addition,  $O_2$  provided by air is more easily delivered throughout a formation because air is less viscous than water and the higher  $O_2$  concentration in air provides the necessary driving force for diffusion into less permeable zones within the formation.

A review of available literature on soil venting was accomplished to determine if other researchers had considered or documented biodegradation as a result of oxygen being supplied through the venting process. The first documented evidence of enhanced biodegradation through soil venting resulted from a failed experiment. In 1980, Texas Research Institute, Inc., (TRI) working for API, conducted a large-scale model experiment to test the effectiveness of a surfactant treatment to enhance recovery of spilled gasoline. The experiment accounted for only 30 of the 246 liters (8 of the 65 gallons) originally spilled and raised questions about where the balance of the gasoline went. Microbial activity was ruled out at the time because of the low dissolved oxygen content of the water. Volatilization was the only remaining pathway for removal, and it was for this reason that follow-on soil venting research (12) was initiated. To conduct the large-scale model experiment, a column study was required to determine a diffusion coefficient.

TABLE 1. COMPARISON OF WATER AND AIR AS CARRIERS OF OXYGEN

Carrier	lb carrier/ lb oxygen	lb carrier/ <sup>(a)</sup> lb hexane
Air saturated water (9 mg/L)	110,000	385,000
Pure oxygen saturated water (45 mg/L)	22,000	77,000
Water containing 500 mg/L of hydrogen peroxide		
235 mg/L oxygen-100% utilized	4,200	14,700
235 mg/L oxygen-30% utilized	14,000	49,000
Air containing 20.9% oxygen	4.3	15

<sup>(a)</sup> Stoichiometric oxygen requirement for mineralization as expressed in Equation (2).

This column study evolved into a biodegradation study where it was concluded that as much as 38 percent of spilled product was biologically mineralized. Researchers concluded that venting should not only remove gasoline by physical means, but would also enhance microbial activity (41).

These findings would likely have generated additional research into the concept of enhancing in situ biodegradation through soil venting, but the follow-on research by TRI may have actually discouraged such efforts. In the follow-on, large-scale model aquifer study that investigated soil venting (12), biodegradation was reported to be insignificant. Effluent air was monitored for  $\text{CO}_2$  to document biological degradation. Average  $\text{CO}_2$  concentration in the two test systems was 0.057 percent (ranged from 0.038 to 0.094 percent) and 0.067 percent (ranged from 0.044 to 0.113 percent), respectively. The ambient concentration of 0.035 percent was subtracted from average concentrations to determine hydrocarbons removed by degradation. Assuming a  $\text{C}_6$  hydrocarbon molecule and that all  $\text{CO}_2$  came from microbial oxidation, calculations showed that less than 1 mole of gasoline was oxidized to  $\text{CO}_2$  in each experiment. This equated to less than 0.2 percent of the original spill of 80 liters (21 gallons) (12). Low  $\text{CO}_2$  concentrations may have resulted from the pH of the water added to the model aquifer. Researchers used Austin City water which varied from pH 9.7 to 9.9 because of lime treatment. The pH of effluent water from the experimental tanks ranged from 8.3 to 9.2. This high pH may have inhibited or prevented significant microbial activity as the critical pH range is reported from 5.5 to 8.5 (42). Even if microbial activity had existed, the high pH of the soil/water system may have acted as a  $\text{CO}_2$  sink, converting much of the evolved  $\text{CO}_2$  and existing  $\text{CaCO}_3$  to bicarbonate and calcium ion. It is also possible that insufficient time was allowed for acclimation.

Since publication of the 1984 TRI soil venting results, supporting research concerning the volatilization aspect has been conducted both in the laboratory and in the field. Most of this work was reviewed as part of the research project reported in this document to search for documented associations between soil venting and biodegradation. Based on a review of current and past research, enhanced biodegradation through soil venting has had only limited attention, most of which has occurred in the last 2 years.

Wilson and Ward (37) suggested that using air as a carrier for oxygen could be 1,000 times more efficient than transferring oxygen in water, especially in deep, unsaturated zones that are difficult to flood. A fine sand or silt saturated with hydrocarbons would require 4,000 pore volumes of air to provide the stoichiometric  $O_2$  required for aerobic degradation compared with 32,000 pore volumes of air-saturated water. Wilson and Ward made the connection between soil venting and biodegradation by observing that "...soil venting uses the same principle (of moving air through soil) to remove volatile components of the hydrocarbon."

In an overview of the soil venting process, Bennedsen et al. (8) conclude that soil venting provides large quantities of oxygen to the vadose zone, possibly stimulating aerobic degradation. They state that water and nutrients would also be required for significant degradation and encouraged additional investigations into this area of study.

In describing sources of  $O_2$  for in situ biodegradation, Riser (31) suggested that air should be particularly effective for contaminated soils in the unsaturated zone. This conclusion is based on the fact that air is much less viscous than water and has a 20-fold greater oxygen content on a mass per unit volume basis. Therefore, air moves more easily through the soil; and if air and water filled porosity are about equal, and pressure gradients are equal, then air should be about 1,000 times more effective than water in transferring oxygen to the subsurface. Riser (31) makes the connection between soil venting and providing oxygen to the vadose zone for biodegradation of contaminants. Table 1 indicates that on a mass of oxygen per mass of carrier basis, air is approximately 25,000 times more efficient than air-saturated water. On a mass of oxygen per volume of carrier basis, air is approximately 30 times more efficient than air-saturated water. Information in Table 1 does not consider the oxygen diffusion efficiencies.

Biodegradation enhanced by soil venting has been observed at several field sites, although documentation is limited. Investigators at a soil venting site for remediation of gasoline-contaminated soil claim significant biodegradation as measured by a temperature rise when air was supplied. Investigators used a pulse pump to send air through a pile of excavated soil and observed a consistent temperature rise that they attributed to biodegradation. They claim that the pile was cleaned up during the summer



primarily by biodegradation (19). However, they did not control for natural volatilization from the aboveground pile and there were not enough data provided to review the biodegradation claim critically.

Researchers at Traverse City, Michigan, measured toluene concentration over time as an indicator of aviation gasoline contamination in the vadose zone. They assumed the absence of advection, attributing all toluene disappearance to biodegradation. Investigators imply that because toluene decayed near the oxygenated ground surface, soil venting is an attractive remediation alternative for light, volatile hydrocarbon spills (43). There is little question that toluene readily degrades under aerobic conditions.

Chevron Research Company is assignee of United States Patent No. 4,765,902, awarded August 23, 1988, for the in situ biodegradation of spilled hydrocarbons using soil venting as a source of oxygen (44). Experimental design data are not available, but findings are presented graphically in the patent literature. Recovery at a gasoline and diesel oil site revealed slightly higher biodegradation removal than through evaporation. Recovery at a gasoline-only site indicated that about two-thirds of the removal was by volatilization and one-third was by biodegradation. At a site containing only fuel oils, approximately 75 liters/well/day (20 gallons/well/day) of fuel oil were removed by biodegradation, whereas vapor pressures were too low for any removal by volatilization. Inventors claim that the process has advantages over strict soil venting because removal does not depend on vapor pressure alone. In the examples stated in the patent, CO<sub>2</sub> was maintained between 6.8 and 11 percent and O<sub>2</sub> between 2.3 and 11 percent in vented air. The patent suggests that the addition of water and nutrients may not be acceptable because of flushing to the water table, but the assignee also claims nutrient addition as part of its patent. The patent recommends flow rates of between 850 and 7,000 liters/minute (30 and 250 ft<sup>3</sup>/minute) per well and states that air flows higher than required for volatilization may be optimum for degradation. In addition to biodegradation, the patent claims removal of hydrocarbons by creation of aerosols.

An international evaluation of in situ bioremediation reviewed 23 relevant projects in The Netherlands, West Germany, and the United States. Of the 23 sites, only one described soil venting as a means of providing oxygen for biostimulation. The project (N5) was conducted by a Dutch firm, Delft

Geotechnics, and describes a soil venting project used both as a physical and biological process. Ninety-six percent of gasoline (petrol) and 33 percent of diesel were removed in 12 months (33). Test plots were constructed in sandy soil to which 125 kg of gasoline were added. Test plots were inoculated with effluent water (the source of which was not stated) and nutrients were added using a C:N:P ratio of 100:10:2. Plots were vented and off-gas analyzed by gas chromatography. A mass balance for gasoline indicated significant biodegradation but CO<sub>2</sub> production indicated that biological mineralization was negligible (45). Researchers concluded that CO<sub>2</sub> was lost to the groundwater as bicarbonate by the following reaction:



Using the CaCO<sub>3</sub> concentrations before and after the experiment, the fraction of petrol lost by biological degradation was computed. Adding this loss to other measured losses resulted in a 96 percent recovery of added gasoline (45).

The full-scale soil venting project at Hill AFB, described above, provides documented evidence of enhanced biodegradation through soil venting both in the laboratory and in the field (3). Column studies on nutrient-amended soils from Hill AFB, dosed with approximately 5,000 mg/kg JP-4 and using air as a source of oxygen, resulted in significant increases in microbial respiration. After 48 days, there were 3-, 3.5-, and 4.5-fold increases in CO<sub>2</sub> evolution at moisture contents of 25, 50, and 75 percent of field capacity, respectively.

During the initial 70 days of venting at Hill AFB, undiluted off-gases were monitored for CO<sub>2</sub>, O<sub>2</sub>, and hydrocarbon concentrations. The fraction of JP-4 biodegraded dropped rapidly from initial values of approximately 30 percent to steady-state values of approximately 15 percent within 30 days after venting began. This was primarily due to increasing air flow rates and not to reduced biodegradation rates. Although volatilization was the primary mechanism of removal, from 15 percent to 30 percent of the jet fuel was biodegraded in situ during the first 70 days of venting (3).

This literature review demonstrates the efficacy of soil venting for the remediation of fuel-contaminated soils. Soil venting is effective in the

physical removal of volatile hydrocarbons by volatilization, and also as a source of oxygen for biological mineralization for both the volatile and nonvolatile fractions of spilled fuels. Treatment of off-gases has been shown to constitute a minimum of 50 percent of soil venting remediation costs. This research will investigate methods for enhancing biological mineralization while minimizing volatilization, with the goal of eliminating or reducing the need for expensive off-gas treatment.

## SECTION III

### MATERIALS AND METHODS

#### A. SITE DESCRIPTION

An in situ field demonstration of enhanced biodegradation through soil venting was conducted at the site of an abandoned tank farm located on Tyndall AFB, Florida. The site is contaminated with fuel, primarily JP-4, and free product has been observed floating on the shallow groundwater table, although no free product was observed in our test plots during the study. The exact nature, age, and source of the contamination were unknown.

Tyndall AFB is located on a peninsula that extends along the shoreline of the Gulf of Mexico in the central part of the Florida Panhandle. The highest ground on the peninsula is 7.6 to 9.1 meters (25 to 30 feet) above mean sea level. The uppermost sediments at Tyndall AFB are sands and gravels of Pleistocene to Holocene age (46). Soils at the site are best described by the Mandarin series consisting of somewhat poorly drained, moderately permeable soils that formed in thick beds of sandy material (47).

The climate at the site is subtropical with an annual average temperature of 20.5°C (69°F). Average daily maximum and minimum temperatures of 25°C and 16°C (77°F and 61°F), respectively. Temperatures of 32°C (90°F) or higher are frequently reached during summer months, but temperatures above 38°C (100°F) are reached only rarely. Average annual rainfall at Tyndall AFB is 140 cm (55.2 inches) with approximately 125 days of recordable precipitation during the year. The depth to groundwater on Tyndall AFB varies from about 0.3 to 3.0 meters (1 to 10 feet). The water table elevation rises during periods of heavy rainfall and declines during periods of low rainfall. Yearly fluctuations in groundwater elevations of approximately 1.5 meters (5 feet) are typical (46). Prior to dewatering at the site, the water table was observed to be as shallow as 46 cm (1.5 feet).

#### B. OVERALL PROJECT RESEARCH PLAN

The scope of work comprised three tasks: initial site characterization, test plan preparation, and field testing.

### 1. Task 1-Initial Site Characterization

The initial site characterization activities included (a) determination of the location of test plots for treatment; (b) determination of contaminant levels and distribution in groundwater, soil, and soil gas; (c) distribution of total and hydrocarbon-degrading bacteria in the soils; (d) determination of soil texture and soil organic matter content; (e) installation of permanent soil gas sampling probes and monitoring wells; and (f) determination of soil gas permeability. The results of the characterization were the basis for the design and provided a baseline of information for the investigation. The initial site characterization data are reported in Reference 48; a summary of the initial conditions is found in Section IV.

### 2. Task 2-Test Plan Preparation

Following the site characterization, a test plan was prepared describing the results of the site characterization and outlining experiments to be performed in the field, along with the appropriate instrumentation and analytical methods to be employed (48).

### 3. Task 3-Field Testing

Following development of the test plan, treatment plots were constructed and air and water/nutrient delivery systems were installed. These systems were tested and modified as necessary before the field test start-up on October 4, 1989, and operated through April 24, 1990, with final sampling in May 1990.

## C. FIELD TESTING OBJECTIVES

A 7-month field study (October 1989 to May 1990) was designed to address the following basic questions:

1. Does soil venting enhance biodegradation of JP-4 at this site?
2. Does moisture addition coupled with soil venting enhance biodegradation at this site?
3. Does nutrient addition coupled with soil venting and moisture addition enhance biodegradation at this site?
4. Will the hydrocarbons in the off-gas biodegrade when passed through uncontaminated soil?

In addition, to the extent possible within the experimental design, other factors were addressed, including:

1. Evaluation of ventilation rate manipulation to maximize biodegradation and minimize volatilization.
2. Calculation of specific biodegradation rate constants from a series of in-situ respiration tests conducted during shutdown of the air extraction systems.
3. Determination of the effects of biodegradation and volatilization on a subset of selected JP-4 chemical components.
4. Determination of the potential for nitrogen fixation under aerobic and anaerobic conditions.
5. Evaluation of alternative vent placement and configuration to maximize biodegradation and minimize volatilization.

#### D. TEST PLOT DESIGN AND OPERATION

##### 1. Test Plot Configuration

To accomplish the project objectives, two treatment plots (Figure 1) and two background plots (Figure 2) were constructed and operated in the following manner:

- a. Contaminated Treatment Plot 1 (V1) -- Venting only for approximately 8 weeks, followed by moisture addition for approximately 14 weeks, followed by moisture and nutrient addition for approximately 7 weeks.
- b. Contaminated Treatment Plot 2 (V2) -- Venting coupled with moisture and nutrient addition for 29 weeks.
- c. Background Plot 3 (V3) -- Venting with moisture and nutrient addition at rates similar to V2, with injection of hydrocarbon contaminated off-gas from V1.
- d. Background Plot 4 (V4) -- Venting with moisture and nutrient addition at rates similar to Vent 2.

##### 2. Air Flow

Air flow was maintained throughout the field study, except during in situ respiration tests. Flow rates were adjusted to maintain aerobic conditions in treatment plots, and background plots were operated at similar air retention times. Off-gas treatment experiments in one background plot (V3) involved operation at a series of flow rates and retention times.

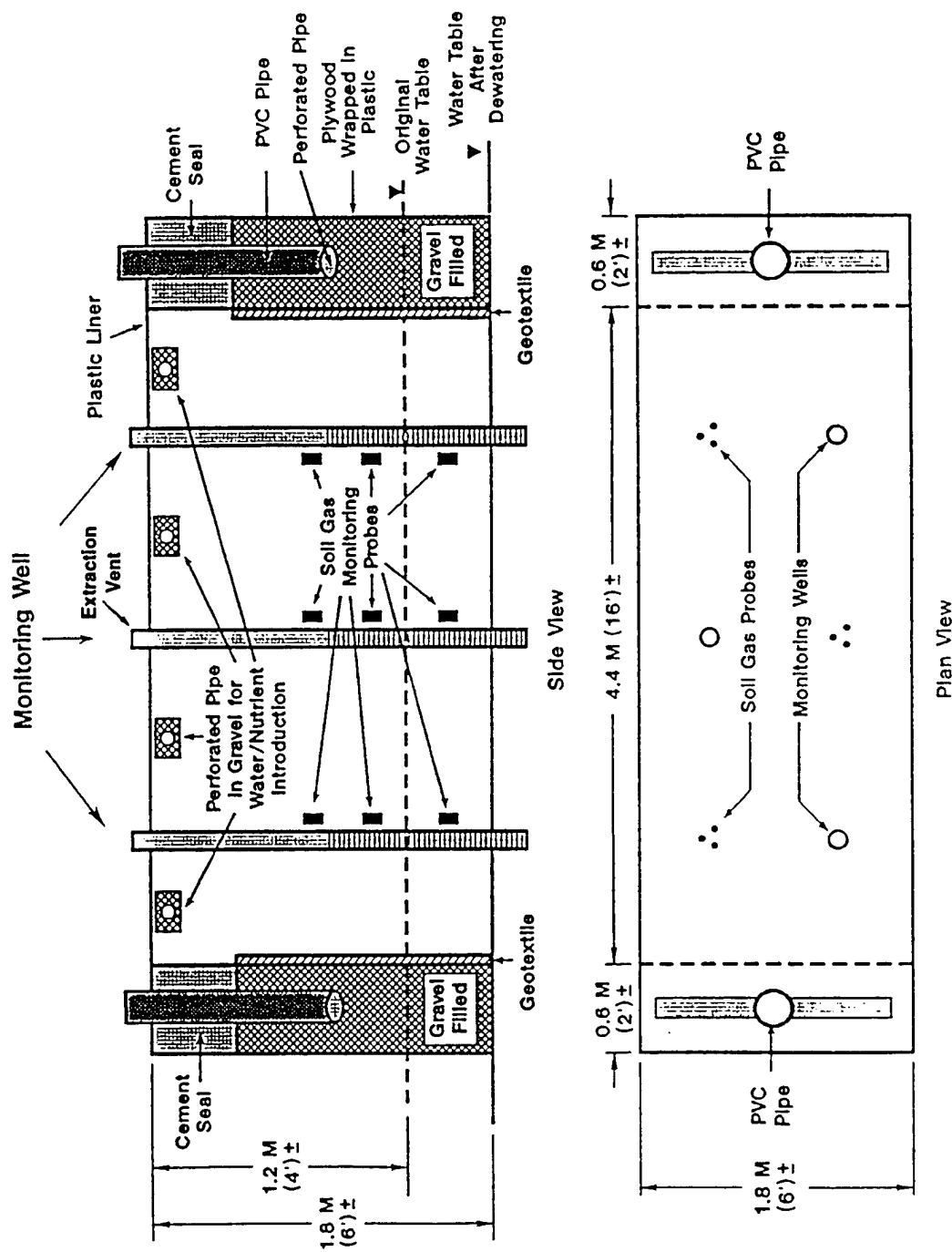


Figure 1. Design of Contaminated Test Cells Installed at Tyndall AFB, Florida.

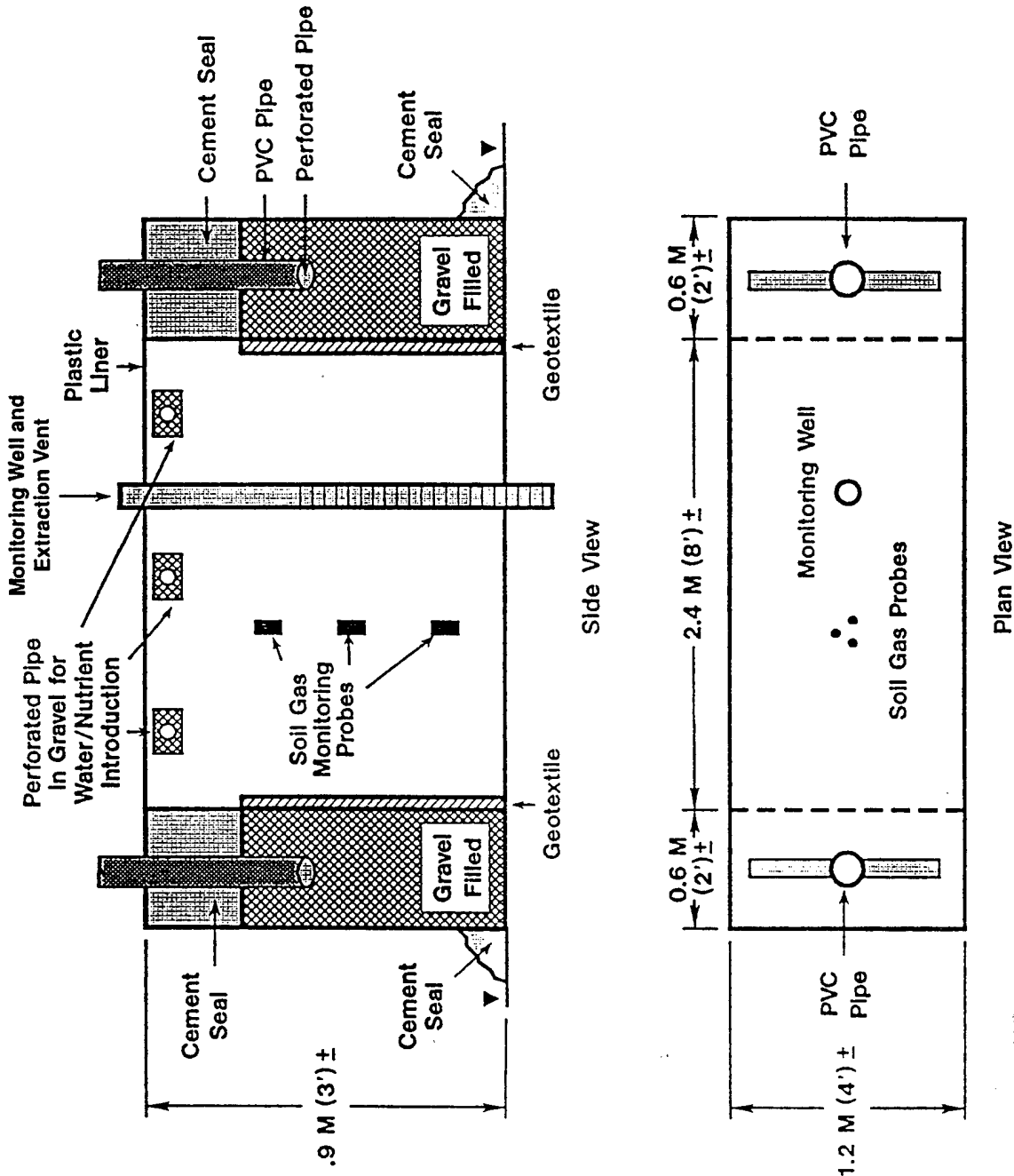


Figure 2. Design of Background Test Cells Installed at Tyndall AFB, Florida.



A schematic of the air flow system is shown in Figure 3. Soil gas was withdrawn from the center monitoring wells in V1 and V2 and from the only monitoring well in V3 and V4. This configuration was selected to minimize leakage of outside air observed when air was withdrawn from the ends of the plots. In all but one plot, V3, atmospheric air was allowed to enter at both ends passively. The atmospheric air entering V1, V2, and V4 was assumed to be hydrocarbon-free. This assumption is valid, considering that the highest background hydrocarbon concentration observed was only 6 ppm and that this level of contamination was observed rarely and for short durations. This concentration of atmospheric hydrocarbon contamination is insignificant considering the relatively short duration of atmospheric contamination and the high hydrocarbon concentration [1,000 - 10,000 ppm] observed in the treatment plots. The soil gas was drawn into the on-site building where it was valved and gaged. Sample ports provided access to the gas streams and were also located at the point of discharge from the plots. Most of the off-gas was discharged by means of an exterior stack. Off-gas from V1 was pumped back to the upstream ends of V3. The system was designed to provide variable air flow rates of 0.28 - 14 liters/minute in V1 and V2 and 0.044 - 2.2 liters/minute in V3 and V4. Experimental calculations supporting the design are located in Appendix A. Flow rates through all test plots were measured with calibrated rotameters.

### 3. Water Flow

To allow control of moisture addition, tap water was applied to the surface of the treatment plots. Figure 4 is a schematic of the water/nutrient delivery design.

The design flow rates allowed variation from 10 to 100 mL/minute in the contaminated treatment plots, and from 2.5 to 25 mL/minute in the background vents. This corresponds to an average annual surface application rate of 43 - 430 cm (17-170 inches). Based on vacuum and oxygen measurements in the soil gas monitoring probes, it was determined that a flow rate of 100 mL/minute in the treatment plots inhibited air flow and oxygen transfer. Using the same technique, a flow rate of 50 mL/minute (215 cm/year surface application rate) was selected as the final water application rate. This rate did not appear to inhibit oxygen transfer to the soil gas monitoring points. To maintain a similar loading in V3 and V4, 30 mL/minute were applied 3 days

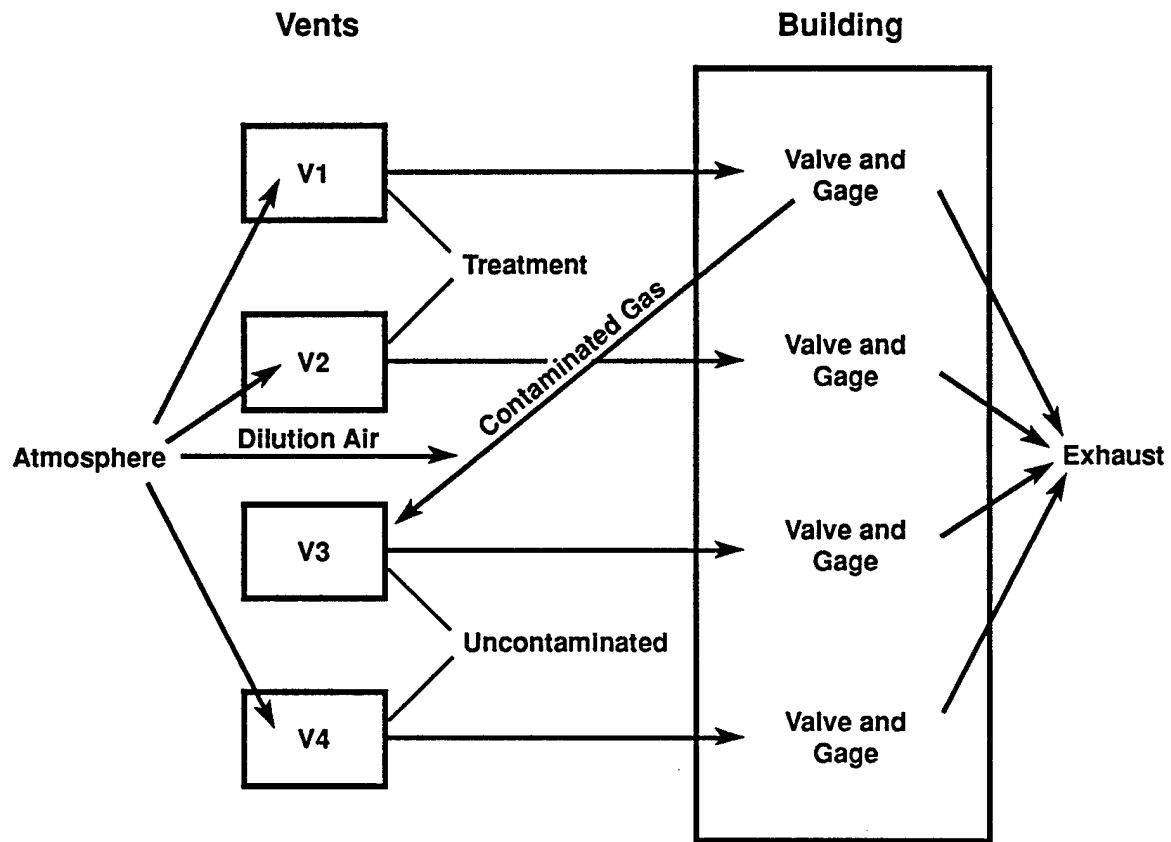


Figure 3. Air Flow Schematic for Tyndall AFB, Florida.

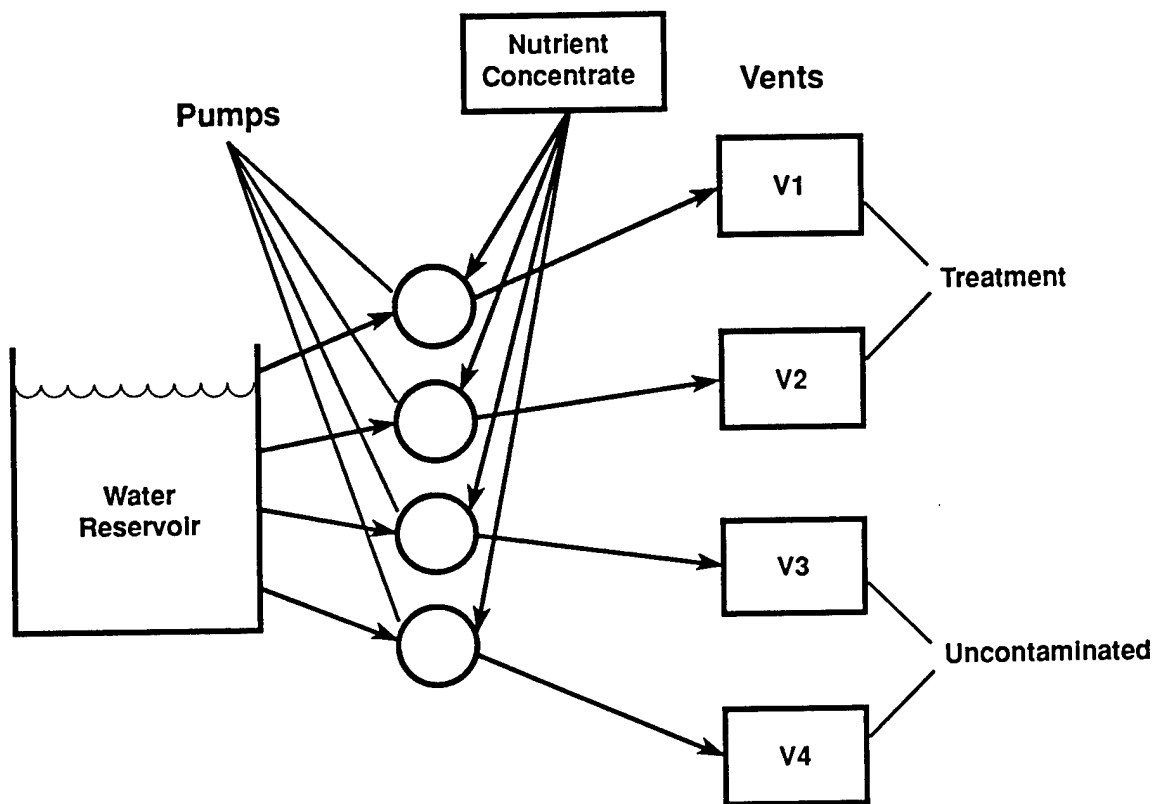


Figure 4. Schematic of Water/Nutrient Flow Design for Tyndall AFB, Florida.

per week resulting in an average loading rate of approximately 13 mL/minute over the course of the study. Experimental calculations supporting the design are located in Appendix A.

#### 4. Nutrient Addition Rates

The objective of nutrient addition was to apply sufficient inorganic nitrogen (N), phosphorus (P), and potassium (K) to ensure, as far as possible, that these nutrients would not become limiting during the biodegradation of fuel hydrocarbons in the test plots. Optimizing nutrient addition rates was not the primary objective of this phase of the study.

Sodium trimetaphosphate (Na-TMP), ammonium chloride (NH<sub>4</sub>Cl), and potassium nitrate (KNO<sub>3</sub>) were used as sources of P, N, and K, respectively. Existing nutrient formulations generally use Na- or K-orthophosphate as a phosphorus source. The relatively high concentration of orthophosphate in these formulations, together with the calcium and iron present in groundwater, results in the precipitation of insoluble phosphate salts. Excessive precipitation of the phosphate and other salts may lead to plugging of the aquifer and, therefore, is detrimental to the operation (38). Na-TMP is a polyphosphate (Na<sub>3</sub>P<sub>3</sub>O<sub>9</sub>) with a ring structure; therefore, its phosphorous is not present in the nutrient form (orthophosphate). However, upon hydrolysis, the trimetaphosphate ion forms three orthophosphate ions through a series of intermediate steps illustrated by Equation (5).



The kinetics of the various hydrolysis steps are relatively slow. Laboratory studies indicate that TMP hydrolysis in sandy soils occurs at a rate of approximately 10 percent/hour (49). Thus, using TMP in the formulations should provide nutrient phosphorus, while minimizing orthophosphate concentrations and aquifer plugging which is observed when orthophosphate is used as a source of phosphorus.

Nutrient additions were initially designed based on an estimate of 2,000 mg/kg total hydrocarbons. Preliminary results of the initial sampling, received after design and purchase of the delivery system, indicated average concentrations of approximately 20,000 mg/kg total hydrocarbons. It was decided that the disparity was best managed by maximizing existing equipment

to maintain project schedules. Concentrations of nutrients were maximized in the nutrient tank, and the delivery rate was increased to the maximum of 20 mL/minute.

Based upon more complete soil sampling collected to a depth of 1.5 meters (5 feet), during September 1989, the average initial total hydrocarbon concentration was 5,135 (SD  $\pm$  5,032) and 7,690 (SD  $\pm$  7,681) mg/kg, hexane equivalent, in Treatment Plots V1 and V2, respectively. Assuming a dry soil weight of 1440 kg/m<sup>3</sup> (90 lb/ft<sup>3</sup>), a treatment plot soil volume of 20 m<sup>3</sup> (26 yd<sup>3</sup>), a C:N:P ratio of 100:10:1, and that two-thirds of the total hydrocarbon is mineralized and one-third is assimilated into cell mass, the required mass of nitrogen and phosphorus for biodegradation of all hydrocarbon in the treatment plots should be 4,931 and 493 grams, respectively, for V1 and 7,381 and 738 grams, respectively, for V2. Table 2 summarizes operation of the test plots including the periods of nutrient addition. An inventory of chemicals at the completion of the project indicated that 170 kg (7.5 bags) of NH<sub>4</sub>Cl (44,580 grams NH<sub>4</sub>Cl-N) or approximately four times the minimum requirement had been delivered. As shown in Table 2, the duration of nutrient application was different in Treatment Plots V1 and V2, resulting in different total nutrient addition. Treatment Plot V2, which received nutrients throughout the project, received approximately six times the theoretical nutrient requirement. Treatment Plot V1 received nutrients only for the final 7 weeks of the project, yielding a nitrogen/phosphorus loading of approximately 7,190 and 700 grams, respectively. Assuming approximately half of the hydrocarbon had been removed from V1 prior to nutrient addition, the theoretical nitrogen and phosphorus requirement would be approximately 2,464 and 246 grams, respectively. Therefore, although V1 received nutrients for only 7 weeks, approximately three times the theoretical requirement was delivered. Also, increasing nutrient concentrations in groundwater samples collected from V2 at 1-, 2-, 3-, and 5-month intervals, after initiation of nutrient addition, indicated that significant amounts of nutrients were passing unused through the treatment plot.

Phosphorus additions were proportional to nitrogen and also well in excess of theoretical requirements. These nutrient additions are calculated on the basis of total hydrocarbons, without considering the fraction removed by volatilization and the fact that most probably only approximately one-third

TABLE 2. OPERATING CONDITIONS PRIOR TO RESPIRATION TESTS IN EACH PLOT  
 (NOTE: Times are cumulative from project initiation.)

Test No.	V 1	V 2	V 3	V 4
1	3 weeks venting no added moisture no added nutrients	3 weeks venting, moisture, and nutrient addition	3 weeks diluted off-gas from V1, moisture, and nutrient addition Note: PVC problems	3 weeks venting, moisture, and nutrient addition
2	8 weeks venting no added moisture no added nutrients	8 weeks venting, moisture, and nutrient addition	8 weeks diluted off-gas from V1, moisture, and nutrient addition Note: Inlet PVC pipe broken	8 weeks venting, moisture, and nutrient addition
3	13 weeks venting, 5 weeks of moisture, no nutrient addition	13 weeks venting, moisture, and nutrient addition	5 weeks of direct flow from V1 13 weeks of moisture and nutrient addition	13 weeks venting, moisture, and nutrient addition
3 A	16 weeks venting, 8 weeks moisture, no nutrient addition	16 weeks venting, moisture, and nutrient addition	8 weeks of direct flow from V1 16 weeks of moisture addition, no nutrients since Test 3	16 weeks venting, moisture, and nutrient addition
4	22 weeks venting, 14 weeks moisture, no nutrient addition	22 weeks venting, moisture, and nutrient addition	19 weeks of direct flow from V1 22 weeks of moisture addition, no nutrients since Test 3	22 weeks venting, moisture, and nutrient addition
4 a	N/A	N/A	3 days direct injection of high concentration JP-4	N/A
5	29 weeks venting, 21 weeks moisture, 7 weeks nutrient addition	29 weeks venting, moisture, and nutrient addition	7 weeks of venting atmospheric air 29 weeks of moisture addition, no nutrients since Test 3	29 weeks venting, moisture, and nutrient addition

of the biodegraded fuel would be converted to cell mass and two-thirds mineralized to CO<sub>2</sub> and water. The intent was to ensure that nutrients, if being delivered, were not limiting. This analysis indicated that the objective was achieved. Soil samples collected at the termination of experiments were compared to initial soil samples to confirm uniform nutrient delivery throughout the test plots.

#### E. EVALUATION OF CONTROL VARIABLES

##### 1. Demonstrating Enhanced Biodegradation and Effects of Moisture and Nutrient Addition

The vented gas was monitored throughout the 7-month project to assess the overall effect of moisture, nutrient addition, and venting rate on the utilization of oxygen, the production of carbon dioxide, and the mass of volatilized hydrocarbon in the vented gas. In addition, five in situ respiration tests were conducted following periods of operation under varying conditions of moisture and nutrient addition. The in situ respiration tests consisted of measuring oxygen consumption and carbon dioxide production with time following shutdown of the air venting system. Operational and shutdown data, which can be found in Appendix B, were used to calculate the percentages of total hydrocarbons removed by biodegradation and volatilization, and to calculate oxygen consumption rate constants (k) under varying conditions of flow rate, moisture, and nutrient addition. Table 2 summarizes operating conditions throughout the project and prior to the respective in situ respiration tests for both treatment and background plots. Canister samples were collected to confirm field measurements and also analyzed for specific constituents. From these samples, a hydrocarbon weight fraction relationship over time in vented gas was established.

Gravimetric soil moisture analyses of both treatment and background plots were completed prior to start-up and during the final characterization effort. In addition, a limited number of samples were collected from the treatment plots after 2 months of operation to determine the extent to which venting caused drying of the soil. This information is only an indicator of the range of soil moisture under which the field test was conducted.

## 2. Demonstrating Hydrocarbon Removal with Soil Sample Data

In addition to the operational and respiration (shutdown) data, comparison of the pre- and posttreatment soil samples may be a significant indicator of the success of the technology. The problem associated with conclusions based on comparison of pretreatment and posttreatment soil sampling is the inherent high variability of field-measured soil hydrocarbon concentrations. A pilot test for in situ air stripping of TCE-contaminated soil found that some posttest soil concentrations were three orders of magnitude higher than pretest concentrations (23). Although some of the increase may have been attributed to migration of TCE toward the extraction points, the authors attribute the results to high variability (more than five orders of magnitude) in soil concentrations in both sets of samples. Initial site characterization confirmed similar heterogeneity at the field site selected for this project. Soil gas analyses revealed variability throughout the treatment area of up to three orders of magnitude. Soil gas concentrations in the shallow soil gas probes (30 - 45 cm; 1 - 1.5 feet) were more than four times higher in V1 than in V2. Based on the September 1989 soil samples, hydrocarbon concentrations varied more than two orders of magnitude in V1 and V2 and average hydrocarbon concentrations were 50 percent higher in V2 than in V1. The disparity between soil gas-phase and soil solid-phase results for samples occurred because the hydrocarbon concentrations in V1 were highest at the 30-cm level, whereas in V2 the 30-cm level had the lowest hydrocarbon concentration. The high water table in July 1989, prior to the dewatering effort, prevented a soil gas survey using the deeper soil gas probes; the result was an erroneous interpretation of relative contamination levels. The disparity between soil gas-phase and soil solid-phase results illustrates the danger of drawing firm conclusions from limited soil gas surveys.

Statistically significant conclusions concerning cleanup effectiveness based on soil sample results are difficult unless the soil is cleaned to the extent that order-of-magnitude variability is no longer a factor. The high variability in soil hydrocarbon concentrations at the field site poses two questions. First, does the variability in soil concentrations



allow for conclusions based on results of pretreatment and posttreatment soil samples? Second, is it possible to compare treatment plots statistically? Considering the first problem, a primary objective was to clean the soil within the time frame allowed for the project. Since minimizing volatilization was also an objective, there was some concern that time limitations would not allow both objectives to be met. In an attempt to satisfy both objectives, Treatment Plot V2 was operated with moisture and nutrient addition from the beginning to maximize cleanup rate and extent. In addition, a 4-month extension to the project was requested and granted. Considering the second problem, total hydrocarbon concentrations, based on methylene chloride extractions of the September 1989 samples, averaged 5,135 (SD  $\pm$  5,032) and 7,690 (SD  $\pm$  7,681) mg/kg for V1 and V2, respectively. A paired students t-test of these data indicates that hydrocarbon concentrations in V1 and V2 are not statistically different and technically could be compared with each other. Although this strategy may be statistically sound, it was used with caution because of the high variability in soil hydrocarbon concentrations.

Background plots were located within 30 meters (100 feet) of the treatment plots during the initial characterization effort in July 1989. Hydrocarbon concentrations were below detectable levels throughout the background area. Both background plots were vented and received amendments provided to treatment plots. One background plot was used to quantify background in situ respiration, while the other was used to evaluate the capacity of the soil to degrade hydrocarbons in the off-gas from Treatment Plot V1.

### 3. Hydrocarbon Vapor Off-Gas Biodegradation

The soil venting project at Hill AFB, Utah, demonstrated that venting is an efficient method for delivering oxygen for microbial degradation (3). Unfortunately, soil venting produces an effluent that may require expensive treatment before discharge. Reinjection of the off-gas or an alternate extraction configuration for maximizing microbial degradation is an attractive and potentially cost-effective alternative to conventional vent system design. To assess the feasibility of alternate venting designs, hydrocarbon off-gas from V1 was pumped to the upstream ends of V3. Hydrocarbon, oxygen, and carbon dioxide were monitored at the inlet and discharge points of V3 with the

intent of observing a loss of oxygen and stoichiometric equivalent amount of hydrocarbon (see Equation 2).

Initially, and for a period of approximately 2 months, off-gas from V1 was diluted before injection at V3 to ensure adequate oxygen/hydrocarbon ratios. Operation was hindered by deterioration of PVC fittings associated with piping between V1 and V3, and because the water table had fallen 30 - 60 cm (1 - 2 feet) below the walls of the V3 plot. PVC piping was removed from the system, the water table was artificially raised, and off-gas from V1 was injected directly into V3 for approximately 3 months. This was possible because by that time oxygen/hydrocarbon ratios in V1 off-gas were adequate for complete mineralization. Hydrocarbon concentrations in the discharge air stream of V3 were consistently lower than the inlet concentrations. Unfortunately, oxygen concentrations were consistently higher in the discharge than in the inlet gas streams. It was obvious that the plot was leaking significantly and masking any oxygen consumption resulting from the observed loss of hydrocarbons. Although leakage was obvious, the magnitude of the hydrocarbon loss could not be totally explained by the leakage calculated from increased oxygen concentrations.

It was determined that a higher concentration of hydrocarbon, injected at a lower flow rate, would be needed to observe oxygen consumption resulting from mineralization of the hydrocarbon. Eighteen liters (5 gallons) of JP-4 were sparged with air for 24 hours to strip the lighter compounds so that a relatively constant concentration of JP-4 vapor could be maintained. The JP-4 vapor was diluted with atmospheric air to achieve the necessary oxygen/hydrocarbon ratio required for mineralization prior to injection into V3. This test lasted 3 days and was successful to the extent that an oxygen loss of approximately 3 percent was observed even though the discharge was diluted by leakage of near atmospheric concentrations of oxygen. A mass balance approach was used to quantify both the rate of leakage and the rate of oxygen consumption ( $k$ ) in V3. The mass balance problem is illustrated and equations for the calculated leakage rate and  $k$  values are presented in Appendix A.

## F. ANALYTICAL METHODS

### 1. Field Methodology

The instrument selected for hydrocarbon analysis was a Summit Interests (Denver, Colorado) Portable GC, Model 1000, with an FID detector. Carbon dioxide and oxygen instrumentation was a Gastehtor, Model 32520X, manufactured by Gastech Inc. (Newark, California), which includes an IR detector for CO<sub>2</sub> and an electrochemical cell for O<sub>2</sub> analyses. A Scott flow blender was used with both instruments to dilute samples. Dilution was necessary to remain within the linear range of the FID and to ensure adequate O<sub>2</sub> for FID operation since combustion air is taken from the airstream sampled. Dilution of CO<sub>2</sub> samples was necessary for measurements above the 5 percent upper-scale range of the Gastehtor instrument. Field instruments were field-calibrated at least once per day. The sampling train was designed to allow dilution and ensure that samples were collected at the same atmospheric pressure under which the instruments were calibrated.

### 2. Laboratory Methods

#### a. Total Organic Carbon in Water Samples

Water samples were collected in the field and stored in amber glass bottles with Teflon<sup>®</sup>-lined caps at 4°C (39°F) with minimal exposure to light until analysis. Total organic carbon (TOC) was determined using Method 415.1 (50). In this method, organic carbon is converted to carbon dioxide by catalytic combustion. The amount of carbon dioxide formed is measured directly by an infrared detector. An Oceanography International Model 0524B Carbon Analyzer was used for all TOC determinations.

#### b. Specific Organic Compounds and Total Hydrocarbons in Water Samples

Hydrocarbon compounds were determined using a separatory funnel liquid-liquid extraction method, Method 3510 (50), followed by gas chromatograph analysis using a flame ionization detector. A Petrocol #3710, diffused silica capillary 5.0 micrometer (μm) film (0.75 mm x 10 meters) column was used. A 500-mL aliquot of the sample was extracted three times with 30-mL volumes of dichloromethane. The dichloromethane extracts were combined and concentrated to 5 mL using a Kuderna-Danish apparatus. The

concentrated extracts were dried over anhydrous sodium sulfate and then analyzed for the specific nonvolatile organics listed in Table 3 using a Shimadzu GC-9A gas chromatograph equipped with a flame ionization detector and Baseline 810 Chromatography Data acquisition system. Total petroleum hydrocarbons were determined using a hexane standard and a mixed aliphatic standard containing C-5 to C-15 hydrocarbons.

c. Specific Organic Compounds and  
Total Hydrocarbons in Soil Samples

A modification of a gas chromatographic method reported by Vandegrift and Kampbell (51) was used for the analysis of the specific compounds in the soil core samples. A subsample of soil, approximately 100 grams, was extruded from the core and placed directly into a tared wide-mouth glass jar (soil moisture content was determined and hydrocarbon concentrations are reported in mg/kg dry weight). The jar was then reweighed to determine the exact amount of soil added. A known volume (80 - 100 mL) of dichloromethane was added and the jar was sealed with a screw-top, Teflon<sup>®</sup>-lined septa cap. The soil/dichloromethane mixture was tumbled for approximately 1 hour, then centrifuged at 2,000 rpm for 20 minutes to separate the phases. A 50-mL aliquot of the dichloromethane was removed and concentrated to 5 mL using a Kuderna-Danish apparatus. The concentrated extract was then analyzed for the specific nonvolatile organics listed in Table 3 using a Shimadzu GC-9A gas chromatograph equipped with a flame ionization detector and Baseline 810 Chromatography Data acquisition system. Total petroleum hydrocarbons were determined using a hexane standard and a mixed aliphatic standard containing C-5 to C-15 hydrocarbons.

d. Specific Organic Compounds and Total  
Hydrocarbons in Soil Gas (Canister) Samples

Soil gas samples were collected in stainless steel evacuated canisters. Prior to use, the canisters were muffled and evacuated to establish a vacuum for sampling. Samples were analyzed for the specific constituents listed in Table 3 by direct injection of the vapor into a Shimadzu GC-9A gas chromatograph (GC) equipped with a flame ionization detector (FID) and Baseline 810 Chromatography Data acquisition system. Total petroleum hydrocarbons were determined using a hexane standard and a mixed aliphatic standard containing C-5 to C-15 hydrocarbons.

TABLE 3. SPECIFIC ORGANIC COMPOUNDS DETERMINED BY  
GAS CHROMATOGRAPHIC ANALYSIS

Aromatics	Aliphatics	
benzene	2-methylbutane	n-octane
toluene	n-pentane	n-decane
p-xylene	2-methylpentane	n-dodecane
n-propylbenzene	n-hexane	n-tridecane
n-butylbenzene	2,4-dimethylpentane	n-tetradecane
	n-heptane	n-pentadecane

#### e. Total Nitrogen

An attempt was made to determine total nitrogen levels in air-dried soil samples using the Dumas method with a Coleman (Coleman Instruments Division, Perkin-Elmer Corp., Oak Brook, Illinois) nitrogen analyzer (52). However, this method was not sensitive enough to determine total nitrogen prior to nutrient addition. Total Kjeldahl Nitrogen (TKN) was determined on all samples to allow calculation of available organic nitrogen. The Semi-Micro-Kjeldahl Method (53) was used. Approximately 0.5 grams of soil were digested using a Technicon Model BD-40 Block Digester prior to distillation and determination of ammonia nitrogen in the distillate by Nesslerization. Dissolved TKN in water samples was analyzed using the same method.

#### f. Ammonium-Nitrogen

Ammonium-nitrogen ( $\text{NH}_4^+\text{-N}$ ) was extracted from air-dried soil with 2 molar (M) KCl solution in a 1:10 (w:v) slurry. The slurry was shaken for 1 hour at 150 rpm on an orbital shaker. After centrifugation, the supernatant was analyzed by distillation with Nesslerization (53). Dissolved  $\text{NH}_4^+\text{-N}$  in water samples was analyzed using the same distillation with the Nesslerization method.

#### g. Nitrate and Nitrite-Nitrogen

Soil nitrate and nitrite-nitrogen ( $\text{NO}_3^-$  and  $\text{NO}_2^-$ -N) were determined in 1:10 (w:v) deionized water extracts. The concentrations of  $\text{NO}_3^-$  and  $\text{NO}_2^-$ -N in the extracts were determined using ion chromatography (54). Ten grams of air-dried soil were suspended in 100 mL of laboratory-grade deionized water in a 250-mL Erlenmeyer flask. The flask was covered with aluminum foil and shaken on an orbital shaker at 150 rpm for 1 hour. A 50-mL aliquot of the slurry was centrifuged at 10,000 x g for 15 minutes. The supernatant was then filtered through a 0.45  $\mu\text{m}$  pore-size membrane filter that had been prerinsed with 100 mL of deionized water. The filtrate was analyzed for  $\text{NO}_3^-$  and  $\text{NO}_2^-$ -N. Because  $\text{NO}_3^-$  and  $\text{NO}_2^-$  are anions, they are highly mobile in soil. Nitrate and nitrite-nitrogen that is readily available to soil microbes should, therefore, be easily extracted with water. Using a simple water extract also helps avoid ion chromatography interference, which may arise from high concentrations of

chloride in the KCl extract recommended by Keeney and Nelson (55). Dissolved  $\text{NO}_3\text{-N}$  and  $\text{NO}_2\text{-N}$  in water samples were analyzed using the same method.

#### h. Water-Soluble Phosphate

Available orthophosphate-phosphorus ( $\text{PO}_4\text{-P}$ ) in the soil samples was estimated as water extractable  $\text{PO}_4\text{-P}$  (56). The same 1:10 (w:v) soil extract prepared for  $\text{NO}_3$  and  $\text{NO}_2\text{-N}$  determinations was analyzed for  $\text{PO}_4\text{-P}$  by ion chromatography (54). Dissolved  $\text{PO}_4\text{-P}$  in water samples was determined using the same method.

#### i. Total Phosphorus

Total phosphorus was determined from a perchloric acid digestion of a 2-gram portion of the air-dried soil sample followed by vanadomolybdomate colorimetry as described by Olsen and Sommer (56).

#### j. Nitrogen Fixation (Acetylene Reduction) Potential

Soil nitrogenase (nitrogen fixation) activity was assayed using the acetylene reduction assay (57). Ten grams of soil, at field moisture content, were weighted into 70-mL glass serum bottles. Each bottle was stoppered with a rubber septum and flushed with nitrogen for 5 minutes using hypodermic needles to introduce and vent the nitrogen. The 6 mL of nitrogen were withdrawn from the bottle with a hypodermic syringe and 6 mL of acetylene were added to provide approximately 10 kPa [0.1 atmosphere (atm)] of acetylene. The samples were incubated for 42 to 50 hours in the dark at 25°C (77°F). Ethylene production was monitored using gas chromatography and flame ionization detection (57, 58). Soil nitrogenase (nitrogen fixation) activity under aerobic conditions was assayed in an identical manner except that the samples were exposed to air, rather than nitrogen.

#### k. Microbial Enumerations

Soils were analyzed for microbial enumeration prior to and at the conclusion of the soil venting phase. Soil samples were collected in aseptic containers from various depths (1-6.5 feet) from soil corings next to the wells. The soils were placed on ice and shipped overnight to the laboratory, where they were immediately stored at 4°C (39°F). Tenfold serial dilutions of the soils were made, using sterile distilled water as the diluent. Aliquots (0.1 mL) of appropriate dilutions were plated in triplicate onto

nutrient agar. After several days of darkness, aerobic incubation at 25°C (77°F), those dilutions developing between 30 and 300 colonies per plate were counted with the aid of a Quebec lighted colony counter. The results were expressed as the colony forming units per dry gram of soil (CFU/g).

#### 1. Stable Carbon Isotopes

Soil gas samples were passed through an in-line activated carbon filter and collected in Tedlar™ bags using a diaphragm pump. Samples of atmospheric air were collected in the same manner. Carbon dioxide in the gas samples was separated for isotopic analyses by a series of freeze-thaw steps at dry ice-alcohol and liquid nitrogen temperatures. Stable isotopic compositions were measured using dual-inlet mass spectrometers by the Geochron Laboratories in Cambridge, Massachusetts. Isotopic compositions are reported in the conventional "δ" notation as parts per thousand (per mil) deviation from the standard:

$$\delta_x(\text{per mil}) = \frac{R_x - R_s}{R_s} \times 1000 \quad (6)$$

where R is the ratio of  $^{13}\text{C}/^{12}\text{C}$  in the sample (x) or the standard (s). Isotopic standards are PDB for carbon (59).



SECTION IV  
RESULTS AND DISCUSSION

A. INITIAL SITE CHARACTERIZATION

The initial characterization effort was begun July 10-19, 1989. Many of the Task 1 (Initial Site Characterization) samples were not collected during the initial visit because of the shallow water table. The remaining samples were collected during the September 1989 visit following the dewatering effort. Activities during July 1989 included equipment and materials acquisition, general selection of treatment and background test plots, initial soil gas survey of treatment and background areas, and collection of a portion of initial characterization samples from both treatment and background plots.

The general treatment and background areas were selected by digging a number of auger holes to check both for contamination and for the presence of rubble that could prevent construction of the cells. A Bacharach TLV Sniffer, calibrated to hexane, was used to measure hydrocarbon vapor concentrations emitted from auger hole soil cores and from the holes themselves. A soil gas survey, using a stainless steel soil gas probe and TLV Sniffer, was conducted to select a suitable site. The primary considerations during site selection were the presence or absence of contamination and the absence of rubble and utilities. Upon selecting the treatment and background plots, a detailed soil gas survey, using the previously described GC/FID and sampling train, was conducted to estimate contamination in the treatment area and confirm the absence of contamination in the background area. Monitoring wells and permanent vapor-monitoring probes were installed in the two treatment plots at three locations and three depths. Details of the initial site characterization are found in Reference 48.

B. OPERATIONAL MONITORING OF TREATMENT PLOTS V1 AND V2

Treatment plots were operated for 188 days between October 4, 1989, and April 24, 1990. Operation was interrupted only for scheduled in situ respiration tests. Discharge gases were monitored for oxygen (Figure 5), carbon dioxide (Figure 6), and total hydrocarbons (Figure 7) throughout the

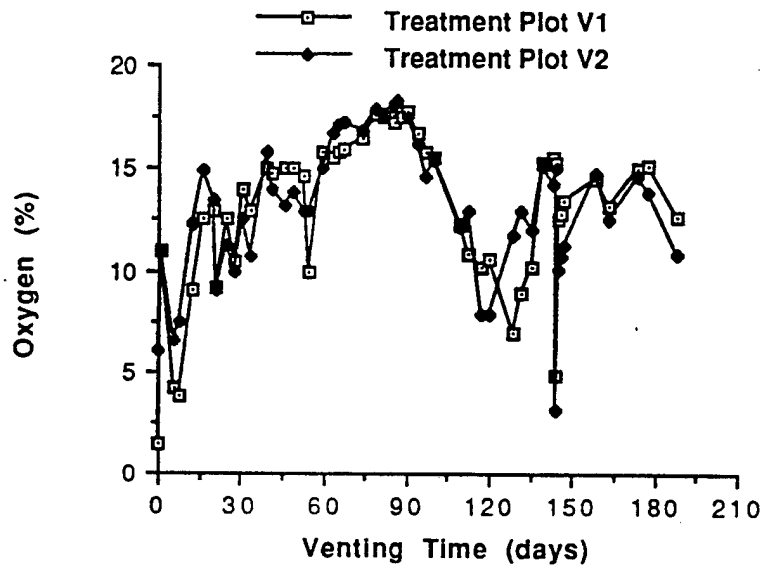


Figure 5. Oxygen Measured in Discharge Gas From Treatment Plots V1 and V2 During the Field Study.

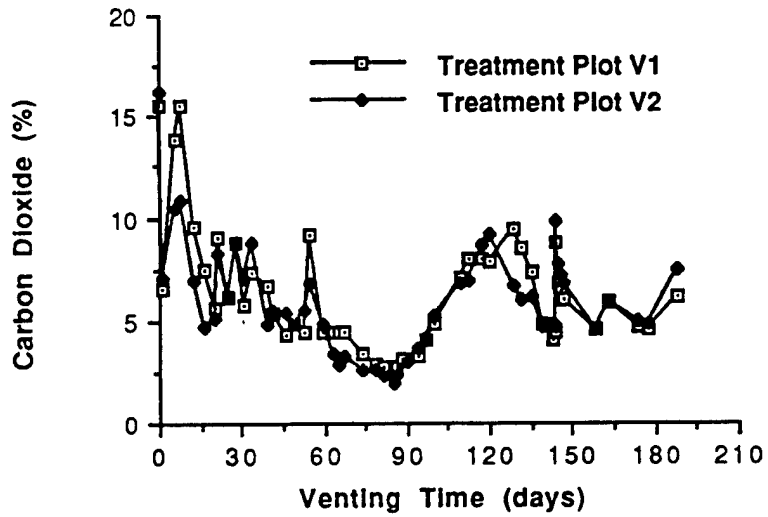


Figure 6. Carbon Dioxide Measured in Discharge Gas From Treatment Plots V1 and V2 During The Field Study.

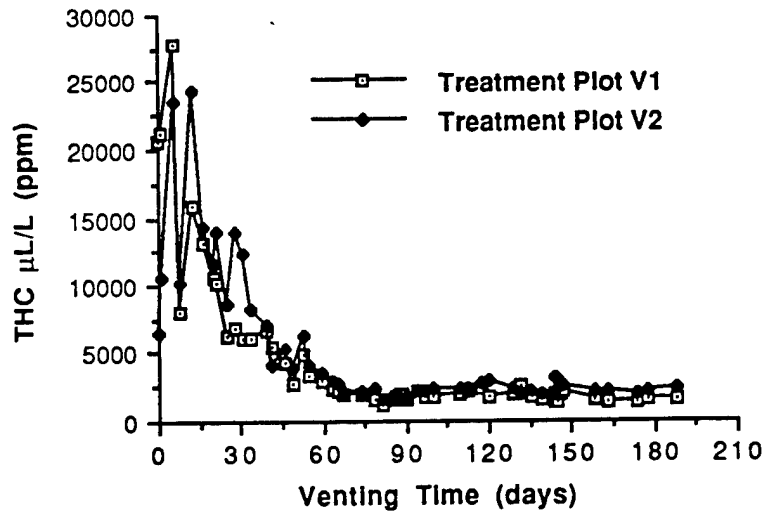


Figure 7. Total Hydrocarbons (THC) Measured in Discharge Gas From Treatment Plots V1 and V2 During the Field Study.

operational period. Summarized data are presented in Appendix B. In Figures 8 and 9, respectively, air flow rates in Treatment Plot V1 are compared with hydrocarbon removal rates (hexane equivalent) attributed to volatilization and biodegradation. The biodegradation component was calculated using the stoichiometric oxidation of hexane shown in Equation (2).

Oxygen consumption was calculated as the difference between oxygen in the Background Plot V4 and oxygen in the treatment plots. Using the oxygen concentration in the background plot, rather than atmospheric oxygen concentration, accounts for the natural biodegradation of organic carbon in uncontaminated soil and ensures that the biodegradation of fuel hydrocarbons was not overestimated. Biodegradation based on carbon dioxide production was similarly calculated. Figure 10 presents air flow rates in Treatment Plot V1, compared with the combined hydrocarbon removal rate due to volatilization and biodegradation. Air flow rates in Treatment Plot V2 are compared with hydrocarbon removal rates (hexane equivalent) attributed to volatilization and biodegradation in Figures 11 and 12, respectively. Figure 13 presents air flow rates in Treatment Plot V2 compared with the combined hydrocarbon removal rate due to volatilization and biodegradation. Hydrocarbon removal rates attributed to volatilization and biodegradation are presented in Figures 14 and 15, respectively, for Treatment Plots V1 and V2. Hydrocarbon removal rates comparing hydrocarbon removal attributed to volatilization and biodegradation in Treatment Plots V1 and V2 are presented in Figures 16 and 17, respectively. Removal rates in Figures 16 and 17 are expressed in mg/(kg day) and are based on an estimated soil bulk density of 1,440 kg/m<sup>3</sup> (90 pounds/ft<sup>3</sup>) and a treatment volume of 20 m<sup>3</sup> (704 ft<sup>3</sup>).

Biodegradation becomes increasingly important over time as a hydrocarbon removal mechanism; this is illustrated in Figures 18 and 19 for Treatment Plots V1 and V2, respectively. Percentages of combined volatilization and biodegradation removal rates attributable to biodegradation are compared in Figure 20 for Treatment Plots V1 and V2.

As shown in Figure 20, biodegradation rates were similar in Treatment Plots V1 and V2 throughout the experimental period, and neither moisture nor nutrient addition appear to have increased biodegradation rates. Cumulative hydrocarbon removal by volatilization and biodegradation is compared in

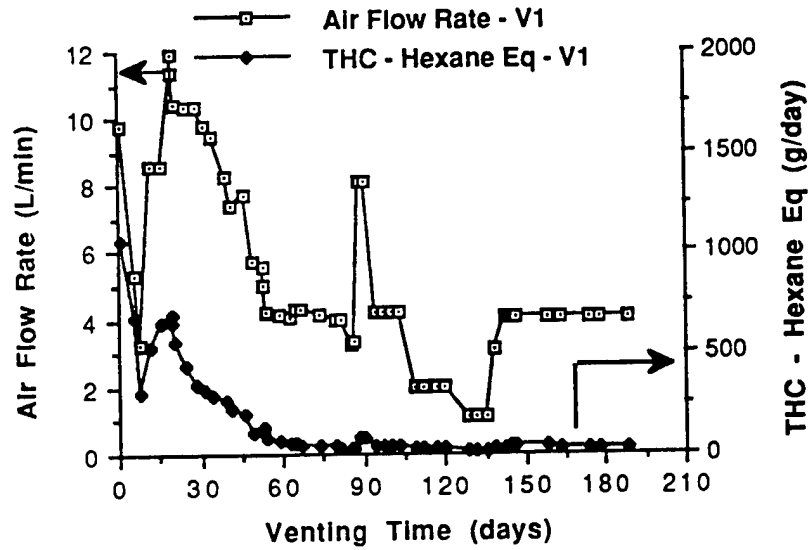


Figure 8. Comparison of Air Flow and Hydrocarbon Removal Rates Attributed to Volatilization in Treatment Plot V1 During the Field Study.

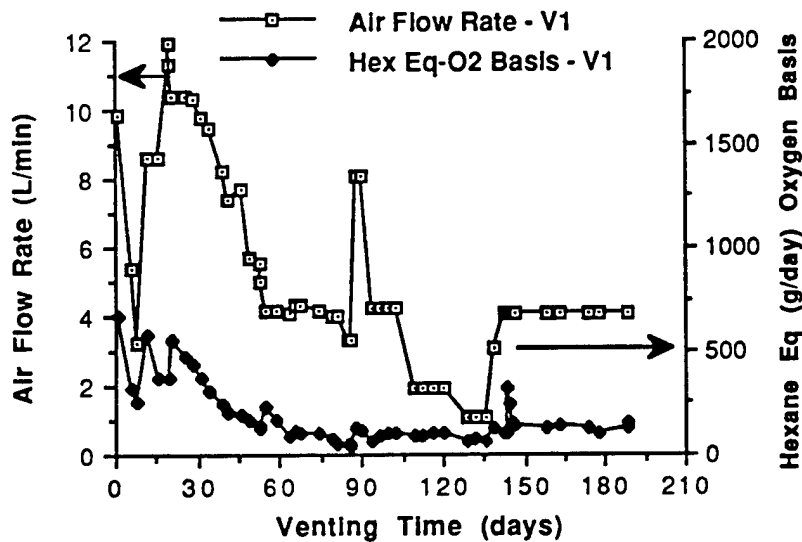


Figure 9. Comparison of Air Flow and Hydrocarbon Removal Rates Attributed to Biodegradation (oxygen basis) in Treatment Plot V1 During the Field Study.

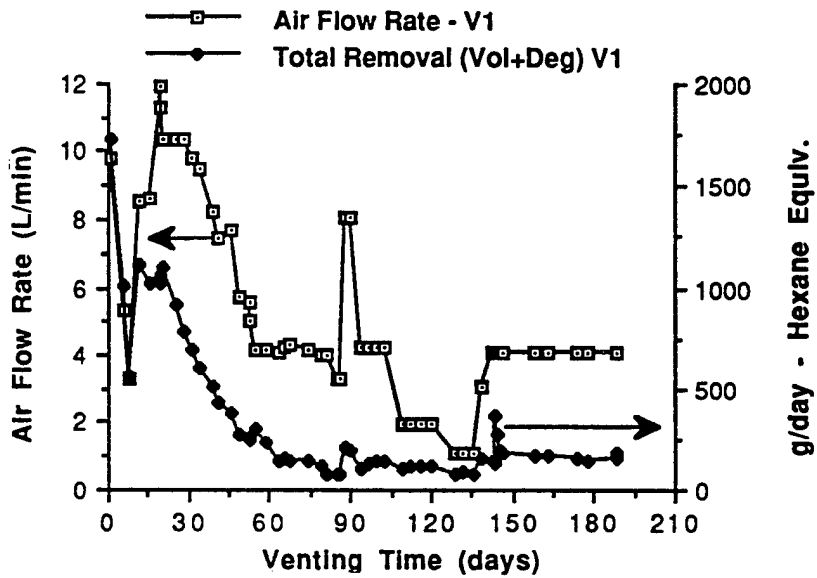


Figure 10. Comparison of Air Flow and Combined Hydrocarbon Removal Rates Attributed to Volatilization and Biodegradation (oxygen basis) in Treatment Plot V1 During the Field Study.

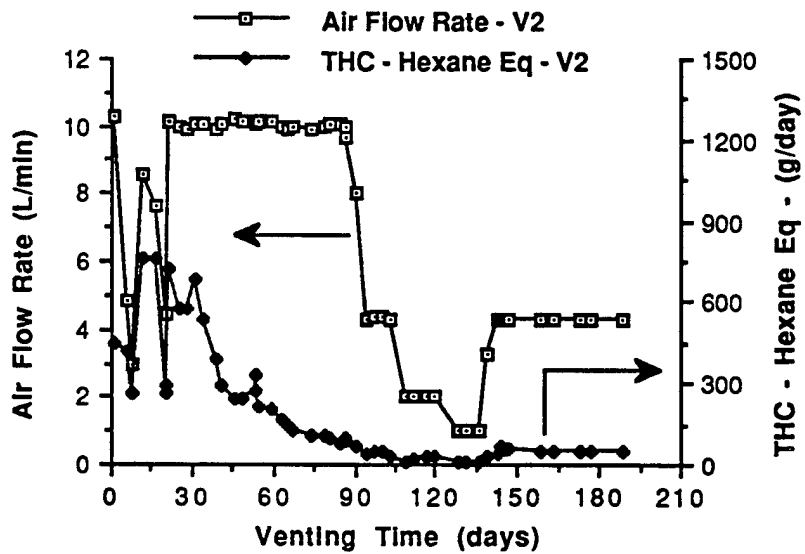


Figure 11. Comparison of Air Flow and Hydrocarbon Removal Rates Attributed to Volatilization in Treatment Plot V2 During the Field Study.

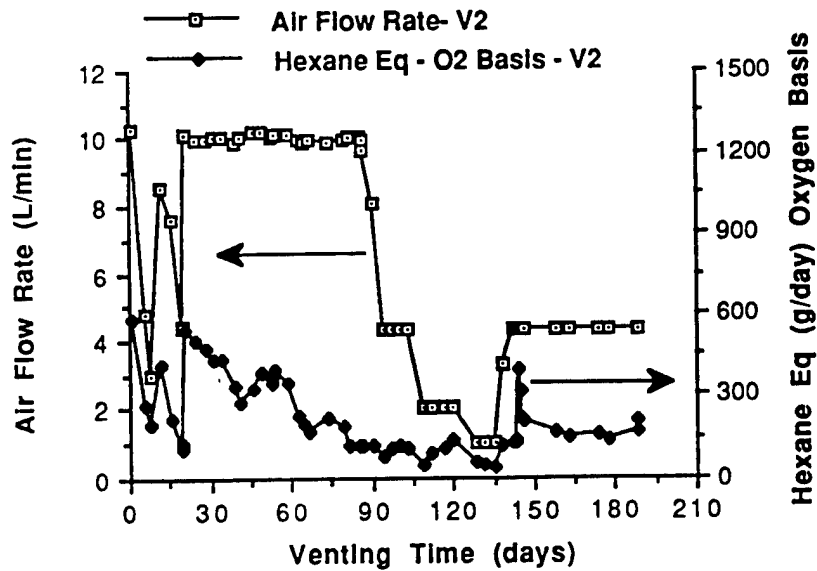


Figure 12. Comparison of Air Flow and Hydrocarbon Removal Rates Attributed to Biodegradation (oxygen basis) in Treatment Plot V2 During the Field Study.

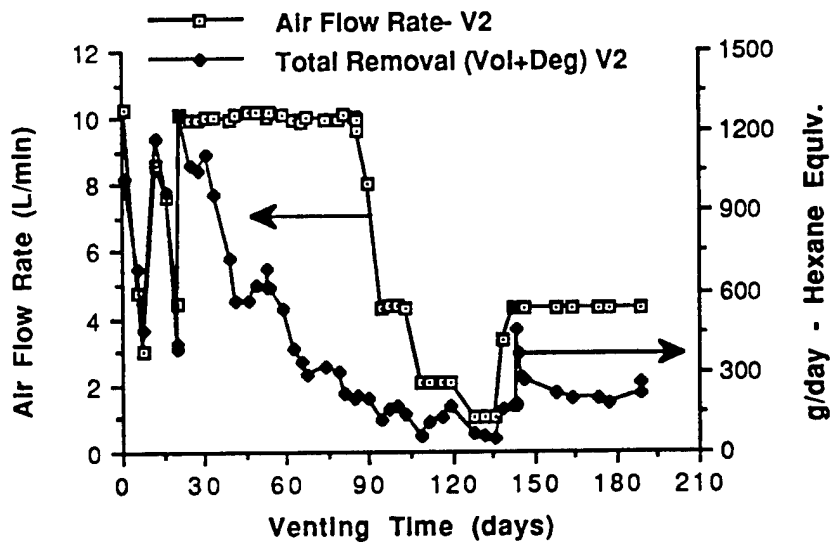


Figure 13. Comparison of Air Flow and Combined Hydrocarbon Removal Rates Attributed to Volatilization and Biodegradation (oxygen basis) in Treatment Plot V2 During the Field Study.

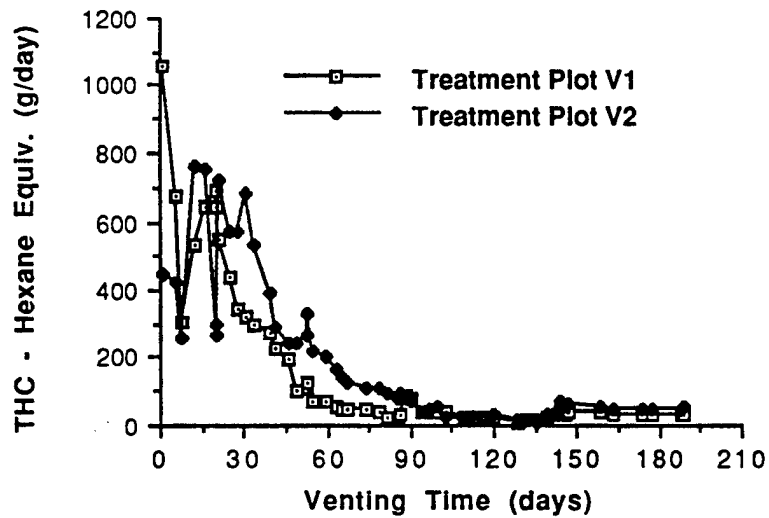


Figure 14. Hydrocarbon Removal Rates Attributed to Volatilization in Treatment Plots V1 and V2 During the Field Study.

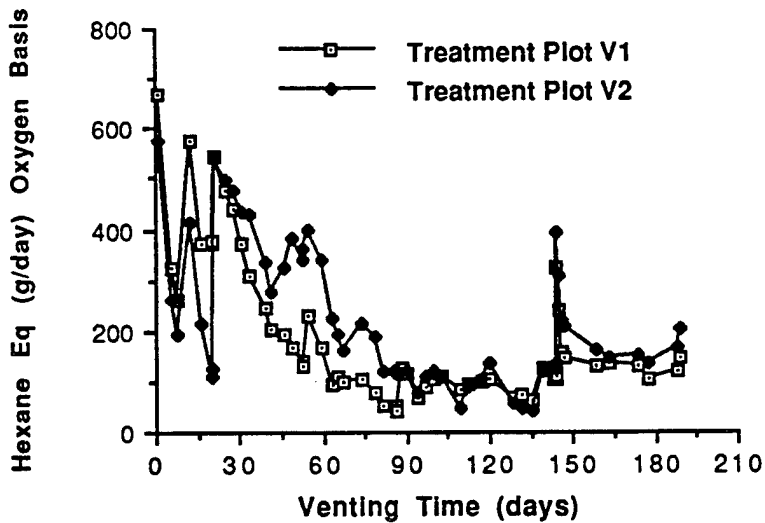


Figure 15. Hydrocarbon Removal Rates Attributed to Biodegradation (oxygen basis) in Treatment Plots V1 and V2 During the Field Study.



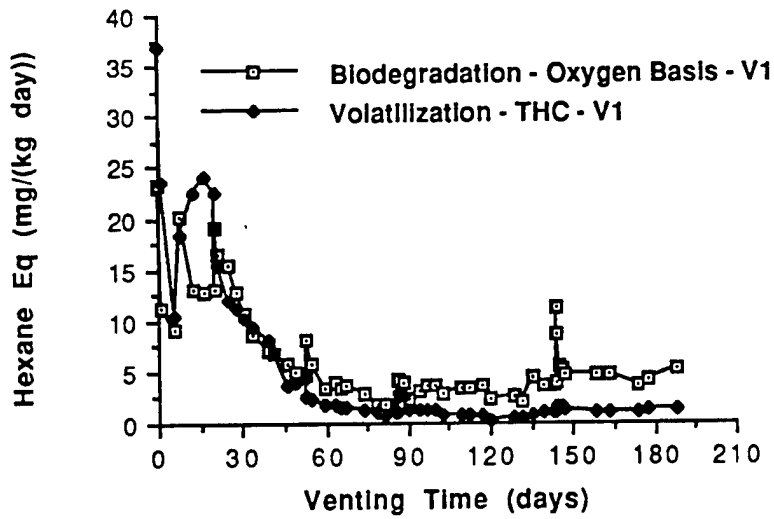


Figure 16. Hydrocarbon Removal Rate Attributed to Volatilization and Biodegradation (oxygen basis) in Treatment Plot V1 During the Field Study.

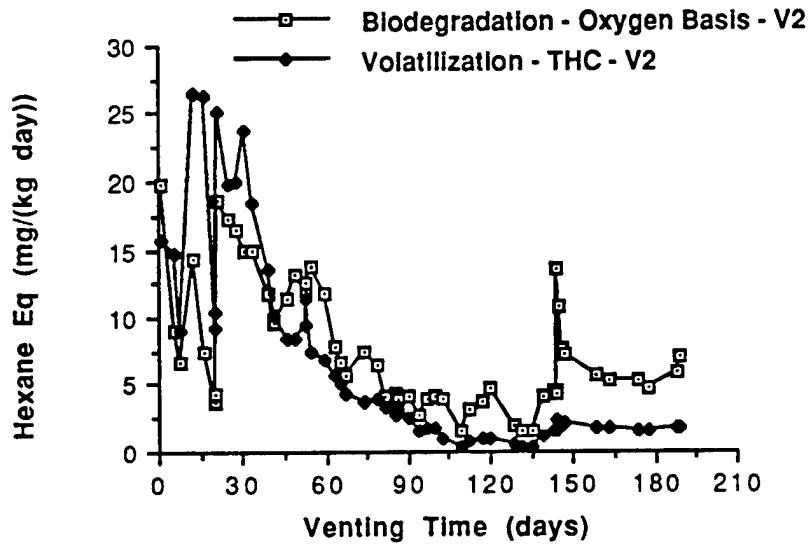


Figure 17. Hydrocarbon Removal Rate Attributed to Volatilization and Biodegradation (oxygen basis) in Treatment Plot V2 During the Field Study.

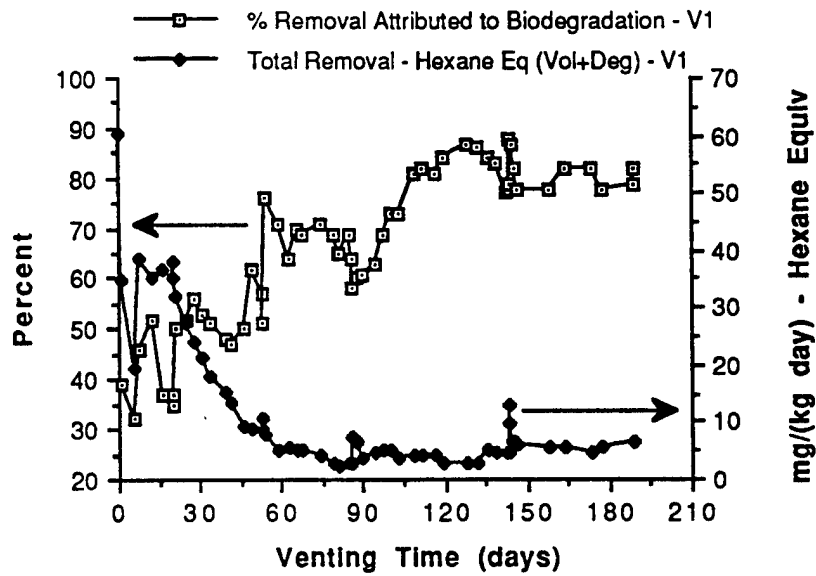


Figure 18. Comparison of the Combined Volatilization and Biodegradation Removal Rates and the Percent of Removal Rate Attributed to Biodegradation (oxygen basis) in Treatment Plot V1 During the Field Study.

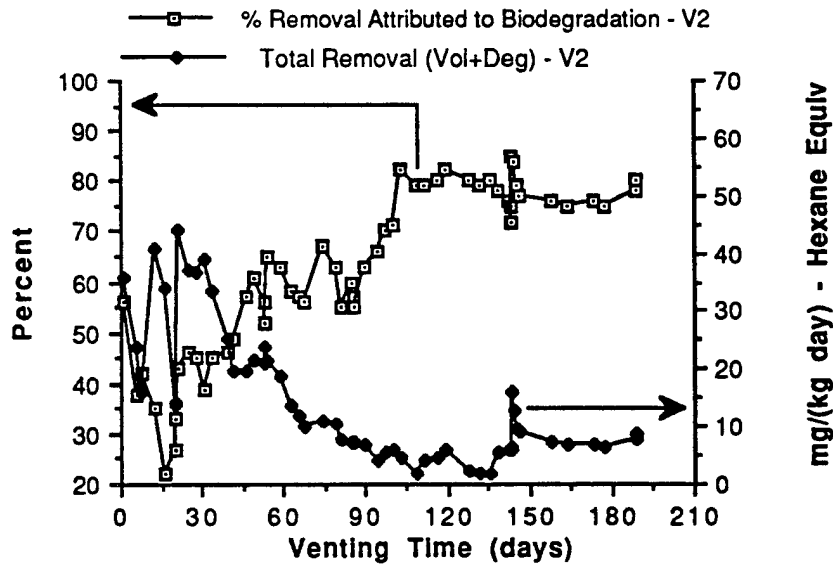


Figure 19. Comparison of the Combined Volatilization and Biodegradation Removal Rates and the Percent of Removal Rate Attributed to Biodegradation (oxygen basis) in Treatment Plot V2 During the Field Study.

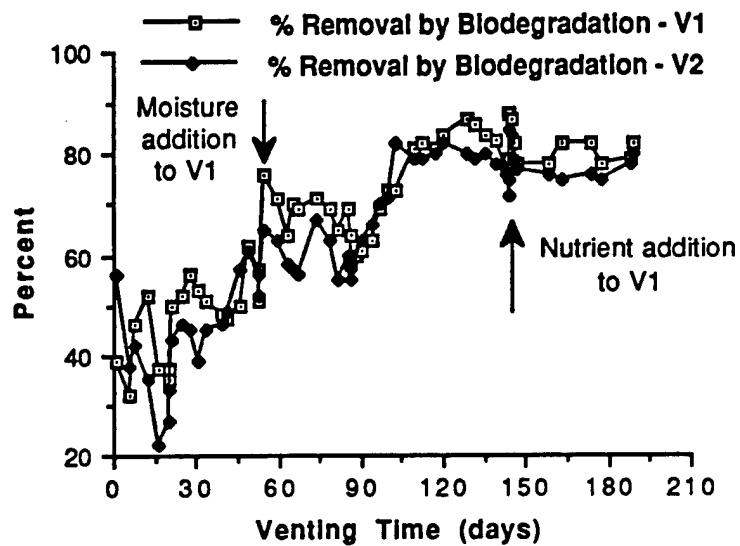


Figure 20. Comparison of the Percent of Combined Volatilization and Biodegradation Hydrocarbon Removal Rates Attributed to Biodegradation (oxygen basis) in Treatment Plots V1 and V2 During the Field Study.

Figures 21 and 22, respectively, for Treatment Plots V1 and V2. The higher hydrocarbon removal rates, from both volatilization and biodegradation, in Treatment Plot V2 over Treatment Plot V1 are consistent with the initial soil samples (see Appendix C) in each plot. Using soil samples collected to a depth of 1.5 meters (5 feet), the average total hydrocarbon concentration was 5,135 (SD  $\pm$  5,032) and 7,690 (SD  $\pm$  7,681) mg/kg, hexane equivalent, in Treatment Plots V1 and V2, respectively.

Cumulative hydrocarbon removal data for volatilization, biodegradation, and total removal for Treatment Plots V1 and V2 are summarized in Figures 23 and 24, respectively. Biodegradation of hydrocarbon, calculated from the production of carbon dioxide, is included for comparison with biodegradation based on the consumption of oxygen. Carbon dioxide concentrations in uncontaminated soil (Background Plot V4), rather than atmospheric carbon dioxide concentrations, were used as the basis for calculating the stoichiometric amount of hydrocarbon (hexane equivalent) biodegraded. At this site, biodegradation of fuel hydrocarbons calculated on the basis of carbon dioxide measurements indicated more biodegradation than calculations based on oxygen measurements. Since the data have been presented using an oxygen basis for fuel hydrocarbon biodegradation, biodegradation estimates are conservative. It is not known whether the difference in biodegradation is the result of an abiotic oxygen source or carbon dioxide source. However, the hydrocarbon biodegradation calculations based on oxygen and carbon dioxide are similar and lead to the same overall conclusions. Comparisons between biodegradation and volatilization are presented using the oxygen basis because there are more potential sources and sinks for carbon dioxide than for oxygen. Figure 25 summarizes total hydrocarbon removal from combined volatilization and biodegradation, based on oxygen and carbon dioxide, for Treatment Plots V1 and V2. Total hydrocarbon removal through the experimental period was approximately 2,000 and 2,500 mg/kg for Treatment Plots V1 and V2, respectively. Removal is expressed in concentration terms for comparison with initial soil contamination.

Operational data for the Treatment Plots are remarkably similar considering that Treatment Plot V2 received moisture and nutrients throughout the experimental period and Treatment Plot V1 received moisture after 8 weeks of operation and nutrients after 22 weeks of operation (Table 2). The

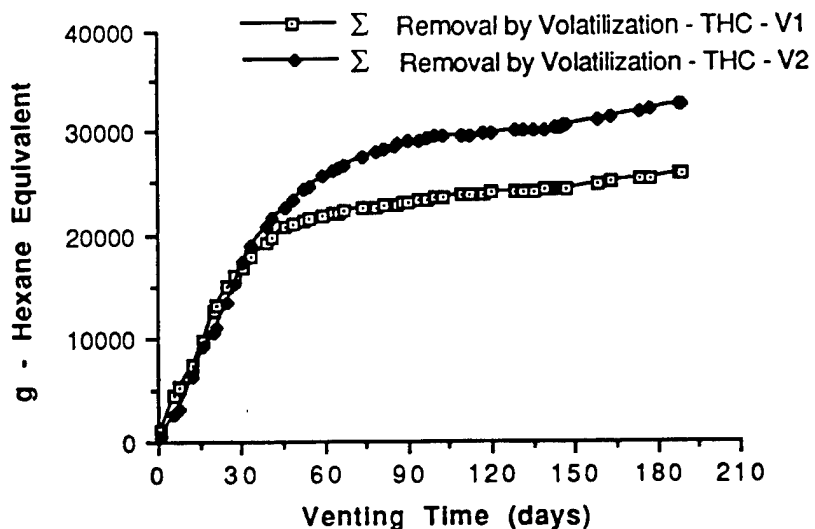


Figure 21. Comparison of Cumulative Hydrocarbon Removal Attributed to Volatilization in Treatment Plots V1 and V2 During the Field Study.

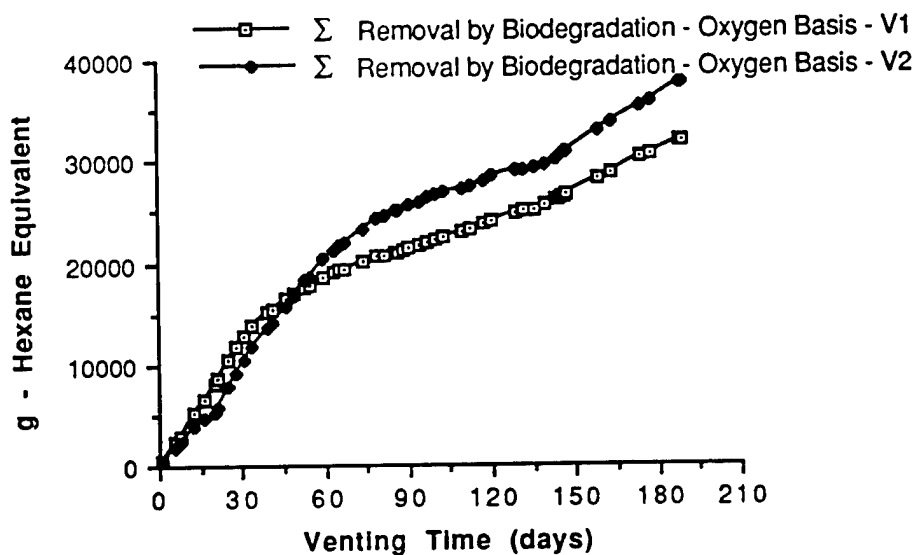


Figure 22. Comparison of Cumulative Hydrocarbon Removal Attributed to Biodegradation (oxygen basis) in Treatment Plots V1 and V2 During the Field Study.

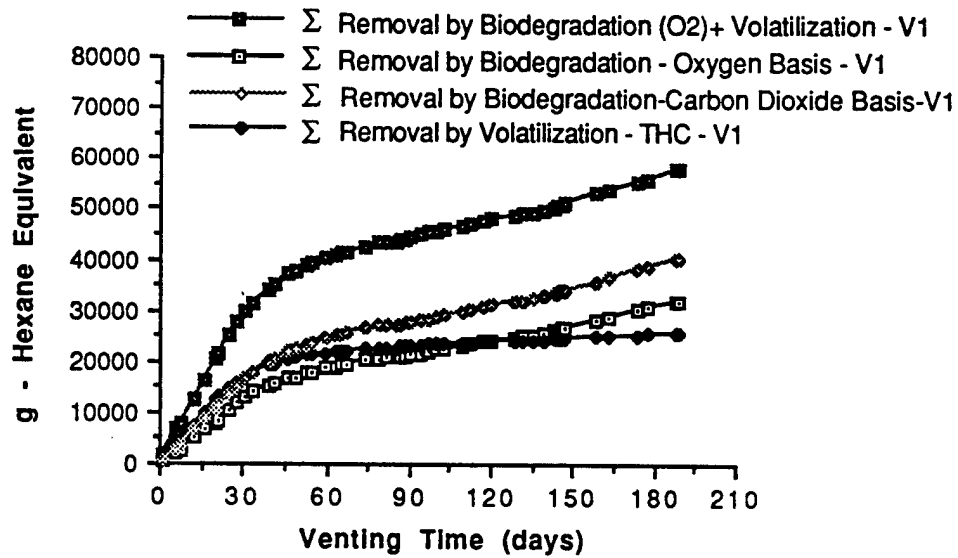


Figure 23. Cumulative Hydrocarbon Removal in Treatment Plot V1 During the Field Study.

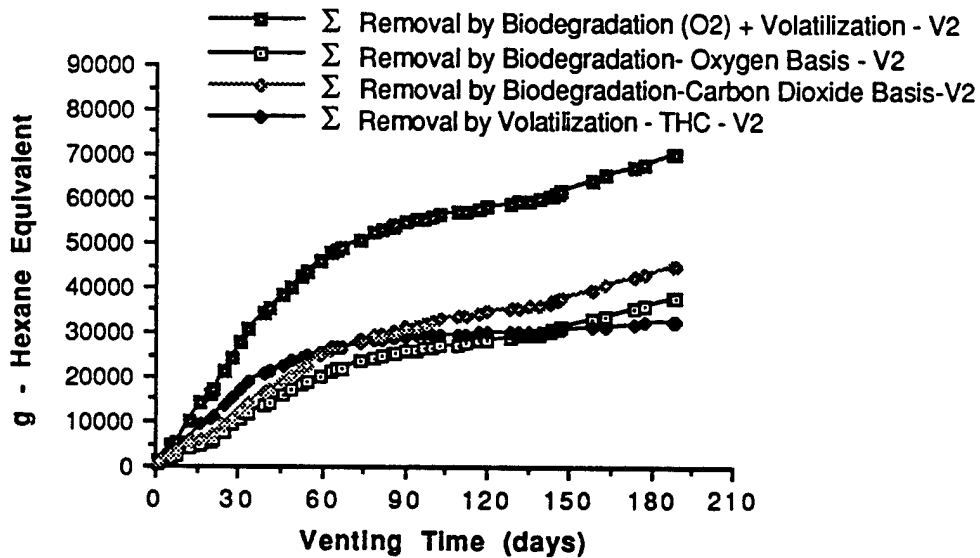


Figure 24. Cumulative Hydrocarbon Removal in Treatment Plot V2 During the Field Study.

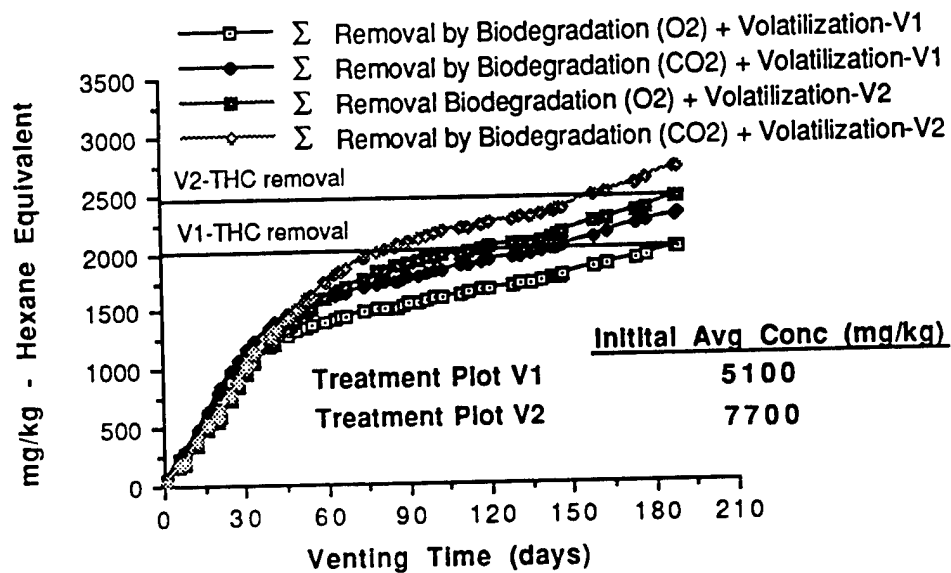


Figure 25. Cumulative Removal of Hydrocarbon from Combined Volatilization and Biodegradation (oxygen and carbon dioxide basis) in Treatment Plots V1 and V2 During the Field Study.

relationships demonstrated above indicate that moisture and nutrients were not a limiting factor in the hydrocarbon biodegradation removal rate.

#### 1. Effect of In Situ Respiration Tests on Operational Data

In the hydrocarbon biodegradation rate data presented, a noticeable spike occurs at Day 146. The spike is a result of data collected immediately and at relatively short-time intervals following an in situ respiration test, when oxygen concentrations were depleted, and prior to completely purging the treatment vents. In situ respiration tests were initiated at 20, 53, 86, 144, and 188 days of venting; and similar spikes occurred, but are not as noticeable because of the longer measurement interval following these in situ respiration tests.

A decrease in oxygen and increases in carbon dioxide and total hydrocarbons are expected following shutdown of venting systems in contaminated soil. In fact, this spike has been described as a method (pulsed pumping) to volatilize compounds from the vadose zone while minimizing venting operation time (60). However, this research indicates that the spike is insignificant as far as cumulative removal is concerned. The spike in hydrocarbon removal rate at Day 146 is unnoticeable in the cumulative removal graphs because the duration of the spike following initiation of venting is extremely short compared with overall venting time.

#### C. FLOW RATE VERSUS TOTAL HYDROCARBON REMOVAL RATE AND PERCENT BIODEGRADATION IN TREATMENT PLOTS

Ely and Heffner (44) suggested that air flow rates higher than required for volatilization of hydrocarbons may be optimum for biodegradation. However, rate constants ( $k$ ) for oxygen consumption and carbon dioxide production have been shown, through shutdown/in situ respiration tests in this research, to follow zero order kinetics for oxygen concentrations above 1 percent. Therefore, lower flow rates resulting in longer retention times should result in higher percentages of hydrocarbon removal by biodegradation.

Figures 18 and 19 show an overall increase throughout the experimental period in the percentage of hydrocarbon removal attributable to biodegradation. Figures 8, 9, 11, and 12 illustrate that after the more



volatile compounds are physically removed, biodegradation becomes increasingly important as the primary removal mechanism.

Figures 26 and 27 compare flow rate with percentage of hydrocarbon removal attributed to biodegradation in Treatment Plots V1 and V2, respectively. Percent of biodegradation appears to be inversely proportional to flow rate in Treatment Plot V1 throughout the experimental period. However, in Treatment Plot V2, percent biodegradation increases through 60 days of venting even though the air flow rate remained constant. This supports the observation that, after the more volatile compounds are physically removed (Figure 7), biodegradation becomes increasingly important as the primary removal mechanism. After initial stripping of the more volatile compounds (Figure 7), percent removal by biodegradation begins to reach a plateau at a constant air flow rate. At this point, reducing the air flow rate may be the only way to significantly increase the percent of removal attributed to biodegradation.

An experiment was conducted to evaluate the relationships among air flow rate, total hydrocarbon removal rate, and percentage of total removal attributed to biodegradation following the period of high volatilization removal (after approximately 75 days of venting). This was begun on Day 89, after the initial period of high volatilization removal. Air flow rates in Treatment Plots V1 and V2 were varied over a 7-week period from January 8, 1990, to February 28, 1990. Flow rates were approximately 8, 4, 2, and 1 liters/minute, which equate to approximately 2, 1, 0.5, and 0.25 air-filled void volumes per day, respectively.

Oxygen, carbon dioxide, and hydrocarbon concentrations were allowed to stabilize at each air flow rate. Data are presented chronologically in Appendix B and the stabilized data at each flow rate are summarized in Table 4. Figures 28 and 29 illustrate the data in Table 4 for Treatment Plot V1 using oxygen and carbon dioxide measurements, respectively, along with total hydrocarbons as the basis for calculating percent removal by biodegradation. Similarly, Figures 30 and 31 illustrate the data in Table 4 for Treatment Plot V2 using oxygen and carbon dioxide measurements, respectively.

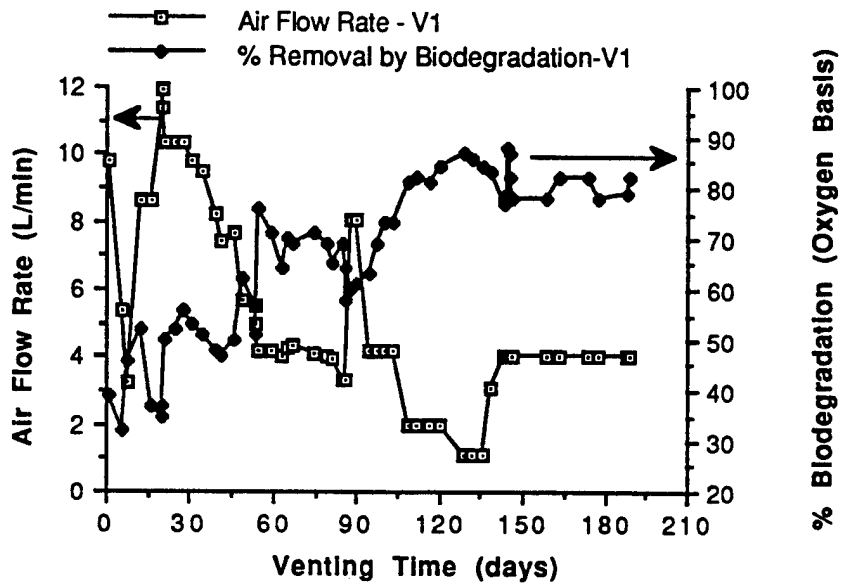


Figure 26. Comparison of Air Flow and Percent Hydrocarbon Removal Attributed to Biodegradation in Treatment Plot V1 Observed During the Field Study.

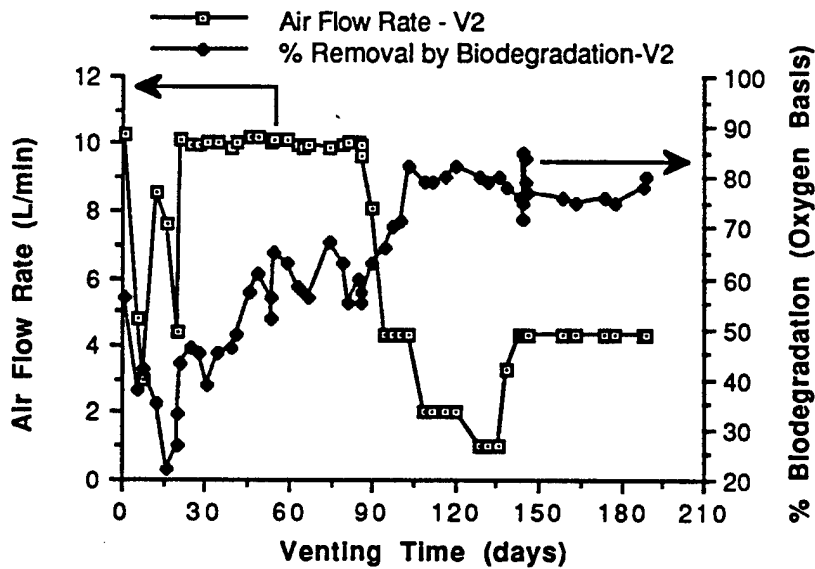


Figure 27. Comparison of Air Flow and Percent Hydrocarbon Removal Attributed to Biodegradation in Treatment Plot V2 Observed During the Field Study.

TABLE 4. SUMMARY OF FLOW RATE VERSUS TOTAL HYDROCARBON REMOVAL AND PERCENT BIODEGRADATION FOR TREATMENT PLOTS V1 AND V2 OBSERVED DURING THE FIELD STUDY

Treatment Plot V1 Discharge													
Date/Time	CO2 (%)	O2 (%)	THC (µL/L)	Flow (L/min)	CO2 (g/day)	Hexane Eq. (g/day)	O2 (g/day)	THC (g/day)	Hexane Eq. (g/day)	THC+CO2 (g/day)	Hexane Eq. (g/day)	THC+O2 (g/day)	% Biol Deg O2 Basis
1/12/90 8:56	3.0	17.8	1582.6	8.06	180	109	66	246	175	73	79	73	62
1/22/90 10:30	4.8	15.5	1822.4	4.22	149	108	40	188	147	84	84	84	73
2/12/90 15:00	7.8	10.6	2227.7	1.94	117	100	22	139	122	86	86	86	85
2/28/90 10:00	7.3	10.2	1852.4	1.14	68	62	11	78	73	86	86	86	85

Treatment Plot V2 Discharge													
Date/Time	CO2 (%)	O2 (%)	THC (µL/L)	Flow (L/min)	CO2 (g/day)	Hexane Eq. (g/day)	O2 (g/day)	THC (g/day)	Hexane Eq. (g/day)	THC+CO2 (g/day)	Hexane Eq. (g/day)	THC+O2 (g/day)	% Biol Deg O2 Basis
1/12/90 9:40	3.0	17.5	1758.4	8.02	179	122	73	252	194	71	77	77	63
1/22/90 10:30	5.2	15.4	2270.0	4.32	167	112	51	217	163	83	83	83	69
2/12/90 15:00	9.1	7.9	2877.4	2.03	145	134	30	175	164	82	82	82	81
2/28/90 10:00	6.1	12.0	2106.7	1.08	53	49	12	65	60	82	82	82	81

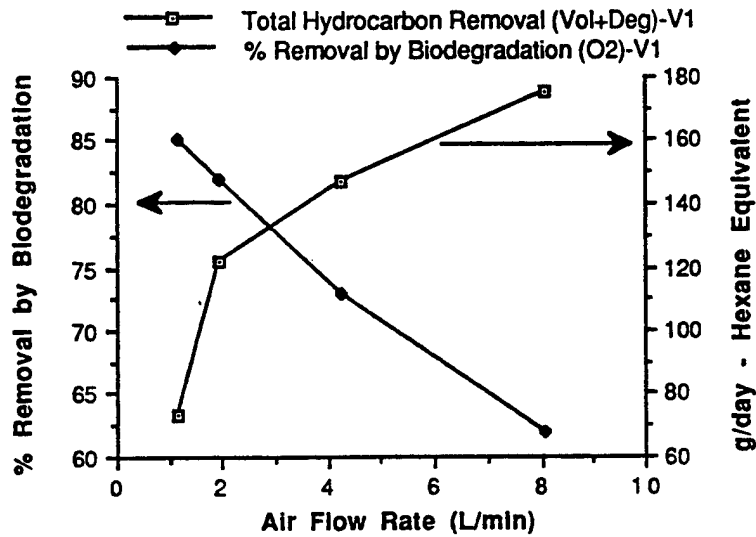


Figure 28. Comparison of Air Flow Rate Versus Total Hydrocarbon Removal and Percent of Total Removal Attributed to Biodegradation in Treatment Plot V1 ( $O_2$  basis) During the Variable Air Flow Rate Study.

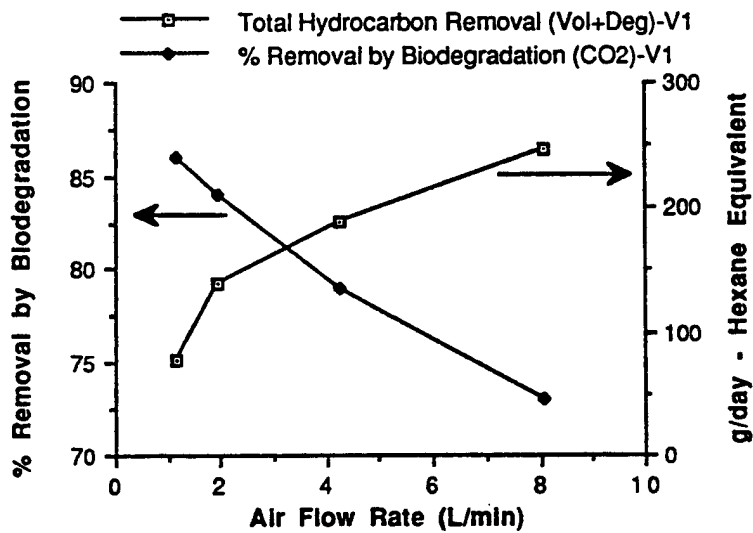


Figure 29. Comparison of Air Flow Rate Versus Total Hydrocarbon Removal and Percent of Total Removal Attributed to Biodegradation in Treatment Plot V1 ( $CO_2$  basis) During the Variable Air Flow Rate Study.

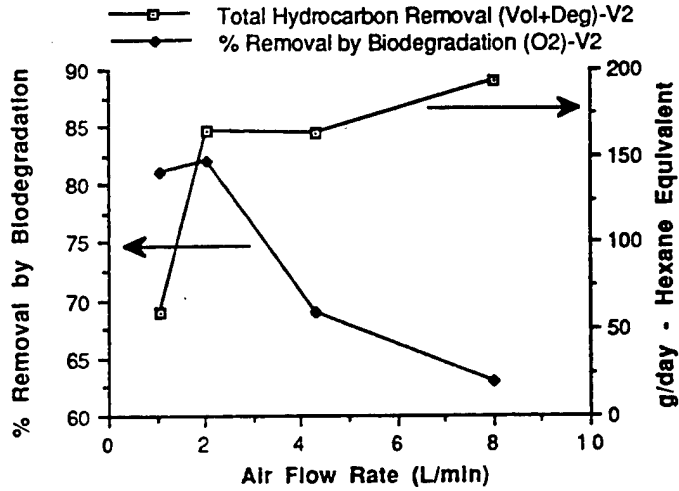


Figure 30. Comparison of Air Flow Rate Versus Total Hydrocarbon Removal and Percent of Total Removal Attributed to Biodegradation in Treatment Plot V2 (O<sub>2</sub> basis) During the Variable Air Flow Rate Study.

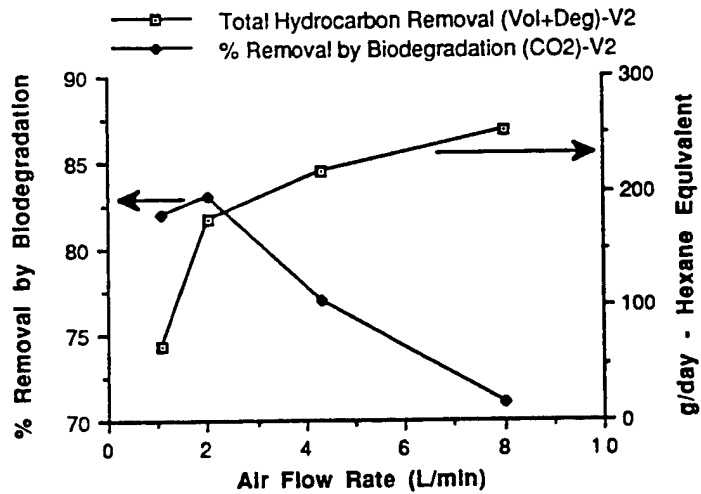


Figure 31. Comparison of Air Flow Rate Versus Total Hydrocarbon Removal and Percent of Total Removal Attributed to Biodegradation in Treatment Plot V2 (CO<sub>2</sub> basis) During the Variable Air Flow Rate Study.

Table 4 and Figures 28 through 31 reveal a tradeoff between maximizing the percentage of hydrocarbon removed by biodegradation and maximizing the overall hydrocarbon removal rate, thereby minimizing the operational time required to remediate a contaminated site. Using the data in Table 4 for Treatment Plot V1, and assuming that 100,000 grams (3,500 mg/kg) of hydrocarbons must be removed, a hypothetical case can be evaluated. If 62 percent biodegradation is desired, then 8 liters/minute (two air-void volumes per day) would be selected with an expected operational time of 571 days. However, if 85 percent biodegradation were desired, then 1 liter/minute (0.25 air-void volumes per day) would be selected with an expected operational time of 1,370 days. Although operational time is increased by a factor of 2.4, total air requirement actually decreases from 6.6 to 2.2 million liters. Optimal air flow conditions in plot V1 appear to be at 2 liters/minute (0.5 air-void volumes per day) where 82 percent biodegradation is achieved. Although 85 percent biodegradation is achieved at 1 liter/minute in plot V1, the hydrocarbon removal rate is greatly reduced. Operating at 2 liters/minute in V1, expected operation time is 820 days (1.4 times that required at 8 liters/minute) and the total air requirement is only 2.3 million liters. Operational times in this case are merely hypothetical as relationships between air flow and removal rate are applicable only over the 7-week field test period. However, similar relationships would probably exist throughout the remediation period, although the magnitude of removal rates vary widely throughout the remediation period (Figures 10 and 13).

The observed relationships among air flow rate, hydrocarbon removal rate, and percentage of removal attributed to biodegradation are plausible based on experimental observations. First, the data suggest that the system is diffusion limited (at least at flow rates greater than 1 liter/minute), resulting in higher hydrocarbon concentrations per unit volume of air extracted with decreasing air flow rates (Table 4). A diffusion-limited system is one in which diffusion of hydrocarbons into the airstream is the limiting factor in removal rate. This is illustrated in Figures 8 through 13 where higher air flow rates in Treatment Plot V2 over those in Treatment Plot V1 had little effect on the rate of hydrocarbon removal after about 15 days of venting. During the first 15-20 days of venting the system was advection limited, meaning that the hydrocarbon removal rate was limited by air

flow rate. An unexplained drop in hydrocarbon concentration occurred at an air flow rate of 1 liter/minute (Table 4). This could have been a measurement error or perhaps resulted from the fact that this was the last measurement in the test, and 7 weeks of venting simply reduced concentrations. Also, the higher hydrocarbon concentration in air at lower flow rates likely provides microbes with a carbon source that may not have been available at lower hydrocarbon concentrations. Second, lower air flow rates result in longer retention times, and since mineralization rates are relatively constant over time, as determined by in situ respiration tests in this research, the increased retention time results in increased relative hydrocarbon mineralization. Ely and Heffner (44) suggested that air flow rates higher than those required for volatilization of hydrocarbons may be optimum for biodegradation. However, this research suggests that the reverse is true, and that decreasing flow rates will increase the percent of hydrocarbon removal by biodegradation and decrease the percent of hydrocarbon removal by volatilization.

1. Eliminating Off-Gas Treatment by Increased Biodegradation and Decreased Volatilization of Spilled Jet Fuel

One of the goals of this research was to demonstrate that a fuel-contaminated site can be remediated without the need for expensive off-gas treatment. If off-gas treatment can be eliminated, operational costs for site remediation using enhanced biodegradation through soil venting are primarily associated with the costs of providing air and monitoring, and, if needed, moisture and nutrients. As shown by this research, moisture and nutrient addition may not be necessary and monitoring costs can be minimized for long-term remedial actions. If moisture and nutrients are not required, and monitoring is minimized, then operational costs are primarily controlled by the cost of providing air. As demonstrated above, the air requirement for achieving total remediation at 82 percent biodegradation is one-third that required to remediate the site at 62 percent biodegradation, even though the operational time is extended only 1.4-fold. The result is that smaller quantities of contaminated gas and hydrocarbon mass are generated, reducing the need for off-gas treatment. Therefore, even though operational time is

extended and the number of extraction wells may need to be increased, a system designed to maximize biodegradation and minimize volatilization of hydrocarbons may result in significantly lower overall operational costs and significantly lower total remediation costs.

#### D. POTENTIAL TEMPERATURE EFFECTS IN TREATMENT PLOTS V1 AND V2

As described above, hydrocarbon removal rates appear to have been unaffected by moisture and nutrient addition. This conclusion, supported by the shutdown/in situ respiration tests, is based on the similarities in hydrocarbon removal rates in Treatment Plots V1 and V2 throughout the experimental period. Although hydrocarbon removal rates in the treatment plots were similar, there was (a) a general decline in hydrocarbon removal rates from initiation of the field study, (b) a reaching of minimum values near the middle of the experimental period, and (c) a general increase in hydrocarbon removal rates through completion of the field study. This depression in total hydrocarbon removal rate, observed during the experimental period, was primarily a result of a similar depression in the fraction of total removal attributed to biodegradation (Figures 16 and 17). Since the treatment plots appeared unaffected by moisture and nutrient addition, soil temperature may be the cause of the depression in biodegradation rates. Soil temperature at this field site was related to ambient air temperature because air was continually drawn through the soil. More importantly, the moisture provided to the treatment plots affected soil temperature as the applied water temperature was a function of air temperature because this water was temporarily stored in a building at the site prior to delivery to the treatment plots.

Local ambient temperature data were obtained from a weather station located near the field site. Due to thermal lag, soil temperature at a given time is a function of earlier ambient air temperature; to help correct this, mean ambient temperature was calculated for 5, 10, 15, and 20 days prior to the time when limited soil temperatures were collected.

The moving 5-, 10-, 15-, and 20-day average ambient aboveground air temperature data are presented in Figure 32, and the 10-day moving average aboveground air temperature data are compared with measured soil temperature



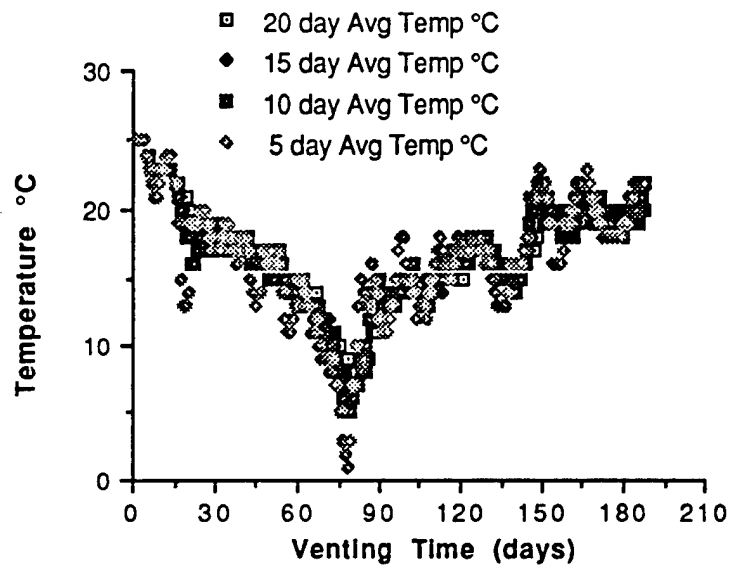


Figure 32. Moving Average of the Daily Mean Ambient Aboveground Air Temperature For 5-, 10-, 15-, and 20-Day Averaging Periods Prior to the Venting Time Shown.

in Figure 33. Soil temperature data before January 5, 1990, were not collected at the field site. Therefore, the relationship between ambient temperature and soil temperature (Figure 34) was used to estimate soil temperatures before this date (Figure 35). Figures 36 and 37 indicate that the observed depression in the hydrocarbon removal rate follows the depression in soil temperature in Treatment Plots V1 and V2. The data collected in this study indicate that soil temperature in the treatment plots is much more important in controlling hydrocarbon removal rate than moisture and nutrient addition.

#### E. OPERATIONAL MONITORING OF GAS TREATMENT PLOT V3

Hydrocarbon vapors from Treatment Plot V1 were introduced into the uncontaminated soil of off-gas Treatment Plot V3 to assess the potential for biological mineralization. For 53 days, a side-stream of the off-gas from Treatment Plot V1 was diluted prior to introduction into off-gas Treatment Plot V3. This was necessary to ensure adequate oxygen (9.5 moles oxygen/mole hexane) for biological mineralization. From Venting Days 54 to 138, off-gas Treatment Plot V3 received the entire undiluted gas stream from Treatment Plot V1 because oxygen/hydrocarbon ratios were adequate for mineralization. As described in Section III, leakage in off-gas Treatment Plot V3 resulted in higher oxygen concentrations in the discharge gas than was observed in the inlet gas stream coming from Treatment Plot V1. However, the reductions in hydrocarbon concentrations between the inlet and discharge were proportionately larger than the observed oxygen increases. This indicated that biodegradation was occurring but was being masked by leakage of near atmospheric concentrations of oxygen. The leakage and actual biodegradation rates were calculated using a mass balance equation presented in Appendix A. A high hydrocarbon/low flow rate test was conducted for 3 days (Venting Days 139 to 142) to determine if biodegradation could not only be calculated from the mass balance, but observed as a loss in oxygen between the inlet and discharge gas streams. If biodegradation was occurring, higher hydrocarbon concentrations should result in more oxygen consumption, and lower flow rates should both minimize leakage rates and increase oxygen consumption.

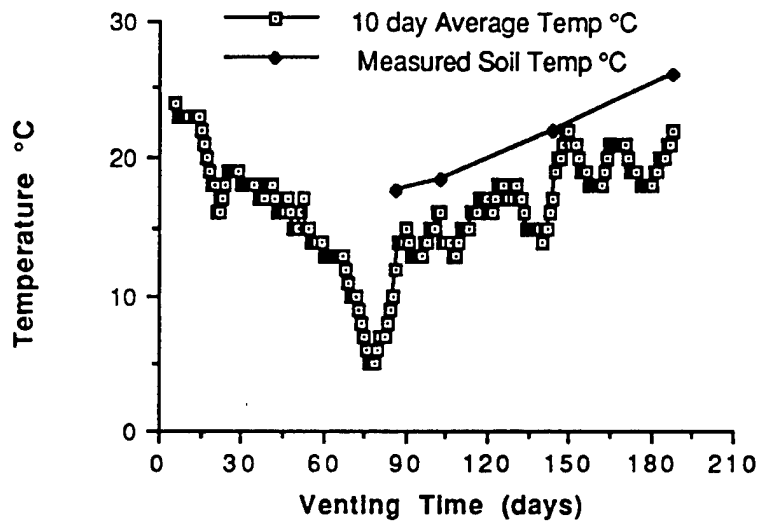


Figure 33. Comparison of the 10-Day Moving Average of the Mean Ambient Aboveground Air Temperature and Corresponding Measured Soil Temperature.

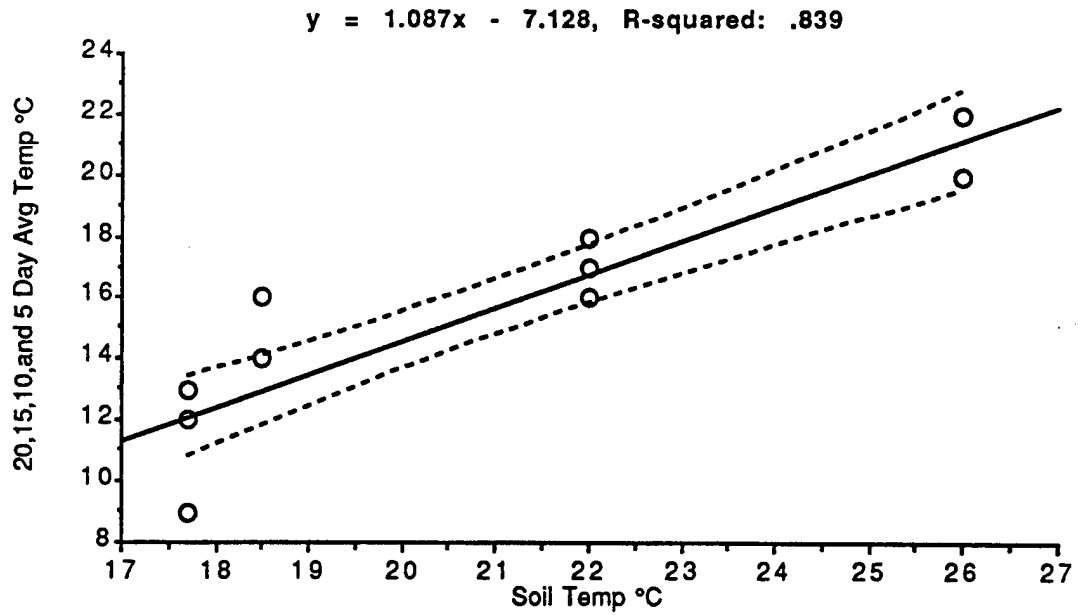


Figure 34. Regression Results and 95 Percent Confidence Interval Bands For Comparison Between 5-, 10-, 15-, and 20-Day Moving Average of the Daily Mean Ambient Aboveground Air Temperature and Measured Soil Temperature Collected During Day 86 to Day 188 of the Field Venting Study.

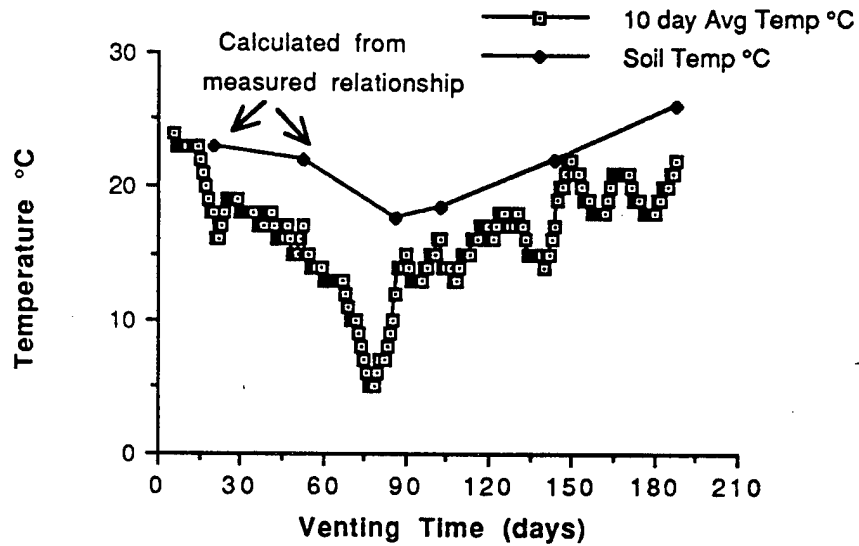


Figure 35. Comparison of 10-Day Moving Average of the Mean Ambient Aboveground Air Temperature and Corresponding Measured and Estimated Soil Temperature.

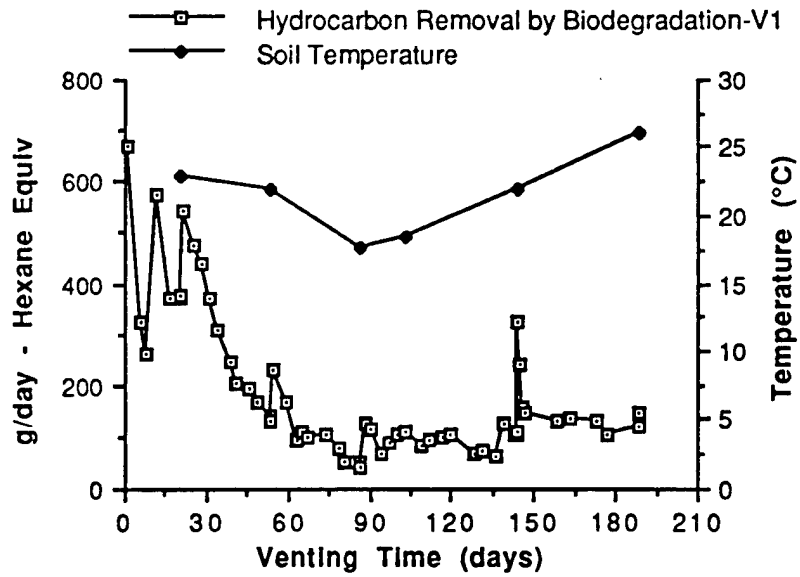


Figure 36. Comparison Of Measured and Estimated Soil Temperature and Hydrocarbon Removal Rate Attributed To Biodegradation (oxygen basis) in Treatment Plot V1.

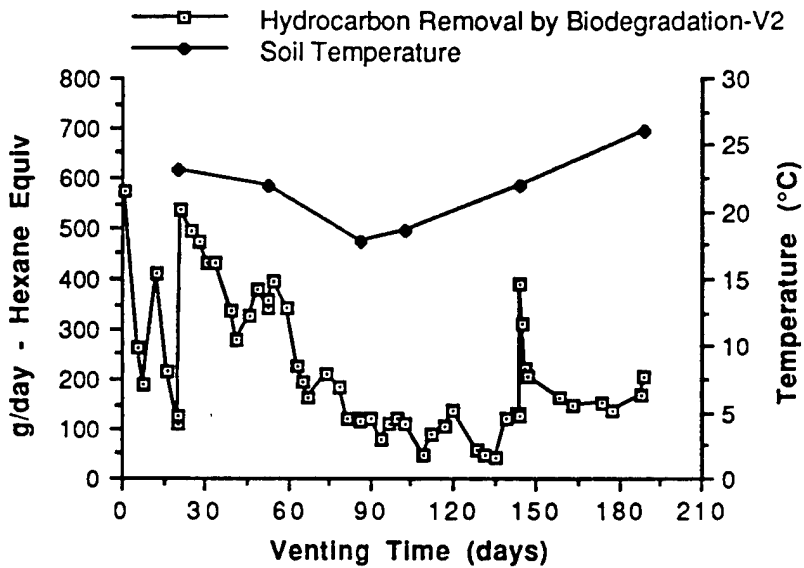


Figure 37. Comparison Of Measured And Estimated Soil Temperature and Hydrocarbon Removal Rate Attributed To Biodegradation (oxygen basis) In Treatment Plot V2.

Air-sparged JP-4 and dilution air were used to produce an inlet hydrocarbon concentration of approximately 7,900 ppm at an oxygen concentration of 20.4 percent. The system stabilized after approximately 24 hours and discharge gas (effluent from V3) contained approximately 900 ppm hydrocarbons and 17.5 percent oxygen. Stoichiometrically, the observed decrease in hydrocarbon concentrations should have resulted in a decrease of 6.6 percent oxygen if no leakage had occurred. Although the observed oxygen consumption was only 2.9 percent, this brief test was successful in that biodegradation of off-gas was not only calculated but observed. Following the high hydrocarbon concentration test, off-gas Treatment Plot V3 was operated by allowing atmospheric air to purge the plot through the end of the field test (Venting Days 143 through 184). Upon introduction of atmospheric air, total hydrocarbons in the discharge air stream dropped to 2.2 ppm within 24 hours. Carbon dioxide concentration in V3 remained elevated (approximately 1 percent) above Background Plot V4 for a period of approximately 20 days. By the end of the field study, total hydrocarbons and carbon dioxide in plots V3 and V4 discharge gases were essentially identical. This indicates that no significant accumulation of hydrocarbons occurred in V3.

Figure 38 compares cumulative hydrocarbons injected into and discharged from off-gas Treatment Plot V3. Summarized data based on the mass balance presented in Appendix A are located in Appendix B. Of the total hydrocarbons passing through Treatment Plot V3, 41 percent were biodegraded and 59 percent passed through untreated. However, the percentages of injected hydrocarbon vapors degraded in V3 varied widely and were dependent on air flow rate, hydrocarbon loading rate, and acclimation over time of the soil microbes to the hydrocarbon vapors.

Figure 39 illustrates that oxygen consumption rate constants ( $k$ ) (see Appendix B), calculated from the mass balance (Appendix A), are relatively consistent (Mean = 1.56, SD  $\pm$  0.91 O<sub>2</sub>/day) in off-gas Treatment Plot V3, and although the data are widely scattered ( $r^2=0.217$ ), there was a statistically significant (95 percent confidence) increase in oxygen consumption over the field test period. The increase in oxygen consumption rate constants ( $k$ ) over time may indicate an acclimation of soil microbes to the hydrocarbon vapor. Calculated rate constants in off-gas Treatment Plot V3 were significantly

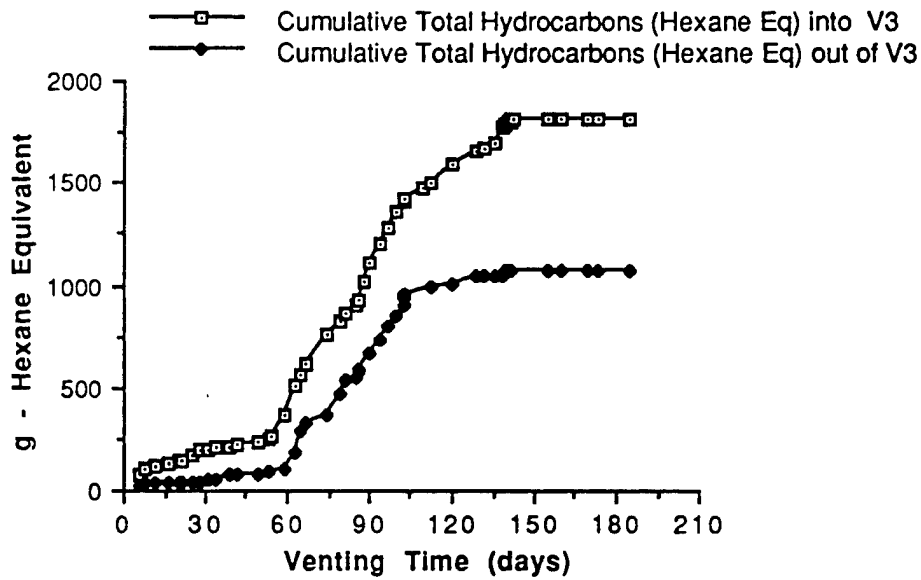


Figure 38. Cumulative Hydrocarbons Injected Into and Discharged From Off-Gas Treatment Plot V3 During the Field Study.

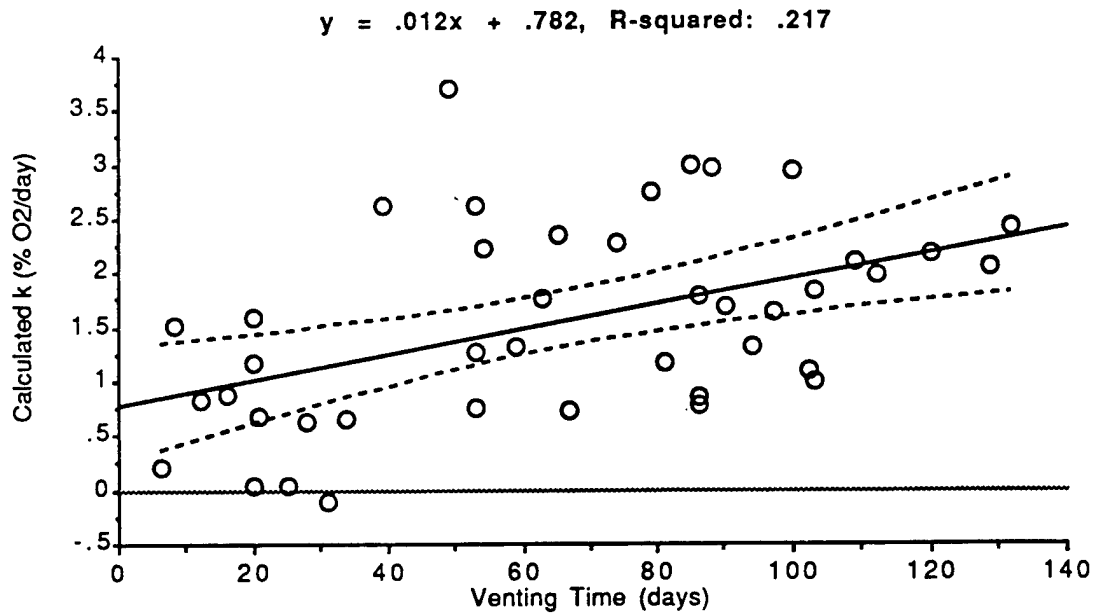


Figure 39. Oxygen Consumption Rate Constants Calculated From a Mass Balance In Off-Gas Treatment Plot V3 Determined Throughout the Field Study.

greater than those observed in the background plot and more closely approached the rate constant values observed in the treatment plots during shutdown/in situ respiration tests. The relative consistency of rate constant values in off-gas Treatment Plot V3 indicates that the percentage of hydrocarbon vapor biodegraded in clean soil is, at least partially, a function of retention time/flow rate. A statistically significant relationship (95 percent confidence) between flow rate and the percent of injected hydrocarbon vapor biodegraded is shown in Figure 40. Although the relationship between air flow rate and percentage of biodegradation is significant (Figure 40), the percentage of biodegradation is relatively widespread for given flow rates.

This occurred because of the wide range of hydrocarbon concentrations injected into off-gas Treatment Plot V3 throughout the field test. Therefore, the percentage of biodegradation was not only associated with air flow rate (retention time), but also, at 95 percent confidence, with hydrocarbon loading rate (Figure 41). Average off-gas biodegradation rate (Appendix B) was 1.34 (SD  $\pm$  0.83) mg/(kg day), or 1.93 (SD  $\pm$  1.2) grams/(m<sup>3</sup> day). Hydrocarbon biodegradation rates in units of mg/(kg day) and grams/(m<sup>3</sup> day), respectively, were positively correlated (95 percent confidence) with total hydrocarbon loading, as shown in Figures 42 and 43. Some loss to dissolution to pore water may have occurred. Using the average water flow rate of 13 mL/minute and the average dissolved hydrocarbon concentration found in V3 (5 mg/liter), a hydrocarbon removal rate of 0.02 mg/(kg day) can be estimated; this is well below the calculated biodegradation rate.

As previously discussed, sorption of the hydrocarbons was not a significant sink. This conclusion is supported by the soils analysis; the average hydrocarbon concentration in the upper 1.2 meters (4 feet) of V3 was 100 mg/kg before and 29 mg/kg after treatment. During the duration of the test of 142 days, it was calculated that approximately 190 mg/kg of injected hydrocarbons were biodegraded. Had sorption been a significant removal mechanism, soil hydrocarbon concentrations would very likely have increased, not decreased.

During 188 days of venting at Treatment Plot V1, 25,800 grams of hydrocarbon were removed from the soil through volatilization. Assuming an average off-gas biodegradation rate of 1.93 grams/(m<sup>3</sup> day), 71 m<sup>3</sup> of uncontaminated soil would be required to biodegrade completely the off-gas



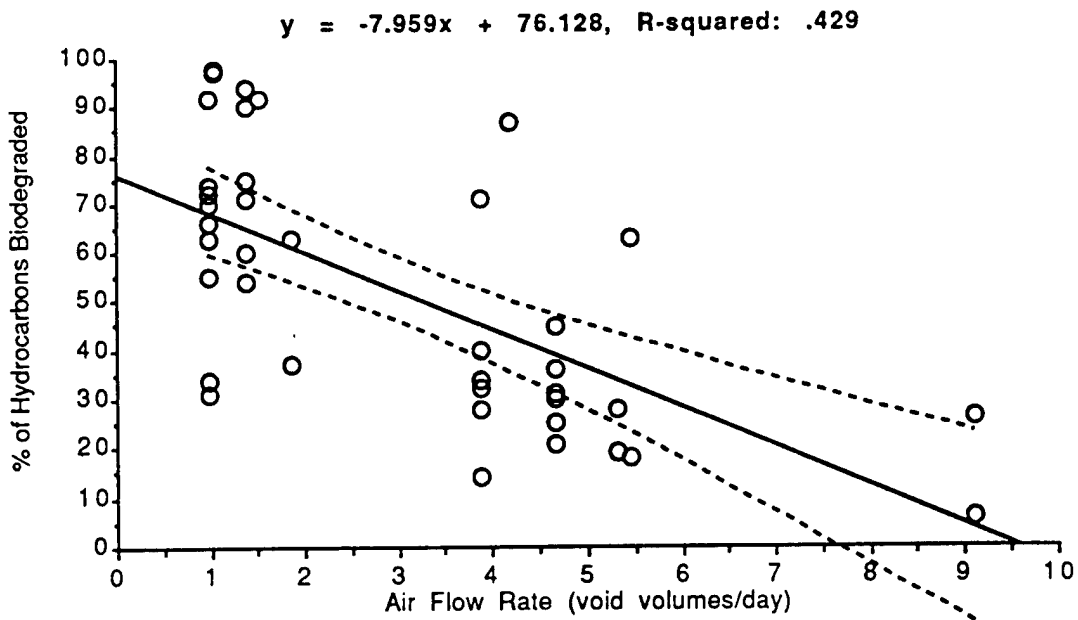


Figure 40. Correlation and 95 Percent Confidence Band Between Air Flow Rate and the Percent of Hydrocarbon Vapor Degraded in the Uncontaminated Soil of Off-Gas Treatment Plot V3.

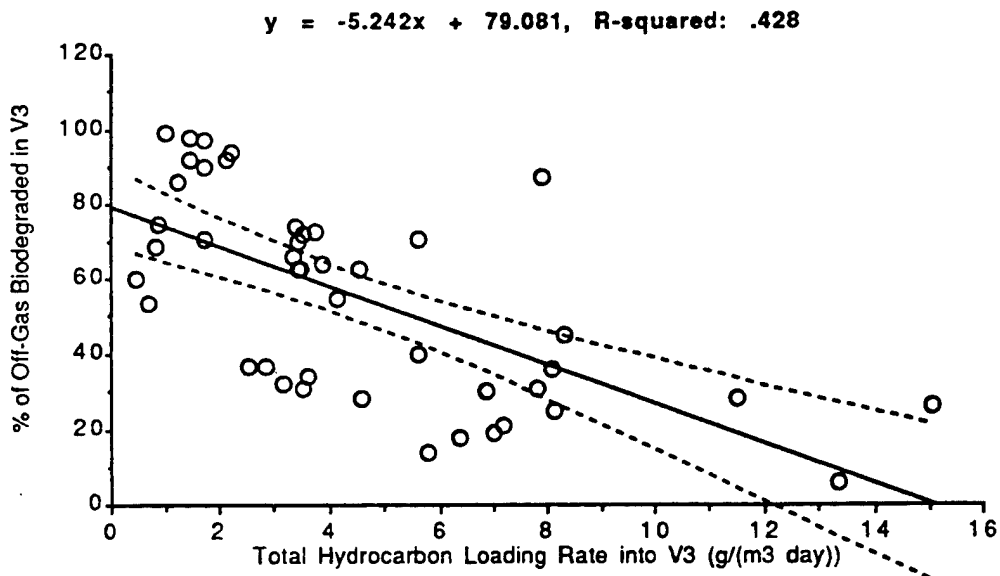


Figure 41. Correlation And 95 Percent Confidence Band Between Hydrocarbon Loading Rate and the Percent of Hydrocarbon Vapor Degraded in the Uncontaminated Soil of Off-Gas Treatment Plot V3.

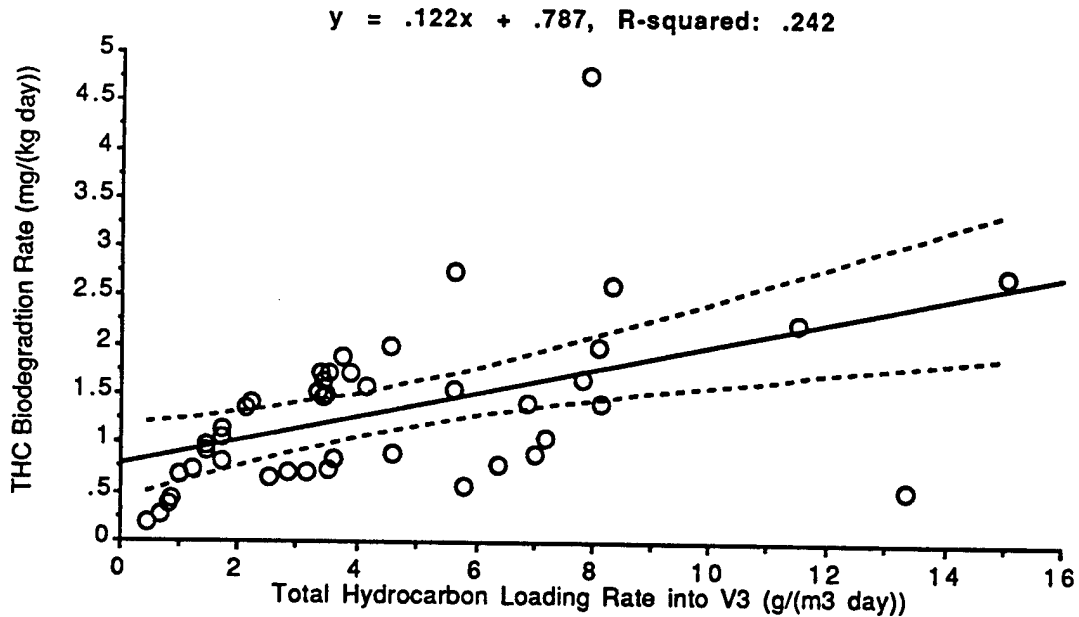


Figure 42. Correlation and 95 Percent Confidence Band Between Hydrocarbon Loading Rate and Hydrocarbon Biodegradation Rate mg/(kg day) in the Uncontaminated Soil of Off-Gas Treatment Plot V3.

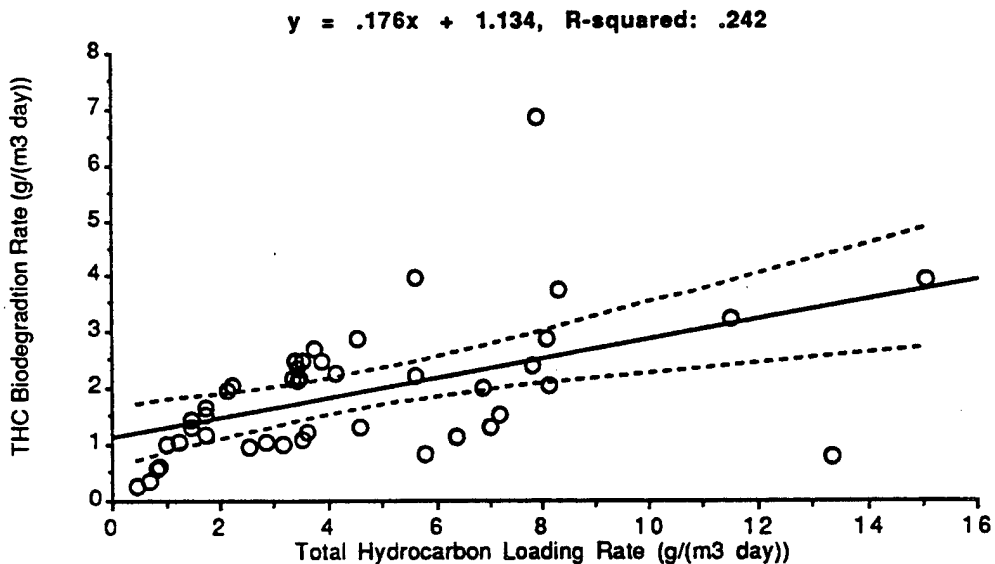


Figure 43. Correlation and 95 Percent Confidence Band Between Hydrocarbon Loading Rate and Hydrocarbon Biodegradation Rate g/(m<sup>3</sup> day) in the Uncontaminated Soil of Off-Gas Treatment Plot V3.

from the 20 m<sup>3</sup> of contaminated soil in Treatment Plot V1. Therefore, a soil volume ratio of approximately 3.6 to 1, uncontaminated to contaminated soil, would be required to biodegrade completely the off-gas from a bioventing system operated similarly to this field project. However, if air flow rates in contaminated soil were designed to maximize biodegradation and minimize volatilization, the ratio of uncontaminated to contaminated soil required would be proportionally less. The data presented indicate that uncontaminated soil at this test site can be successfully used as a biological reactor for the mineralization of hydrocarbon vapors (off-gas) generated during remediation of fuel-contaminated soil using the enhanced biodegradation through soil venting technology investigated in this field study.

#### F. IN SITU RESPIRATION TESTS

In situ respiration Tests 1 through 5 were conducted October 24-26 and November 28 through December 1, 1989; January 3-8, March 3-11, and April 24-26, 1990, respectively. In addition, two limited in situ respiration tests, Tests 3A and 4A, were conducted from January 25-26 and March 9-12, 1990. The in situ respiration tests were designed to determine the order and rate of hydrocarbon biodegradation kinetics under varying conditions of moisture and nutrient addition as described in Table 2. Treatment Plot V2 received moisture and nutrients throughout the experimental period and therefore serves as a control for kinetic changes due to soil temperature and other factors not related to moisture and nutrients. The in situ respiration tests were conducted by (1) shutting down the air delivery system to both the treatment and background plots, and (2) by measuring the oxygen consumption and carbon dioxide production over time. One percent oxygen concentration was the minimum that could be accurately measured. Data are presented chronologically in Appendices B and C. Figures 44, 45, and 46 are plots of respiration data for Vapor-Monitoring Well V1-1B and are typical of the plots for other vapor monitoring wells. Figures 44 and 45 illustrate that oxygen consumption follows zero rather than first order kinetics for all tests at Vapor-Monitoring Well V1-1B.

Based on the statistical analysis presented in Table 5, respiration in Treatment Plot V1 was best modeled by zero order kinetics at all locations except V1-1A and V1-2A. At these locations, first order plots achieved

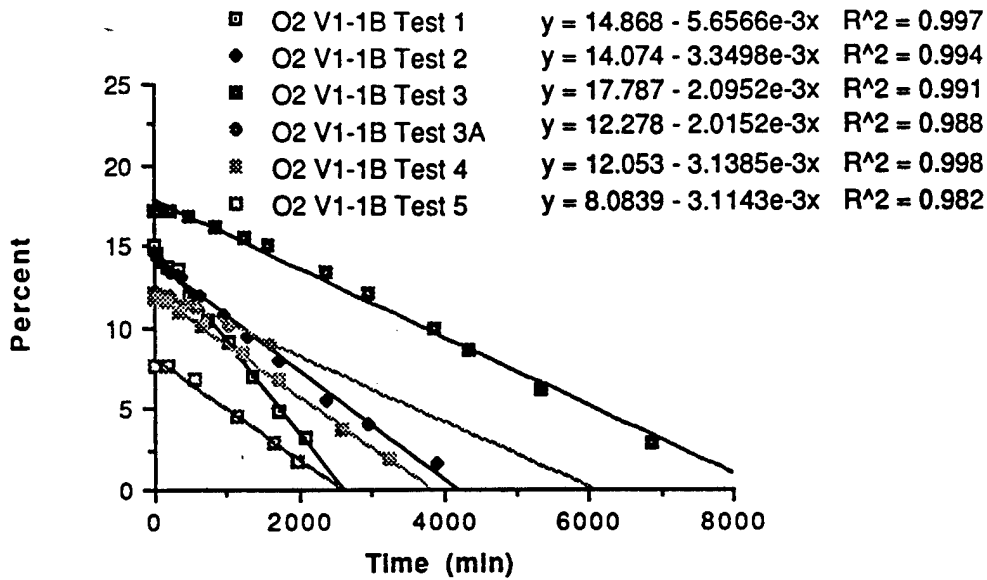


Figure 44. Zero Order Plot of Oxygen Consumption in Vapor Monitoring Well V1-1B for Respiration Tests 1 Through 5.

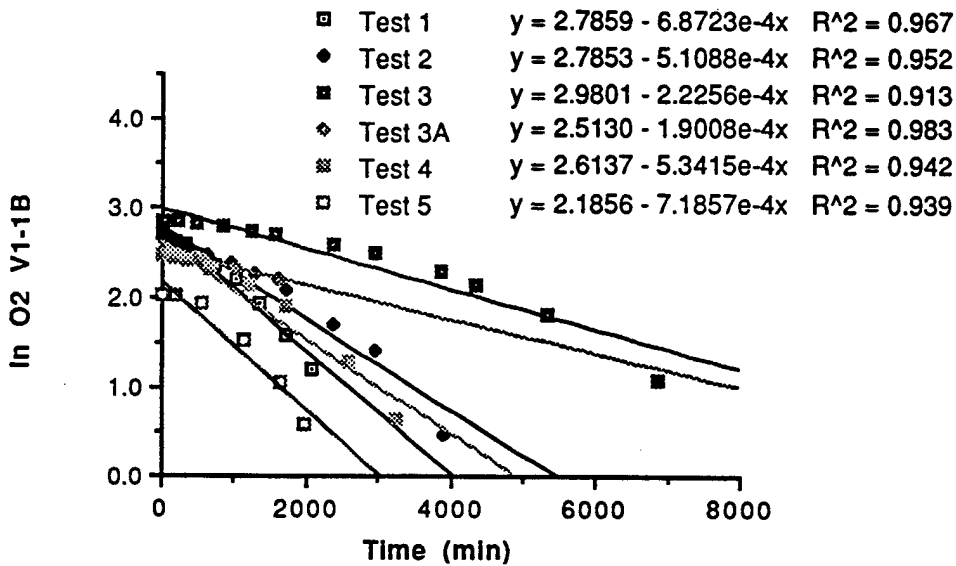


Figure 45. First Order Plot of Oxygen Consumption in Vapor Monitoring Well V1-1B for Respiration Tests 1 Through 5

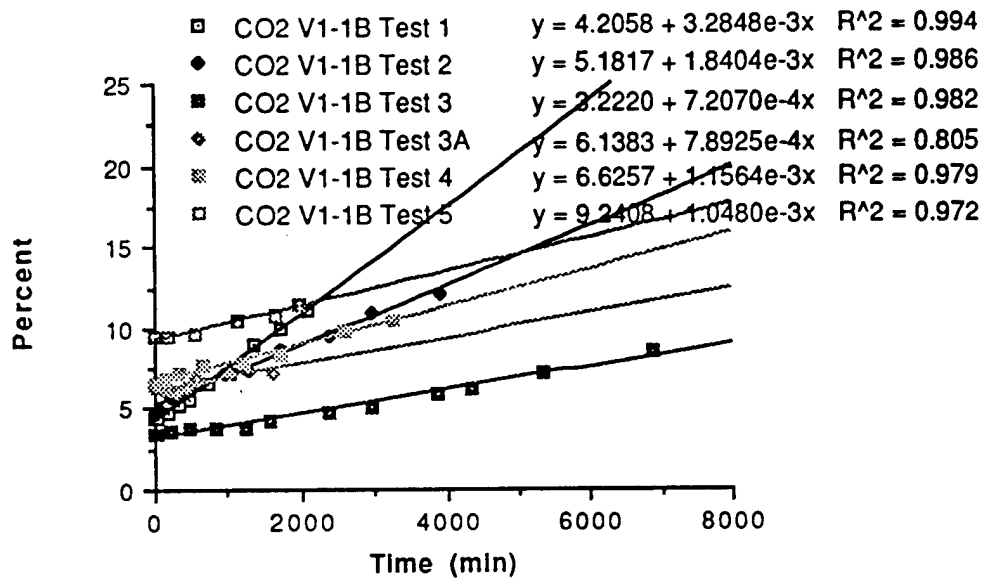


Figure 46. Zero Order Plot of Carbon Dioxide Production in Vapor Monitoring Well V1-1B for Respiration Tests 1 Through 5.

TABLE 5. SUMMARY OF CORRELATION COEFFICIENTS (R-squared) AND RATE CONSTANTS (k) FOR TREATMENT, OFF-GAS, AND BACKGROUND PLOTS

Vapor Well Location	Test No.	Zero Order R-squared	Zero Order k (%/min)	First Order R-squared	First Order k (1/min)
V1-1A	1	0.975	0.00874	0.991	0.00127
	2	0.925	0.00329	0.991	0.000488
	3	0.996	0.00256	0.947	0.000279
	4	0.986	0.00558	0.997	0.000698
	5	0.992	0.00568	0.973	0.00153
V1-1B	1	0.997	0.00566	0.967	0.000687
	2	0.994	0.00335	0.952	0.000511
	3	0.991	0.0021	0.913	0.000223
	3A	0.998	0.00202	0.983	0.00019
	4	0.998	0.00314	0.942	0.000534
V1-1C	1	0.982	0.00311	0.939	0.000719
	2	0.994	0.0048	0.89	0.000765
	3	0.994	0.00304	0.959	0.00043
	4	0.99	0.00203	0.917	0.000204
	5	0.987	0.00273	0.922	0.000463
V1-2A	1	0.968	0.00283	0.924	0.000612
	2	0.934	0.0115	0.993	0.00149
	3	0.878	0.0037	0.984	0.000529
	4	0.99	0.00249	0.927	0.000327
	5	0.976	0.00514	0.971	0.00072
V1-2B	1	0.975	0.00961	0.994	0.00159
	2	0.996	0.00618	0.935	0.00086
	3	0.99	0.00367	0.964	0.000512
	3A	0.998	0.00219	0.918	0.000233
	4	0.963	0.00306	0.975	0.00023
V1-2C	1	1	0.00392	0.953	0.000533
	2	0.999	0.00542	0.942	0.00102
	3	0.964	0.00411	0.906	0.000555
	4	0.973	0.00304	0.919	0.000469
	5	0.983	0.00201	0.889	0.000218
V1-3A	1	0.993	0.00343	0.948	0.000449
	2	0.99	0.00402	0.928	0.00071
	3	0.989	0.000805	0.911	0.00111
	4	0.97	0.00305	0.954	0.000289
	5	0.984	0.00231	0.976	0.000223
V1-3B	1	0.963	0.00456	0.991	0.000557
	2	0.972	0.00616	0.955	0.00113
	3	0.995	0.0073	0.935	0.001
	3A	0.983	0.00372	0.985	0.00046
	4	1	0.00198	0.963	0.000183
	5	0.976	0.00266	0.98	0.000203
	4	1	0.00333	0.966	0.00042
	5	0.993	0.00405	0.96	0.000657

TABLE 5. SUMMARY OF CORRELATION COEFFICIENTS (R-squared) AND RATE CONSTANTS (k) FOR TREATMENT, OFF-GAS, AND BACKGROUND PLOTS (CONTINUED)

Vapor Well Location	Test No.	Zero Order R-squared	Zero Order k (%/min)	First Order R-squared	First Order k (1/min)
V1-3C	1	0.989	0.00603	0.937	0.000896
	2	0.984	0.00368	0.959	0.000583
	3	0.998	0.00192	0.948	0.000188
	4	0.987	0.00287	0.939	0.000391
	5	0.979	0.00356	0.937	0.000565
V1-average of all regressions	1		0.00613		0.000959
	2		0.00339		0.000475
	3		0.00218		0.000231
	4		0.00386		0.000529
	5		0.00494		0.000948
V2-1A	1	0.897	0.00612	0.841	0.000641
	2	0.791	0.00341	0.871	0.000303
	3	0.987	0.00269	0.971	0.000153
	4	0.98	0.00378	0.997	0.000292
	5	0.975	0.00519	0.983	0.000517
V2-1B	1	0.952	0.00546	0.991	0.000754
	2	0.944	0.00592	0.991	0.00101
	3	0.99	0.00498	0.997	0.00039
	3A	0.971	0.00473	0.995	0.000623
	4	0.956	0.00397	0.995	0.000711
V2-1C	5	0.952	0.00609	1	0.00136
	1	0.983	0.00418	0.987	0.000541
	2	0.985	0.00493	0.943	0.000979
	3	0.998	0.00339	0.993	0.000224
	4	0.996	0.00337	0.955	0.000514
V2-2A	5	0.985	0.00327	0.938	0.00105
	1	0.837	0.00491	0.766	0.000405
	2	0.961	0.0039	0.996	0.000339
	3	0.99	0.00254	0.979	0.000141
	4	0.999	0.00444	0.975	0.000347
V2-2B	5	0.989	0.00572	0.992	0.0005
	1	0.988	0.00637	0.978	0.00078
	2	0.976	0.00394	0.932	0.0008
	3	0.998	0.00358	0.986	0.000232
	3A	0.975	0.00318	0.953	0.000476
V2-2C	4	0.999	0.0052	0.942	0.000674
	5	0.933	0.00459	0.912	0.000995
	1	0.973	0.00584	0.97	0.000932
	2	0.53	0.0016	0.653	0.000723
	3	0.994	0.00346	0.98	0.000234
	4	0.998	0.00479	0.886	0.000915
	5	0.645	0.00227	0.716	0.00104

TABLE 5. SUMMARY OF CORRELATION COEFFICIENTS (R-squared) AND RATE CONSTANTS (k) FOR TREATMENT, OFF-GAS, AND BACKGROUND PLOTS (CONCLUDED)

Vapor Well Location	Test No.	Zero Order R-squared	Zero Order k (%/min)	First Order R-squared	First Order k (1/min)
V2-3A	1	0.941	0.00645	0.875	0.000586
	2	0.905	0.00387	0.971	0.000394
	3	0.995	0.00322	0.992	0.00019
	4	0.976	0.00475	0.991	0.000459
	5	0.961	0.00538	0.996	0.000507
V2-3B	1	0.978	0.00614	0.979	0.000844
	2	0.947	0.00536	0.987	0.00107
	3	0.996	0.00328	0.995	0.000208
	3A	0.991	0.00386	0.995	0.000431
	4	0.995	0.00386	0.972	0.000538
V2-3C	5	0.984	0.00436	0.979	0.000726
	1	0.997	0.00604	0.937	0.00123
	2	0.968	0.00611	0.858	0.0014
	3	0.999	0.00344	0.995	0.000241
	4	0.997	0.00392	0.945	0.00063
V2 - average of all regressions	5	0.903	0.00362	0.877	0.000826
	1		0.00572		0.000746
	2		0.00434		0.000780
	3		0.00340		0.000224
	4		0.00423		0.000564
*V3-average of A,B,C locations	5		0.00450		0.000836
	1	0.825	0.000289	0.83	0.0000163
	3	0.982	0.000466	0.985	0.000029
	4	0.743	0.000225	0.722	0.0000152
	4A	0.99	0.000715	0.989	0.0000459
*V4-average of A,B,C locations	5	0.958	0.000389	0.961	0.000021
	1	0.787	0.000225	0.79	0.0000119
	3	0.982	0.000207	0.985	0.0000101
	4	0.962	0.000279	0.968	0.0000143
	5	0.003	0.0000078	0.011	0.00000078

\* Measurements at the A, B, and C locations were nearly identical. Therefore, averages are representative of all locations.



higher coefficients of determination on the majority of tests. Respiration in V2 was also most consistently modeled by zero order kinetics at most locations and during most tests. However, in seven of the nine locations, first order kinetics better described the data during at least one test (Table 5). Only location V2-1B was consistently better described by first order kinetics. It was concluded that overall respiration for Treatment Plots V1 and V2 was most consistently modeled by zero order kinetics during all in situ respiration tests.

Both zero- and first-order kinetic models were statistically significant and either could have been used to model and compare kinetics under varying moisture and nutrient conditions. For simplicity, zero order kinetics were selected as the basis for comparison.

Oxygen and carbon dioxide concentrations, measured in the vapor monitoring wells prior to initiating the in situ respiration tests, were highly variable. Regardless of initial concentration, however, oxygen consumption and carbon dioxide production rates were relatively consistent. For this reason, the data were normalized by dividing oxygen concentration data measured in each vapor monitoring well by the initial oxygen concentration at each location. A regression of the normalized data versus time for each plot and each respiration test yielded a normalized zero order rate constant that, when multiplied by the initial average oxygen concentration in the plot, yielded the actual zero order rate constant ( $k =$  percent/minute).

The normalized regressions and 95 percent confidence interval bands for Treatment Plots V1 and V2 are shown in Figures 47 and 48, respectively, for respiration Test 4. Both normalized and actual rate constant data are summarized in Table 6. Figures 49 and 50 graphically present the rate constant data given in Table 6.

In Treatment Plot V1, the rate constant showed a significant drop between Test 1 and Test 2, and between Test 2 and Test 3. The rate constant significantly increased between Test 3 and Test 4 in Treatment Plot V1, but there was not a significant increase between Test 4 and Test 5.

Since moisture was added to Treatment Plot V1 after Test 2 and nutrients were added after Test 4, their addition would seem to be of no benefit and even detrimental in the case of moisture addition. In Treatment Plot V2,

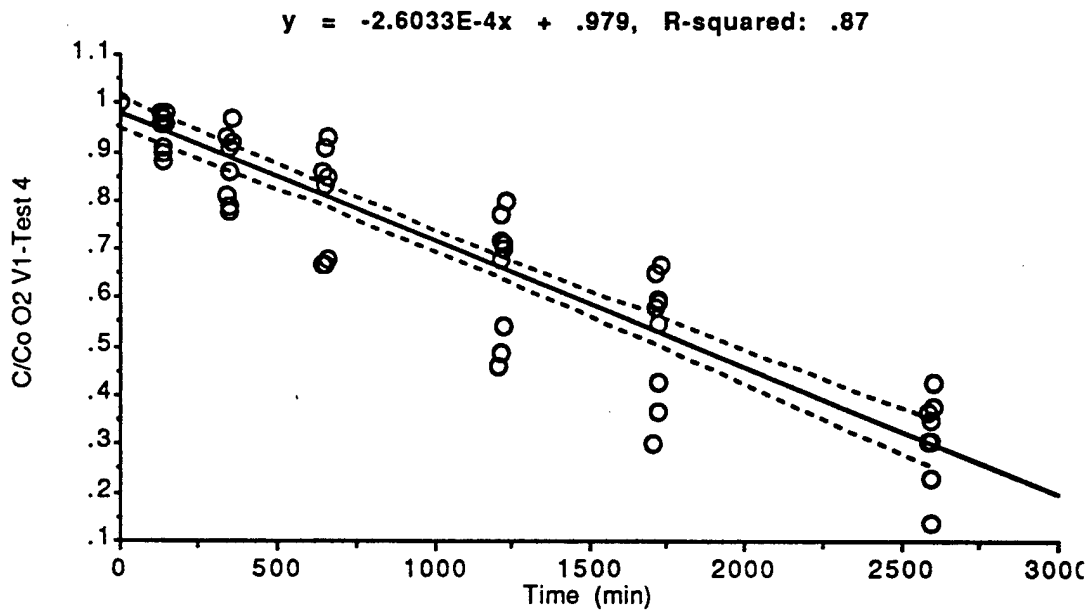


Figure 47. Regression of Normalized Data and 95 Percent Confidence Band for Treatment Plot V1 and Respiration Test 4.

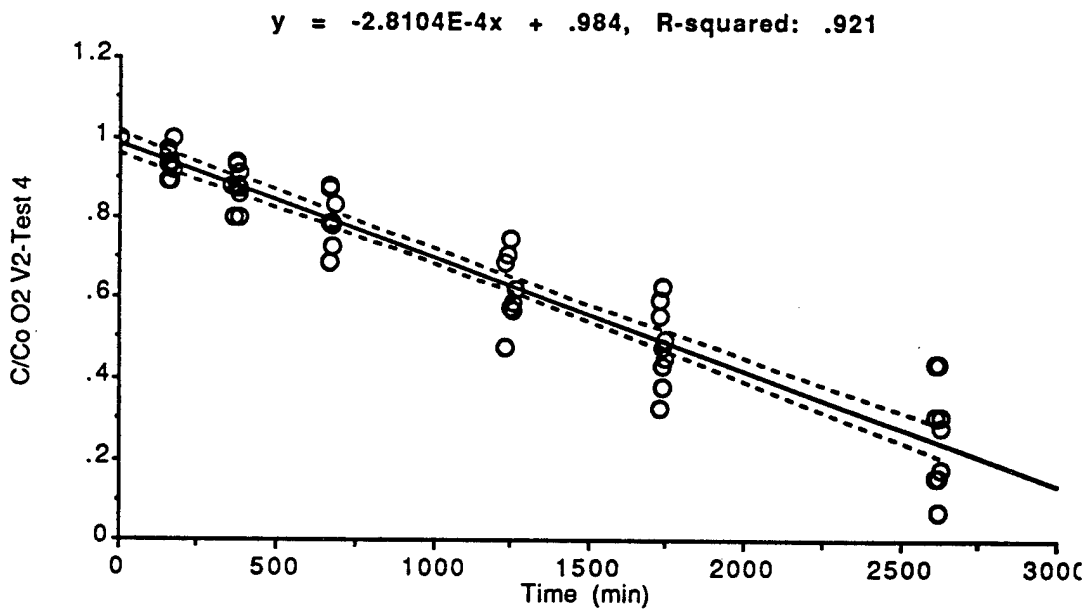


Figure 48. Regression of Normalized Data and 95 Percent Confidence Band for Treatment Plot V2 and Respiration Test 4.

TABLE 6. SUMMARY OF NORMALIZED AND ACTUAL ZERO ORDER OXYGEN CONSUMPTION RATES AND 95 PERCENT CONFIDENCE INTERVALS

Location	Initial Avg O <sub>2</sub> (%)	Min 95% Norm K (%O <sub>2</sub> /min)	Avg Norm K (%O <sub>2</sub> /min)	Max 95% Norm K (%O <sub>2</sub> /min)	Minimum 95% K (%O <sub>2</sub> /min)	Average K (%O <sub>2</sub> /min)	Maximum 95% K (%O <sub>2</sub> /min)
<b>Test 1</b>							
V1	15.4	.000356	.000396	.000435	.005487	.006095	.006702
V2	15.8	.000304	.000343	.000382	.004797	.005413	.006031
V3	18.2	.000010	.000015	.000020	.000187	.000277	.000367
V4	19.2	.000009	.000013	.000017	.000180	.000251	.000322
<b>Test 2</b>							
V1	15.3	.000208	.000223	.000238	.003185	.003416	.003648
V2	13.7	.000312	.000363	.000413	.004280	.004969	.005659
V3							
V4							
<b>Test 3</b>							
V1	17.6	.000116	.000122	.000127	.002049	.002142	.002235
V2	19.7	.000158	.000173	.000189	.003103	.003416	.003729
V3	17.4	.000028	.000029	.000031	.000480	.000510	.000541
V4	20.6	.000009	.000010	.000011	.000186	.000205	.000225
<b>Test 4</b>							
V1	14.2	.000234	.000260	.000286	.003327	.003696	.004065
V2	16.2	.000260	.000281	.000302	.004212	.004552	.004894
V3	14.3	.000007	.000015	.000023	.000106	.000214	.000322
V4	20.3	.000012	.000014	.000015	.000240	.000276	.000313
V3 (4A)	17.2	.000040	.000042	.000045	.000685	.000727	.000769
<b>Test 5</b>							
V1	10.3	.000347	.000397	.000448	.003576	.004093	.004611
V2	11.6	.000363	.000439	.000515	.004215	.005096	.005979
V3	19.2	.000017	.000020	.000023	.000331	.000389	.000446
V4	19.4	-.000006	.000004	.000007	-.000111	.000008	.000126

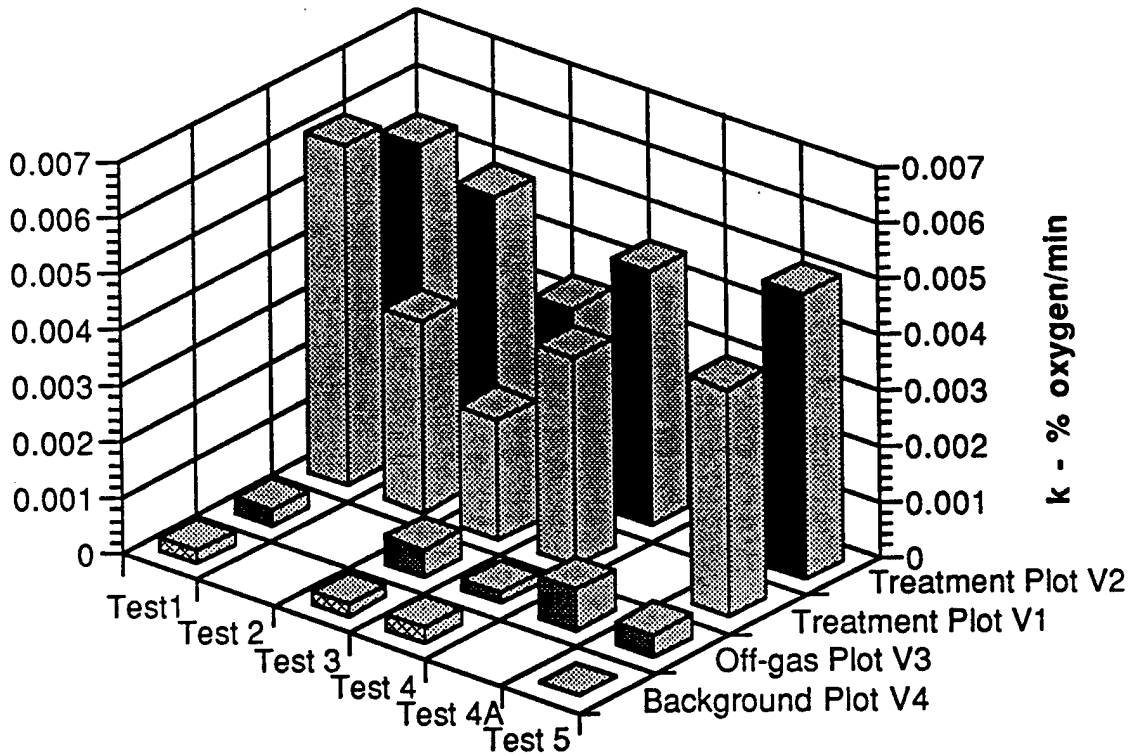


Figure 49. Average Zero Order Rate Constants Determined by In Situ Respiration Tests.

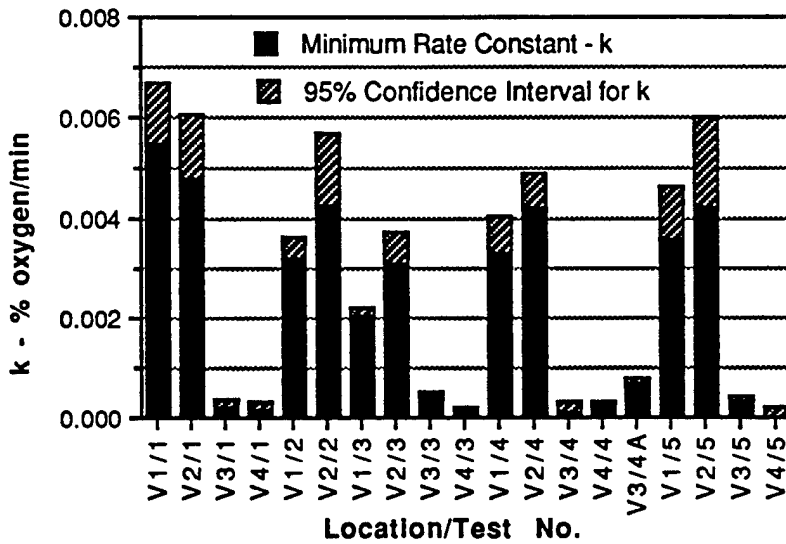


Figure 50. Minimum Zero Order Rate Constants And Range of 95 Percent Confidence Intervals Determined by In Situ Respiration Tests.

there was a statistically significant drop in the rate constant from Test 2 to Test 3 and a statistically significant increase in the rate constant between Test 3 and Test 4. Although a depression appears in the rate constant data (Figures 49 and 50), there were no other statistically significant differences in Treatment Plot V2 rate constants.

Statistically significant differences in the respiration rates between Treatment Plots V1 and V2 and the Background Plot V4 on all tests, and between off-gas Treatment Plot V3 and Background Plot V4 on Tests 3, 4A, and 5 were found. This relationship is illustrated in Figures 49 and 50. Based on the data presented, the biodegradation of jet fuel in contaminated soil and biodegradation of hydrocarbon off-gas resulted in statistically significant increases in respiration over that observed in uncontaminated soil.

#### G. STATIC VERSUS DYNAMIC RATE CONSTANTS IN TREATMENT PLOTS V1 AND V2

Static rate constants were determined during shutdown of the air delivery system. Theoretically, these rate constants should also accurately model the operating system. Dynamic rate constants require air retention time data that are directly proportional to air-filled porosity within the test plots. Air-filled porosity was estimated by assuming a bulk density, calculating total porosity, and applying moisture content data to determine air-filled porosity.

Physical analysis of the soil texture classified all samples as sand and a bulk density of 1440 kg/m<sup>3</sup> (90 pounds/ft<sup>3</sup>) was assumed. Moisture content data were determined prior to operation, prior to moisture addition at Treatment Plot V1, and at the conclusion of the project after 7 months of operation. In situ respiration Tests 1 and 2 were conducted prior to moisture addition at Treatment Plot V1, whereas Treatment Plot V2 had received moisture from the beginning of the project (Table 2). Therefore, soil moisture data collected December 1, 1989, provided the best estimate of moisture content both before and after moisture addition. It was assumed that, following moisture addition to Treatment Plot V1, the moisture contents in Treatment Plots V1 and V2 were equal.

Moisture content on December 1, 1989, was determined from samples collected at 30-, 60-, 90-, and 120-cm (1-, 2-, 3-, and 4-foot) intervals. Average moisture content was 6.48 percent (SD = 2.14 percent) by weight and 9.78 percent (SD = 4.11 percent) by weight in Treatment Plots V1 and V2, respectively. The samples collected at 150 cm (5 feet) were disregarded because they appeared to be saturated and the accuracy of these analyses was questionable. In addition, it was believed that the 120-cm (4-foot) sample better represented the moisture content in the 120-150 cm (4-5 foot) interval.

Air flow rates through all test plots were measured with calibrated rotameters. The rotameters were initially calibrated in Battelle's instrument laboratory, then periodically calibrated in the field using a bubble meter. Flow rates were not totally stable prior to the first three in situ respiration tests and this variability alone could lead to false comparisons of static and dynamic rates. A sensitivity analysis comparing dynamic and static rate constants, and considering possible variability in air flow rate, water level, and moisture content, is summarized in Tables 7 and 8 for Treatment Plots V1 and V2, respectively.

Comparing the dynamic  $k$  values in Tables 7 and 8 with the confidence intervals for static  $k$  values in Table 6 indicates that over the range of possible dynamic  $k$  values there is generally no significant difference in static and dynamic rate constants in either Treatment Plots V1 or V2 for Tests 1 through 5. Dynamic  $k$  values for Test 2 are only slightly out of the 95 percent confidence range for V1, but there is a rather large difference in V2. Dynamic  $k$  values for Test 5 are out of the 95 percent confidence range for Treatment Plots V1 and V2. Assuming accurate air flow and soil moisture data, the observed disparity between static and dynamic  $k$  values is likely to be related to the difference between initial average oxygen concentrations, measured in the vapor-monitoring probes during shutdown/in situ respiration tests, and the discharge oxygen concentration, measured just prior to the shutdown/in situ respiration tests, used to calculate dynamic rate constants.

Differences between the average oxygen concentration in vapor-monitoring probes and the oxygen concentration in the discharge airstreams are an indication of nonuniform flow through the treatment plots. Since static  $k$  values were determined by equally weighting data from each monitoring well (Figures 47 and 48), it follows that nonuniform flow through the treatment

TABLE 7. COMPARISON OF STATIC AND DYNAMIC k (% oxygen/min) FOR TREATMENT PLOT V1

Test No.	Water Depth cm (ft)	Treatment Volume m3 (ft3)	Moisture (%)	Air Filled Porosity	Rotameter Reading(Cal)	Air Flow (L/min)	Retention Time (min)	Discharge O2 (%)	Dynamic k (% O2/min)	Static k (% O2/min)	Difference (%)	Initial Average O2 (%)
1	268 (8.78)	23.5 (829)	6.5	0.36	14.5(12/1)	11.89	704	13	0.01123	0.00610	46	15.4
	268 (8.78)	23.5 (829)	6.5	0.36	11(12/1)	7.53	1,111	13	0.00711	0.00610	14	
	268 (8.78)	23.5 (829)	2.2	0.42	14.5(12/1)	11.89	826	13	0.00956	0.00610	36	
	268 (8.78)	23.5 (829)	2.2	0.42	11(12/1)	7.53	1,304	13	0.00606	0.00610	-1	
	268 (8.78)	23.5 (829)	10.8	0.29	14.5(12/1)	11.89	581	13	0.01359	0.00610	55	
2	268 (8.78)	23.5 (829)	10.8	0.29	11(12/1)	7.53	918	13	0.00861	0.00610	29	15.3
	230 (7.53)	19 (669)	6.5	0.36	8.6(12/1)	4.99	1,353	14.7	0.00458	0.00342	25	
	230 (7.53)	19 (669)	6.5	0.36	9.3(12/1)	5.7	1,185	14.7	0.00523	0.00342	35	
	230 (7.53)	19 (669)	2.2	0.42	8.6(12/1)	4.99	1,589	14.7	0.00390	0.00342	12	
	230 (7.53)	19 (669)	2.2	0.42	9.3(12/1)	5.7	1,391	14.7	0.00446	0.00342	23	
3	230 (7.53)	19 (669)	10.8	0.29	8.6(12/1)	4.99	1,118	14.7	0.00555	0.00342	38	17.6
	230 (7.53)	19 (669)	10.8	0.29	9.3(12/1)	5.7	978	14.7	0.00634	0.00342	46	
	232 (7.6)	19.2 (678)	9.8	0.31	8.2(12/1)	4.6	1,289	17.8	0.00241	0.00214	11	
	232 (7.6)	19.2 (678)	9.8	0.31	8.2(1/8)	3.62	1,638	17.8	0.00189	0.00214	-13	
	232 (7.6)	19.2 (678)	1.7	0.43	8.2(12/1)	4.6	1,777	17.8	0.00174	0.00214	-23	
4	232 (7.6)	19.2 (678)	1.7	0.43	8.2(1/8)	3.62	2,257	17.8	0.00137	0.00214	-56	14.2
	232 (7.6)	19.2 (678)	18.00	0.19	8.2(12/1)	4.6	795	17.8	0.00390	0.00214	45	
	232 (7.6)	19.2 (678)	18.00	0.19	8.2(1/8)	3.62	1,010	17.8	0.00307	0.00214	30	
	233 (7.65)	19.4 (685)	9.8	0.31	9(1/8)	4.22	1,418	15.3	0.00395	0.00370	6	
	233 (7.65)	19.4 (685)	1.7	0.43	9(1/8)	4.22	1,955	15.3	0.00286	0.00370	-29	
5	226 (7.42)	19.6 (655)	9.8	0.31	9(1/8)	4.22	1,357	12.7	0.00604	0.00409	42	10.3
	226 (7.42)	19.6 (655)	1.7	0.43	9(1/8)	4.22	1,871	12.7	0.00438	0.00409	7	
	226 (7.42)	19.6 (655)	18.0	0.19	9(1/8)	4.22	837	12.7	0.00980	0.00409	58	

Test No.	Dynamic k Range (95% confidence level) % O2/min	Static k Range (95% confidence level) % O2/min	Significantly Different
1	.0061 to .0136	.0055 to .0067	No
2	.0039 to .0063	.0032 to .0036	Yes
3	.0014 to .0039	.0020 to .0022	No
4	.0029 to .0064	.0033 to .0041	No
5	.0044 to .0098	.0036 to .0046	No





plots would result in a difference between calculated static and dynamic rate constants.

#### H. STATIC VERSUS DYNAMIC RATE CONSTANTS IN OFF-GAS TREATMENT PLOT V3

The rate constant for off-gas Treatment Plot V3 increased significantly, at the 89 percent confidence level, between Tests 1 and 3, indicating a likely increase in microbial activity due to degradation of off-gas from Treatment Plot V1. The dynamic rate constants in off-gas Treatment Plot V3 have been shown (Figure 39) to average 1.56 (SD  $\pm$  0.91) percent/day [.0011 (SD  $\pm$  .00063) percent/minute]. The static rate constants (Table 6) determined from in situ respiration tests are significantly less than the dynamic rates with the exception of Test 4A. This occurred because off-gas Treatment Plot V3 became substrate-starved rapidly after shutdown of the hydrocarbon injection system. Only in Test 4A were measurements taken immediately following shutdown and at short enough time intervals to observe the true early time rate constant that compares favorably with dynamic rate constants.

#### I. POTENTIAL TEMPERATURE EFFECTS ON IN SITU RESPIRATION TESTS

The potential effect of temperature on hydrocarbon removal due to biodegradation was previously discussed and hydrocarbon removal rates were shown to have a similar pattern as both average ambient air temperature and soil temperature. Figures 51 and 52 compare average soil temperature with oxygen consumption rates during in situ respiration tests in Treatment Plots V1 and V2. The figures infer a relationship between soil temperature and biological activity as measured by the rate of oxygen consumption. Based on the respiration data presented, soil temperature had a much more dramatic effect on the rate of biodegradation than did moisture and nutrient addition.

Treatment Plot V2 received moisture and nutrients throughout the experimental period and should be a satisfactory control for temperature and other unmeasured variables. Figures 53 and 54 present the results of two methods for correcting rate constants in Treatment Plot V1 using observed rate constant differences, attributed to temperature, in Treatment Plot V2.

Method 1 (Figure 53) was accomplished by adding the total observed rate constant differences between Test 1 and Tests 2 through 5 in Treatment Plot

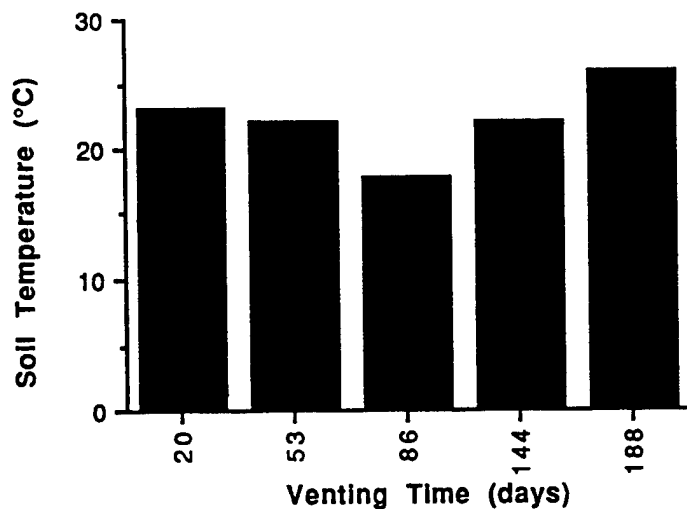


Figure 51. Average Soil Temperature Measured or Calculated to Correspond with In Situ Respiration Tests.

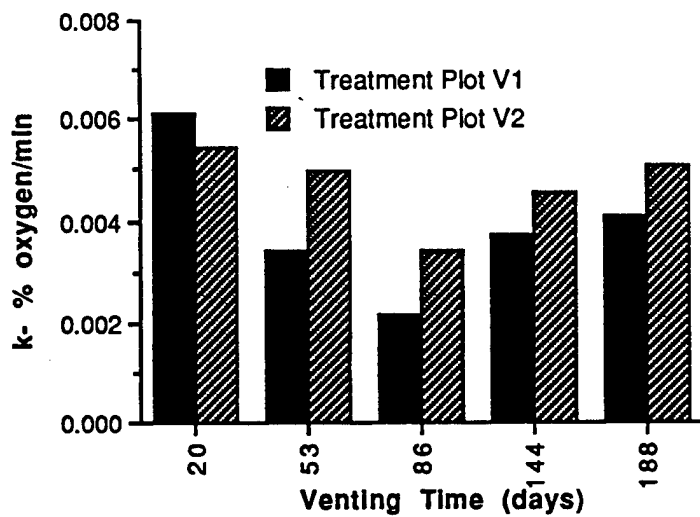


Figure 52. Oxygen Consumption Rate Constants Determined by In Situ Respiration Tests for Treatment Plots V1 and V2.

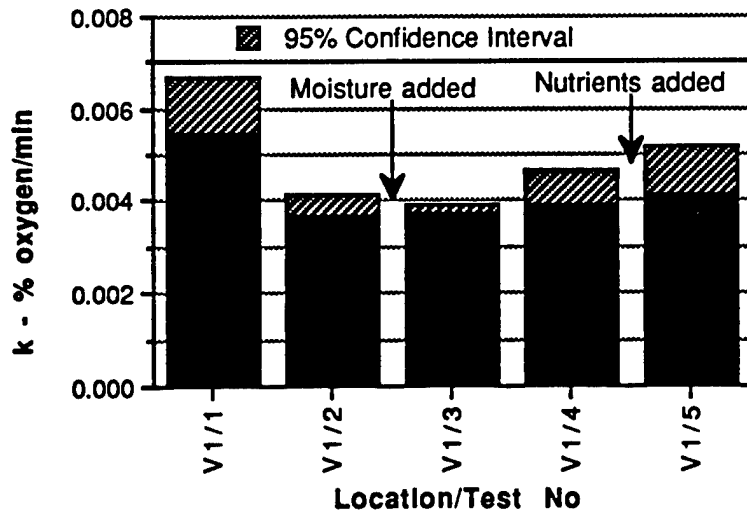


Figure 53. Temperature-Corrected (Based on Total Change in V2) Oxygen Consumption Rate Constants (k) Determined by Respiration Tests for Treatment Plot V1. Mean k is at the Center of the 95 Percent Confidence Interval.

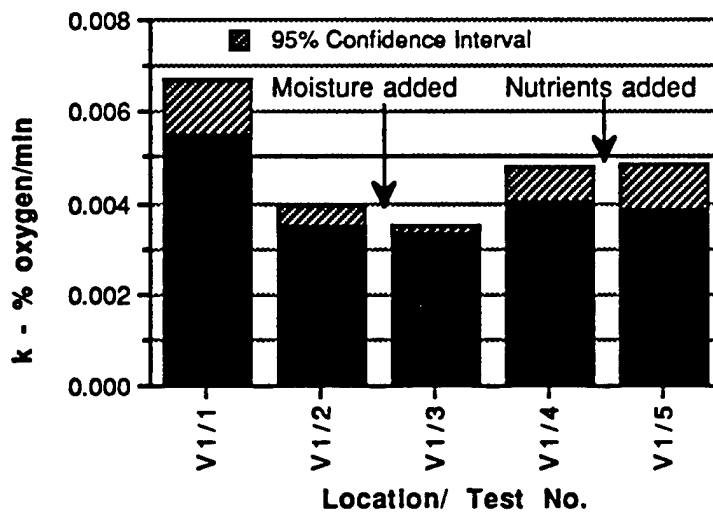


Figure 54. Temperature-Corrected (Based on Percent Change in V2) Oxygen Consumption Rate Constants (k) Determined by Respiration Tests for Treatment Plot V1. Mean k is at the Center of the 95 Percent Confidence Interval.

V2, to measured rate constants in Tests 2 through 5 in Treatment Plot V1. Method 2 (Figure 54) applies the ratio of rate constants between Test 1 and Tests 2 through 5 in Treatment Plot V2, to measured rate constants in Tests 2 through 5 in Treatment Plot V1.

In aquatic systems, the van't Hoff-Arrhenius equation predicts a doubling of the rate constant with each temperature increase of 10°C (50°F), assuming typical activation energy values (61). Figure 55 is the Arrhenius plot for determining activation energy using measured soil temperature/rate constant relationships from Tests 3, 4, and 5 for Treatment Plots V1 and V2. Using the Arrhenius constants determined from the plots in Figure 55, the rate constants for Treatment Plots V1 and V2 were corrected to 23°C (73°F), the soil temperature at Test 1 (Figures 56 and 57, respectively).

The Arrhenius equation appears to model adequately the effects of temperature on the hydrocarbon biodegradation rate in contaminated soil at this field site. This conclusion is based on the similarity in corrected rate constants for Treatment Plot V1 as shown in Figures 53, 54, and 56, and the insignificant differences (95 percent confidence) in Arrhenius-corrected rate constants, with the exception of Tests 1 and 3, in Treatment Plot V2 (Figure 57).

Moisture was added to Treatment Plot V1 following respiration Test 2, and nutrients were added following respiration Test 4. Regardless of the temperature correction approach (Figures 53, 54, or 56), rate constants were not significantly increased between Tests 2 and 3, and between Tests 4 and 5. Therefore, it can be concluded that moisture and nutrient addition were of insignificant benefit to the rate of hydrocarbon biodegradation in Treatment Plot V1. The methods illustrated in Figures 54 and 56 show a significant decrease in the rate constant between Tests 2 and 3, but Method 1 (Figure 53) does not.

Although moisture and nutrient addition did not effect biodegradation rates, data presented in Figures 51 through 57 indicate that soil temperature probably did. Figures 58 and 59 present correlations between measured soil temperature and oxygen consumption rate ( $k$ ) (including the 95 percent confidence interval range for  $k$ ) for in situ respiration Tests 3 through 5 and for Treatment Plots V1 and V2, respectively. Figures 58 and 59 support the

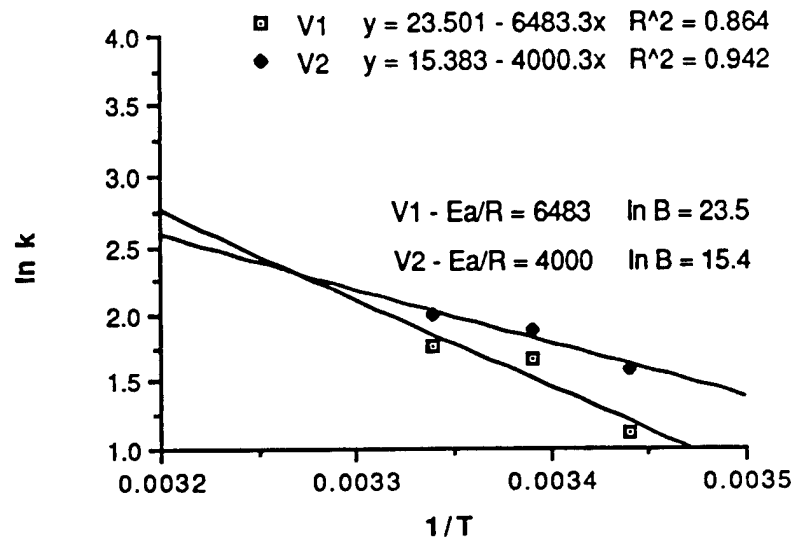


Figure 55. Arrhenius Plot for Determining Activation Energy Using Measured Soil Temperature/Rate Constant Relationships From Tests 3, 4, and 5 for Treatment Plots V1 And V2.

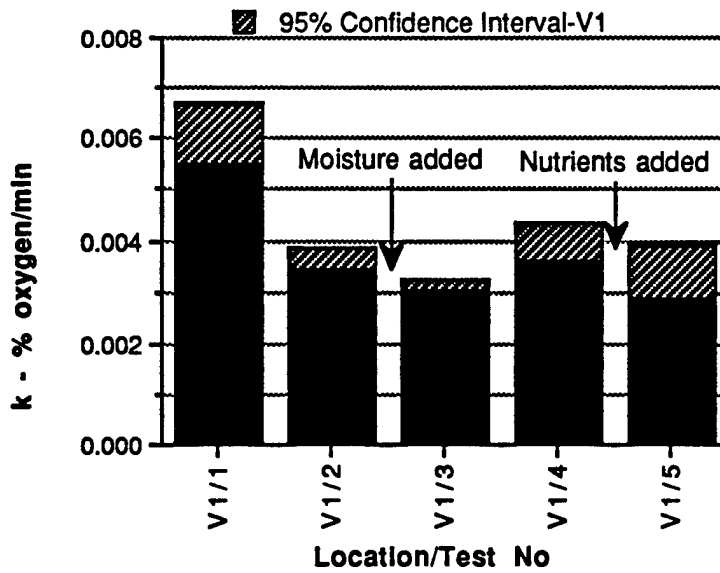


Figure 56. Temperature-Corrected (23°C Based on Arrhenius Plot) Oxygen Consumption Rate Constants (k) Determined by Respiration Tests for Treatment Plot V1. Mean k is at the Center of the 95 Percent Confidence Interval.

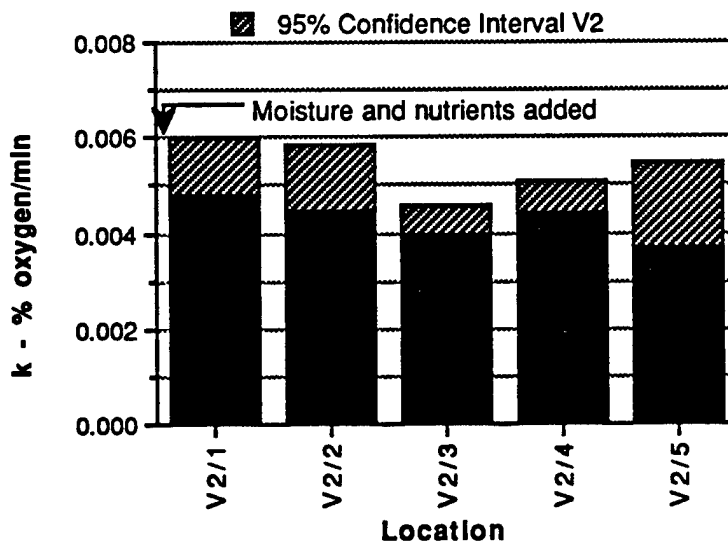


Figure 57. Temperature-Corrected (23°C Based on Arrhenius Plot) Oxygen Consumption Rate Constants (k) Determined by Respiration Tests for Treatment Plot V2. Mean k is at the Center of the 95 Percent Confidence Interval.

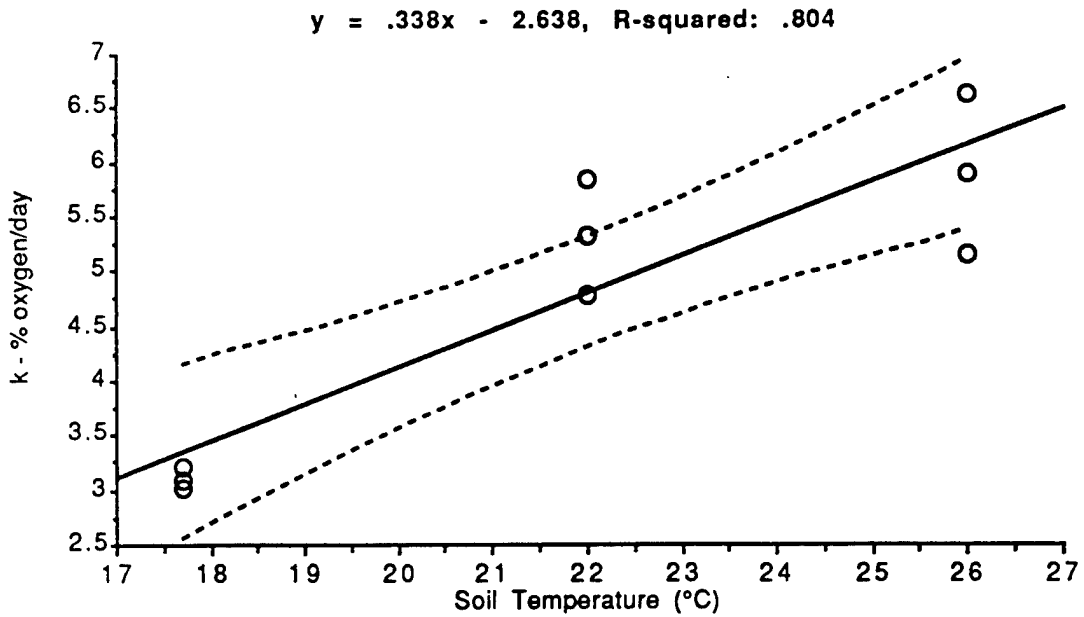


Figure 58. Correlation and 95 Percent Confidence Band Between Measured Soil Temperature and Oxygen Consumption in Treatment Plot V1 During Respiration Tests 3 Through 5.

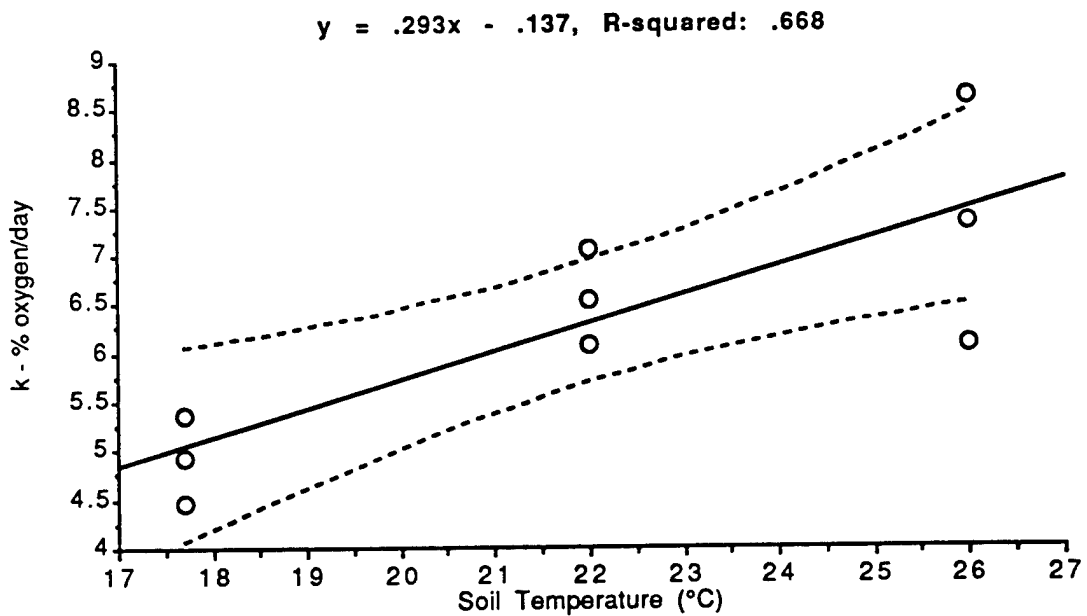


Figure 59. Correlation and 95 Percent Confidence Band Between Measured Soil Temperature and Oxygen Consumption In Treatment Plot V2 During Respiration Tests 3 Through 5.

conclusion, with 95 percent confidence, that respiration rate as measured by oxygen consumption was related to soil temperature.

#### J. NUTRIENT BALANCE

The data presented indicates that either nutrients did not limit biodegradation of jet fuel at the field site, or that nutrients were not adequately delivered to the subsurface. Initial soil samples collected in July and September 1989 were low in concentrations (generally < 3 mg N/kg) of  $\text{NO}_3 + \text{NO}_2\text{-N}$  and  $\text{NH}_4\text{-N}$  (Appendix C). Initial concentrations of  $\text{PO}_4\text{-P}$  were below detectable levels (< 0.7 mg P/kg) except for one sample containing 4.45 mg P/kg. Soil samples collected in December 1989 indicated that  $\text{NH}_4\text{-N}$  concentrations in Treatment Plot V2, which had been receiving nutrients for 2 months, had significantly increased from an average of 2 mg N/kg to 25 mg N/kg. However, there was not a significant increase in  $\text{PO}_4\text{-P}$  concentrations in Treatment Plot V2 between the initial and December 1989 soil samples and concentrations were still below detectable (<0.7 mg P/kg) levels. Nutrient concentrations in the December 1989 soil samples from Treatment Plot V1, which had received no nutrients at that time, were essentially unchanged from the initial samples.

Final soil samples, collected in May 1990, indicated that  $\text{NH}_4\text{-N}$  concentrations in Treatment Plot V2, which had received nutrients throughout the field test, had significantly ( $p < 0.06$ ) increased from an average of 2 mg N/kg to 22 mg N/kg, but there was no significant difference in  $\text{NH}_4\text{-N}$  concentrations between samples collected in December 1989 and final samples collected in April 1990. Treatment Plot V1 received nutrients for the final 7 weeks of the field test. Final soil  $\text{NH}_4\text{-N}$  concentrations averaged 12 mg N/kg, but were not significantly different ( $p = 0.2$ ) than initial concentrations (Appendix C). Most of the final soil concentrations of  $\text{PO}_4\text{-P}$  remained below detectable levels (<0.7 mg P/kg) (Appendix C). Many of the soil samples had Total-P concentrations that were below the detection limit. Therefore, comparison by t-test was difficult because of the low number of comparable data points in each test plot. A t-test combining all comparable initial and final Total-P concentrations in all test plots indicated a significant ( $p < 0.08$ ) average increase from 26 to 43 mg P/kg.



Groundwater concentrations of  $\text{NH}_4\text{-N}$  increased throughout the field test in Treatment Plot V2. Initial concentrations averaged 2.4 mg N/liter whereas final concentrations averaged 8,560 mg N/liter (Appendix C). In Treatment Plot V1, groundwater  $\text{NH}_4\text{-N}$  concentrations increased from an average of 0.22 to 4,319 mg N/liter between initial and final samples. Groundwater concentrations of  $\text{PO}_4\text{-P}$  increased by three orders of magnitude during the field test.

Evaluation of soil and water samples indicated that nutrients were delivered to the test plots, but that most of the nutrients passed through the vadose zone to the groundwater. If all of the nutrients delivered had remained in the vadose zone,  $\text{NH}_4\text{-N}$  and Total-P concentrations should have increased by approximately 1,000 mg N/kg and 100 mg P/kg, respectively.

Total nitrogen (TKN) and total phosphorus concentrations in initial soil samples averaged 81 and approximately 22 mg/kg, respectively, in Treatment Plot V1. Average total phosphorus concentrations are only approximate because 3 of 10 samples were below the detection limit of 15 mg/kg. During 188 days of venting Treatment Plot V2, 32,000 grams (1110 mg/kg) of hydrocarbons (hexane equivalent), or 26,800 grams (930 mg/kg) of carbon (hexane equivalent), were removed as carbon dioxide. Alexander (62) indicates that typical soil microbes volatilize 2 grams of carbon, as carbon dioxide, for each gram of carbon assimilated into cell protoplasm. Assuming this ratio is accurate, approximately 13,400 grams (465 mg/kg) of carbon were converted to cell mass. Using Alexander's (62) C:N:P ratio of 100:10:1, approximately 46 and 5 mg/kg of nitrogen and phosphorus, respectively, should have been required to account for the observed fuel biodegradation. Since 81 and 22 mg/kg of nitrogen and phosphorus, respectively, were available naturally, it is not surprising that nutrient addition had no observable effect on the fuel biodegradation rate. Using the same calculation method, the naturally available nutrients should be adequate for the biodegradation of fuel at concentrations up to 2,000 mg/kg. Additional recycling of available nutrients should allow biodegradation of fuel at even higher concentrations.

Significant biodegradation of jet fuel was observed at both Hill AFB, Utah, (3) and Tyndall AFB, Florida, without addition of nutrients. The source of available nutrients is extremely important if results of these two field studies are to be applied at other sites. A possible source of available

organic nitrogen is nonsymbiotic nitrogen fixation by indigenous microorganisms.

#### K. NITROGEN FIXATION POTENTIAL

Soil nitrogenase (nitrogen fixation) potential was assayed using the acetylene reduction assay described by Knowles (57). The acetylene reduction assay is, as stated by Alexander (62), "...based on the finding that microorganisms that reduce  $N_2$ , which has a triple bond in the molecule, also can reduce acetylene, also a molecule with a triple bond." Alexander (62) also states, "It seems likely that many soils may support the (nitrogen) fixation when nitrate or available ammonium is present at low levels."

Anaerobic acetylene reduction (ethylene production) rates measured in initial soil samples, collected at 30, 60, and 90 cm (1, 2, and 3 feet) from Treatment Plots V1 and V2, averaged 200 nmole/(kg hr) (Appendix C). Soil samples collected in December 1989 from Treatment Plot V1 at 30, 60, 90, 120, and 150 cm (1, 2, 3, 4, and 5 feet), had an average ethylene production rate of 125 nmole/(kg hr) (Appendix C).

Alexander (62) describes a method for estimating the rate of nitrogen fixation based on the rate of acetylene reduction (ethylene production). He concluded that a ratio of  $3C_2H_2:1N_2$  "...is frequently approached in pure culture or soil and is sometimes attained." He also warns that this ratio should be used with caution because it has been observed to range from 0.75 to 4.5 or greater. Assuming a 3:1 ratio, the nitrogen fixation potential, based on initial and December 1989 soil samples, was approximately 0.0448 and 0.028 mg N/(kg day), respectively. At this rate, fixing the observed 81 mg/kg (2,330 grams) of organic nitrogen in Treatment Plot V1 would take from 5 to 10 years. Fuel contamination has existed at this site for at least 20 years, therefore, it is conceivable that the observed organic nitrogen was fixed by soil microbes.

The presence of large quantities of carbon in soil (i.e., a fuel spill) stimulates nitrogen fixation because nitrogen-fixing microbes are primarily heterotrophs dependent on carbon for energy and cell synthesis. Also, as observed at this field site, soil that is contaminated with petroleum hydrocarbons is usually anaerobic and nitrogen fixation is maximized under

anaerobic conditions (62). It can be safely assumed that a source of carbon and an anaerobic condition in soil are provided following a fuel spill. Therefore, the spill itself may provide the optimum conditions for providing a source of nitrogen through nonsymbiotic nitrogen fixation.

The average anaerobic acetylene reduction (ethylene production) rate, measured in final soil samples, was 24 nmole/(kg hr) (Appendix C), and was significantly ( $p=0.1$ ) less than the initial average rate of 200 nmole/(kg hr). Since  $\text{NH}_4\text{-N}$  was provided in large quantities, the reduced nitrogen fixation potential in the final soil samples is consistent with the quote (62) above that, "It seems likely that many soils may support the (nitrogen) fixation when nitrate or available ammonium is present at low levels."

#### L. INITIAL AND FINAL HYDROCARBON CONCENTRATIONS IN SOIL SAMPLES

Soil hydrocarbon concentrations (initial and final) were estimated from methylene chloride extracts of soil samples. Methanol extracts of initial soil samples resulted in total hydrocarbon concentrations that were at least one order of magnitude lower than concentrations determined from methylene chloride extracts. Because of the large differences in hydrocarbon concentrations resulting from the two methods, final soil samples were extracted with methylene chloride only. Soil hydrocarbon concentrations were calculated by multiplying the total integrated area in the chromatogram by the average response factor of all standards, multiplying the total integrated area by the response factor for the hexane standard (hexane equivalent), and by multiplying the integrated area for each weight fraction by the average response factor for the weight fraction (weighted average). In general, to be consistent with other estimates of hydrocarbon removal and concentration, the hexane standard qualification is presented here.

Table 9 summarizes average results of the hexane equivalent and weighted average methods using samples collected from 30 to 150 cm (1 to 5 feet) for Treatment Plots V1 and V2, and all samples for off-gas Treatment Plot V3 and Background Plot V4. Depending on the method used, total hydrocarbon removal, based on measured soil concentrations, ranged from 116 to 2,942 mg/kg and 770 to 2,856 mg/kg in Treatment Plots V1 and V2, respectively (Table 9).

TABLE 9. SUMMARY OF AVERAGE SOIL HYDROCARBON CONCENTRATIONS IN INITIAL AND FINAL SAMPLES

Calculation Method and Location of Soil Samples	Treatment Plot V1			Paired t-test (p) Comparing Initial to Final
	Average Conc. Initial Samples (mg/kg)	Average Conc. Final Samples (mg/kg)	Average Conc. Reduction (mg/kg)	
Hexane Equivalent Average 30 to 150 cm (1 to 5 ft)	5,135	2,193	2,942	0.02
Weighted Average 30 to 150 cm (1 to 5 ft)	3,872	2,198	1,674	0.07
Combined Average 30 to 150 cm (1 to 5 ft)	4,736	2,194	2,542	0.03
Treatment Plot V2				
Hexane Equivalent Average 30 to 150 cm (1 to 5 ft)	7,690	7,681	2,856	0.09
Weighted Average 30 to 150 cm (1 to 5 ft)	5,799	5,687	940	0.48
Combined Average 30 to 150 cm (1 to 5 ft)	6,733	7,000	1,895	0.19
Treatment Plot V3				
Hexane Equivalent Average 30 to 90 cm (1 to 3 ft)	150	202	117	0.37
Weighted Average 30 to 90 cm (1 to 3 ft)	212	125	178	0.11
Treatment Plot V4				
Hexane Equivalent Average 30 to 90 cm (1 to 3 ft)	129	102	97	0.21
Weighted Average 30 to 90 cm (1 to 3 ft)	110	89	76	0.24

Statistical comparisons between initial and final soil samples collected from 30 to 150 cm (1 to 5 feet), using the Students t-test for paired samples and the hexane equivalent method, confirmed a significant ( $p < 0.1$ ) reduction in soil hydrocarbon concentrations between initial and final soil samples in Treatment Plots V1 and V2, respectively. When using the weighted average quantification method, Treatment Plot V1 shows a statistically significant decrease, but Treatment Plot V2 does not.

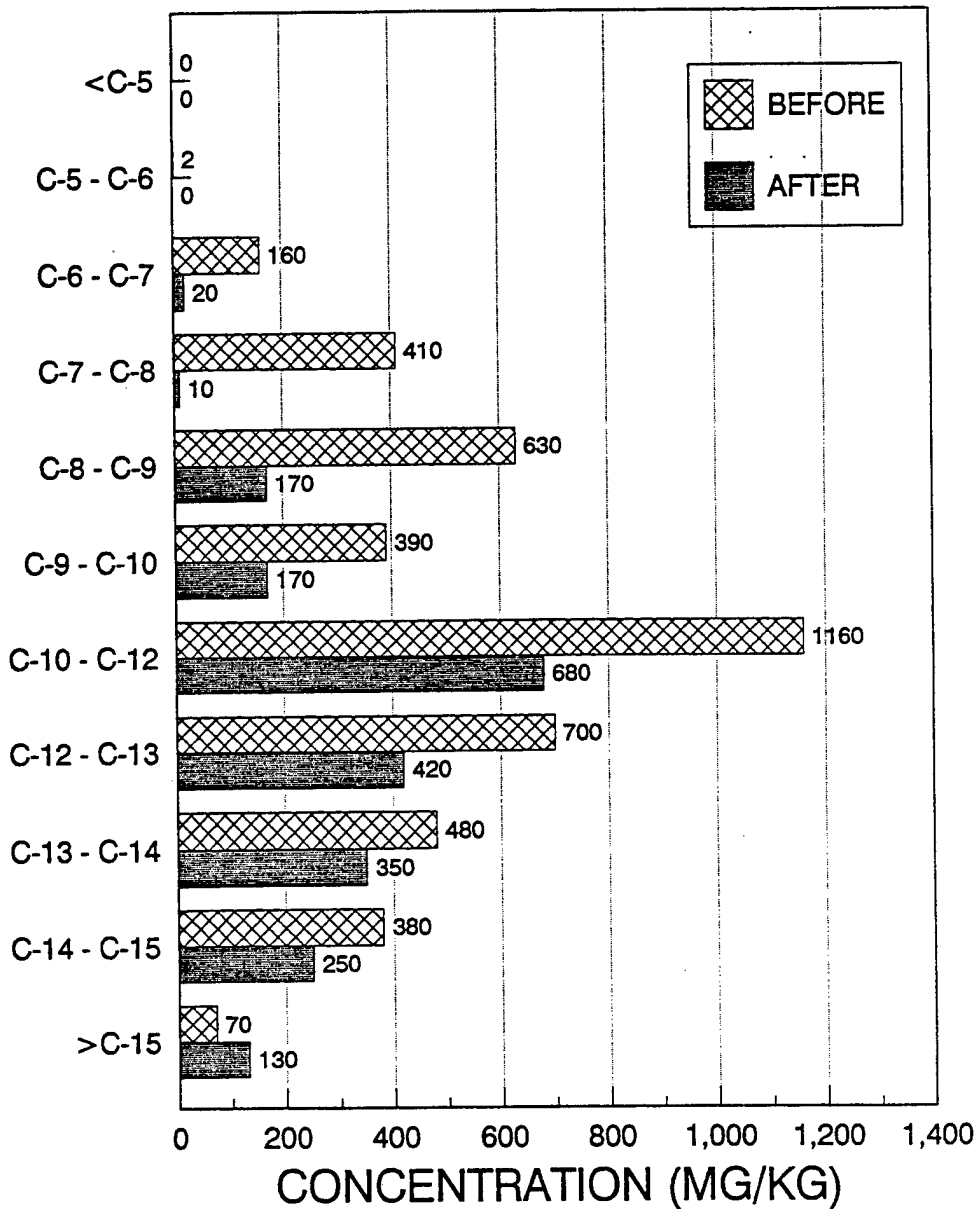
Figures 60 and 61 show the average molecular weight distribution before and after treatment. Figures 62 and 63 present average hydrocarbon concentrations as a function of depth before and after treatment. Figures 64 and 65 show before and after concentrations of specific hydrocarbons. It is apparent that lower molecular weight hydrocarbons have been selectively removed; however, because of the short-term nature of the test and the relatively small fraction of the total hydrocarbons removed, further conclusions are not possible.

Average soil hydrocarbon concentrations in off-gas Treatment Plot V3 and Background Plot V4 did not significantly change between initial and final samples.

#### 1. Mass Balance of Soil Hydrocarbon

During the field test period, based upon oxygen utilization of 25,820 grams (900 mg/kg) and 31,990 grams (1,110 mg/kg), hexane equivalent, of total hydrocarbons were mineralized from Treatment Plot V1 by volatilization and biodegradation, respectively. In Treatment Plot V2, 32,600 grams (1,130 mg/kg) and 37,640 grams (1,310 mg/kg), hexane equivalent, were volatilized and biodegraded, respectively (Appendix B). Assuming that an additional 50 percent of the carbon removed as carbon dioxide was converted to cell protoplasm (28), a total of 73,810 grams (2,560 mg/kg) and 89,060 grams (3,090 mg/kg), respectively, of total hydrocarbons (hexane equivalent) were removed from Treatment Plots V1 and V2 during the field test.

Based on initial and final soil samples (Table 9) collected from 30 to 150 cm (1 to 5 feet), average soil hydrocarbon concentrations (hexane equivalent) were reduced by 2,940 and 2,860 mg/kg, respectively, in Treatment Plots V1 and V2 during the field test. Considering the wide range of soil hydrocarbon concentrations, the extent of soil remediation predicted by



BEFORE DATA AVERAGED FROM 7/89 AND 9/89 SAMPLES  
 AFTER DATA AVERAGED FROM 4/90 SAMPLES

Figure 60. Average Molecular Weight Distribution in Plot VI Before and After Treatment; Concentrations Below Detection Limits are Illustrated as 0.

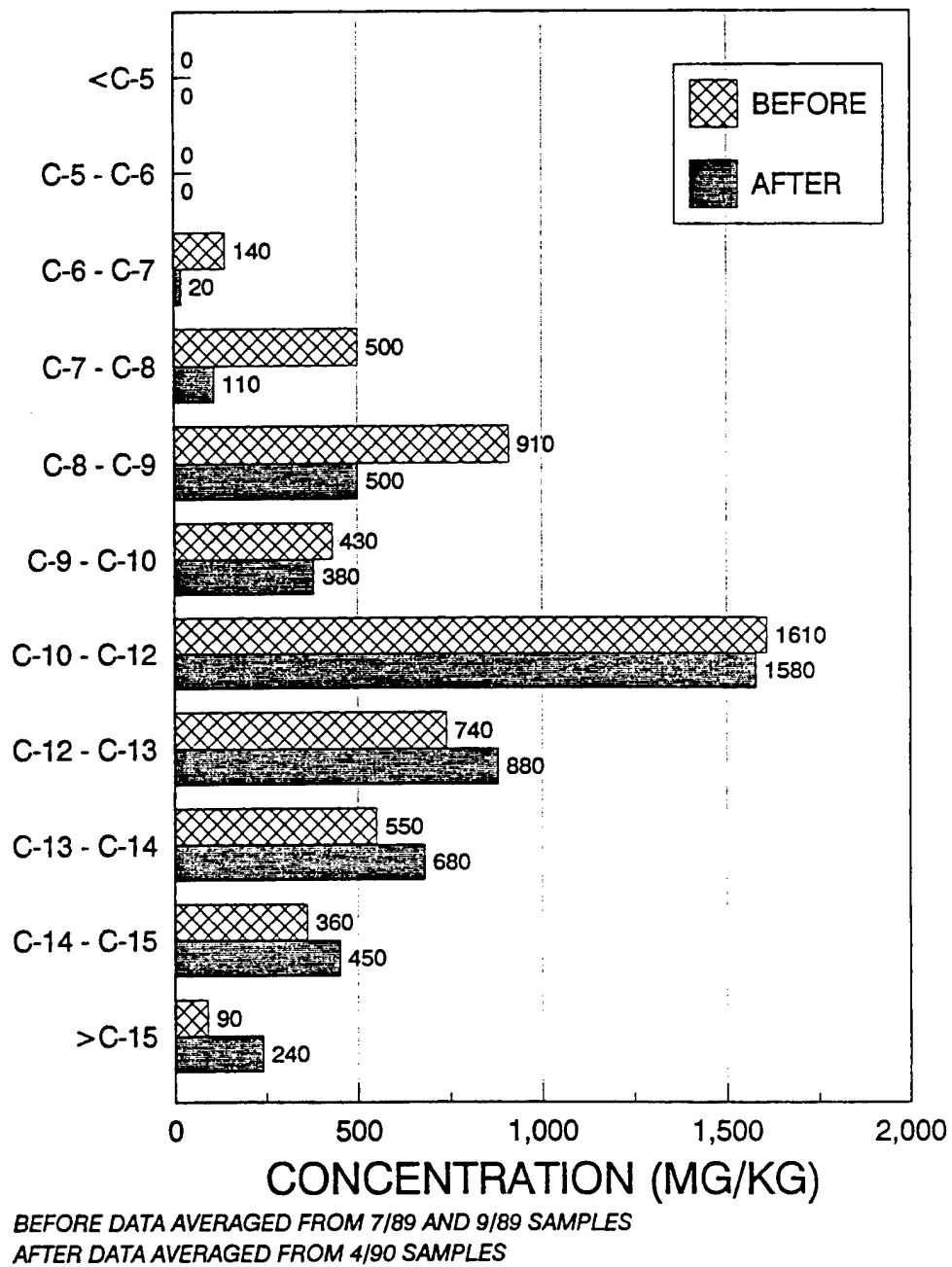
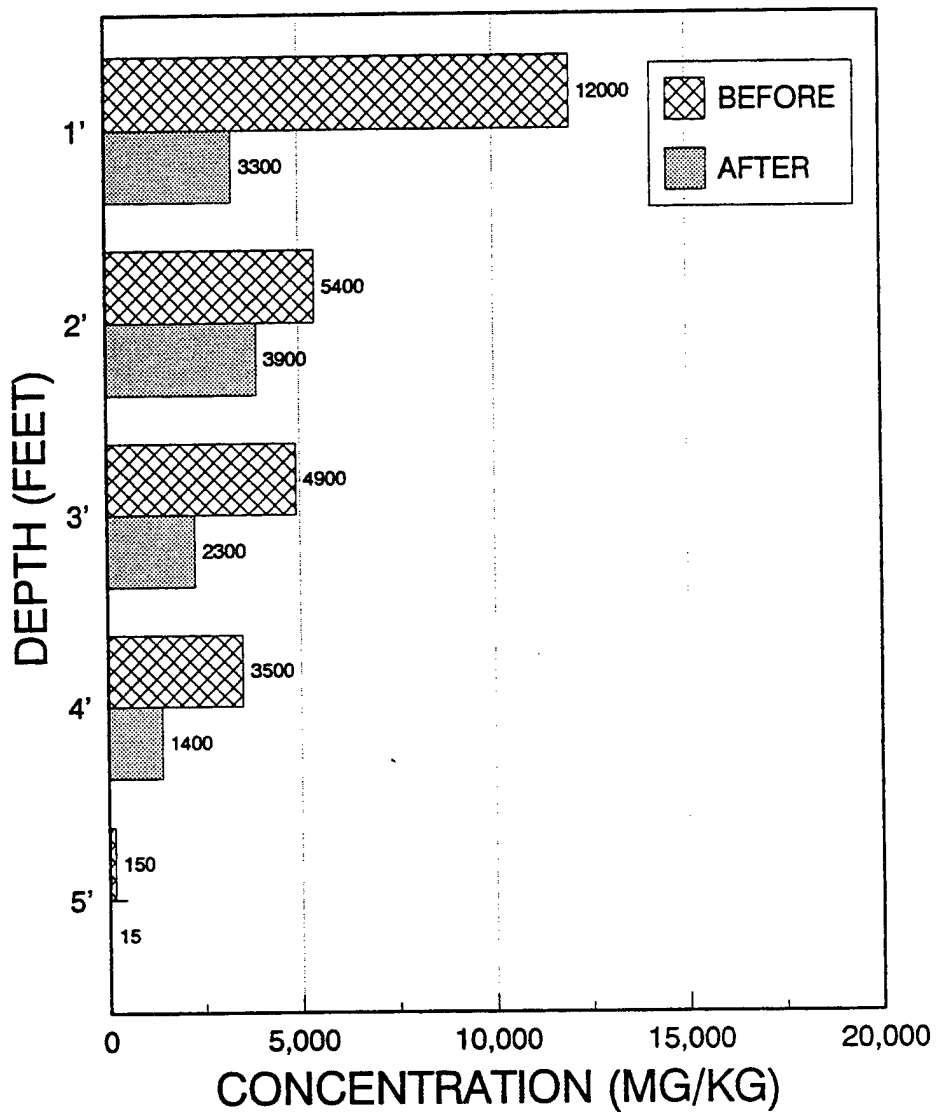


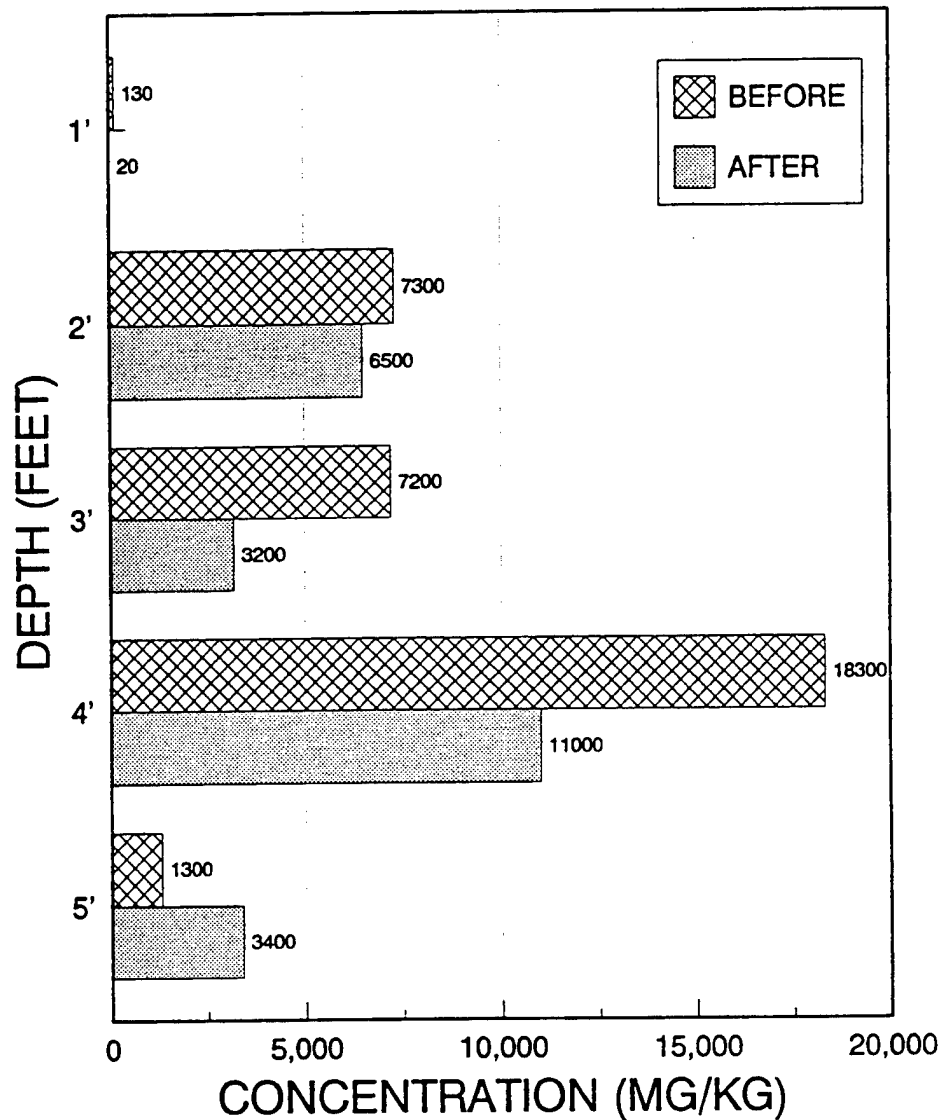
Figure 61. Average Molecular Weight Distribution in Plot V2 Before and After Treatment; Concentrations Below Detection Limits are Illustrated as 0.



BEFORE DATA FROM 7/89 AND 9/89 SAMPLES  
 AFTER DATA FROM 4/90 SAMPLES

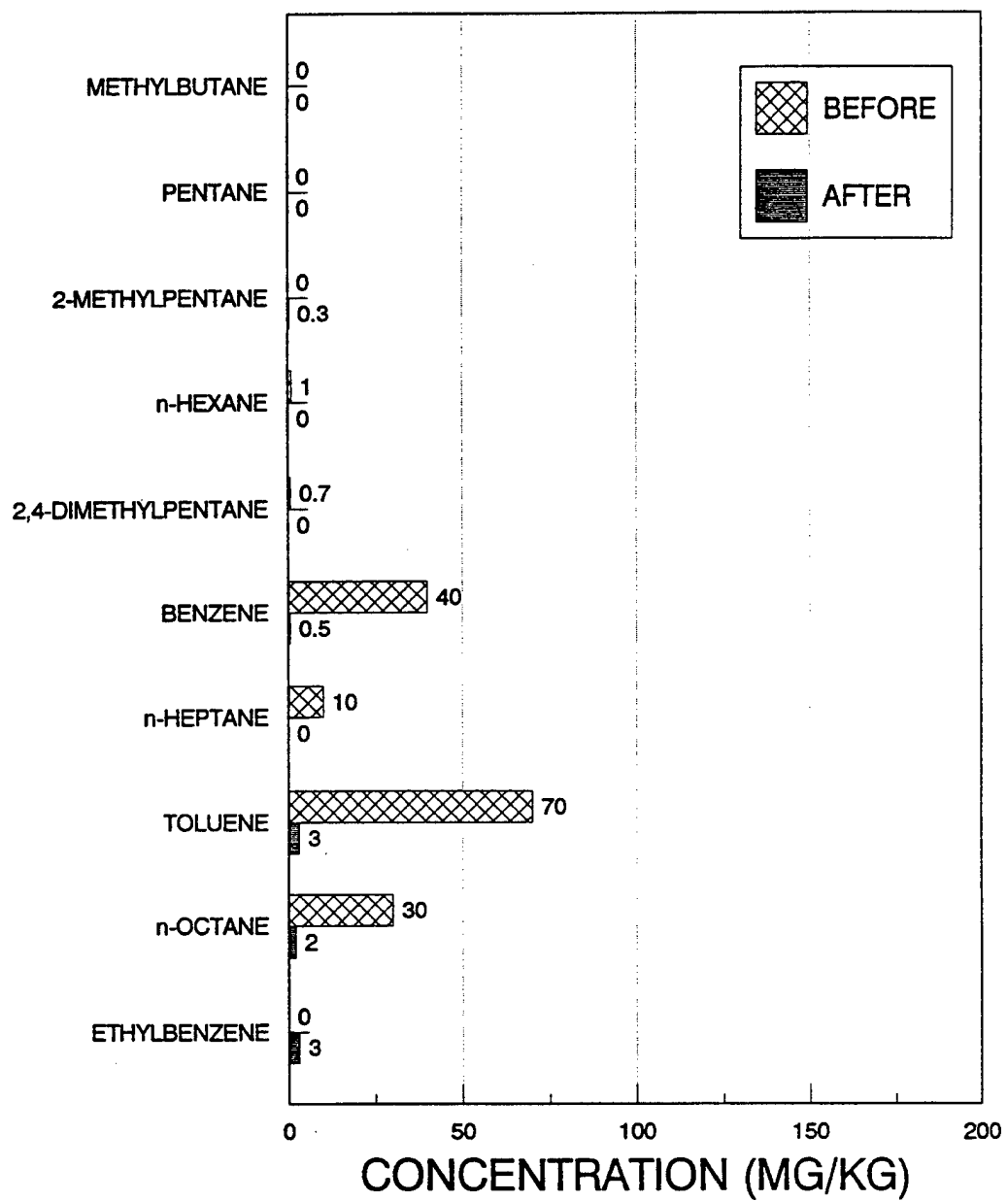
Figure 62. Hydrocarbon Concentrations as a Function of Depth Before and After Treatment in Plot V1; Quantifications Based Upon Hexane Standards





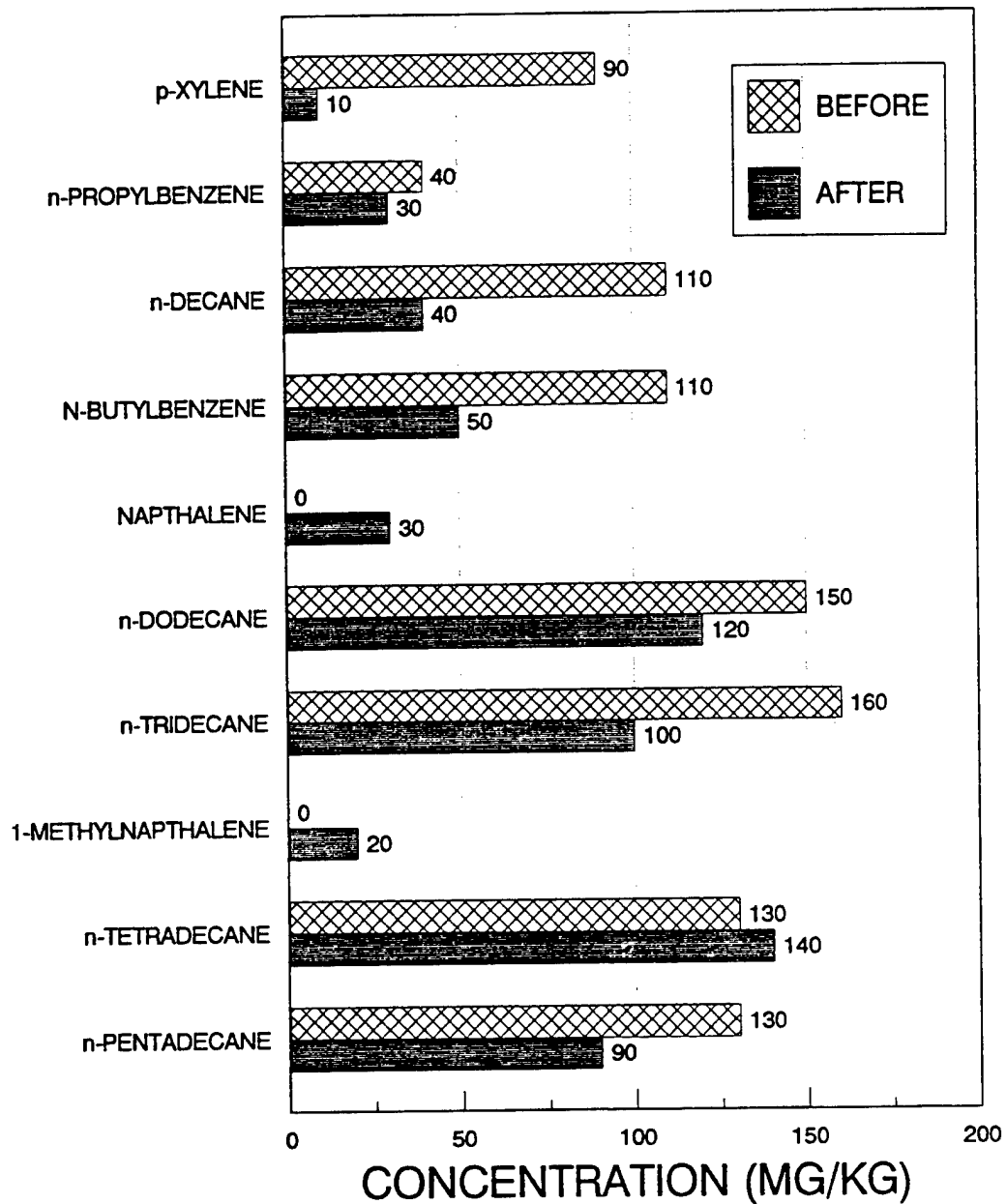
BEFORE DATA FROM 7/89 AND 9/89 SAMPLES  
 AFTER DATA FROM 4/90 SAMPLES

Figure 63. Hydrocarbon Concentrations as a Function of Depth Before and After Treatment in Plot V2, Quantifications Based Upon Hexane Standards.



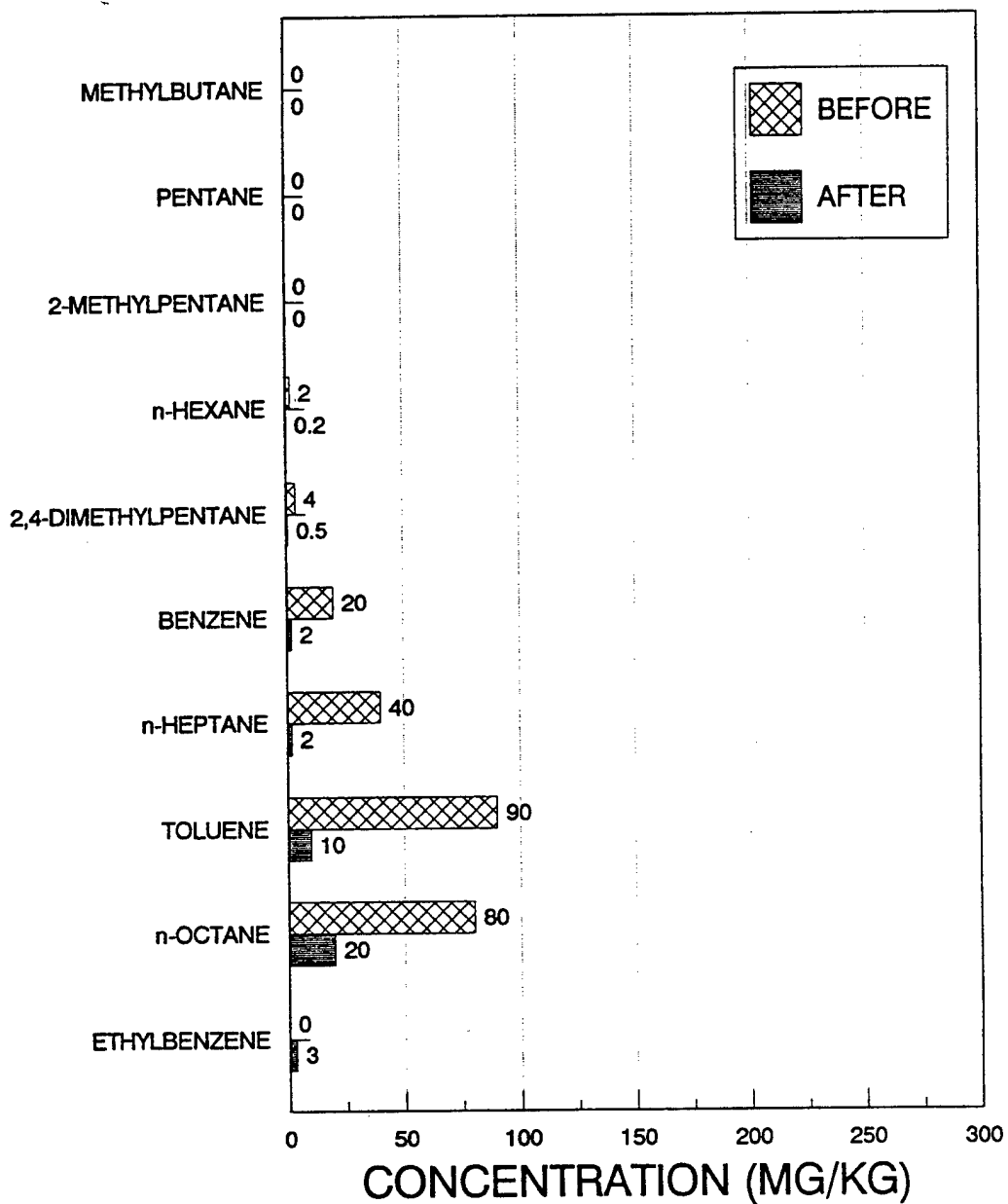
BEFORE DATA AVERAGED FROM 7/89 AND 9/89  
 AFTER DATA AVERAGED FROM 4/90

Figure 64. Specific Hydrocarbon Concentrations Before and After Treatment In Plot V1.



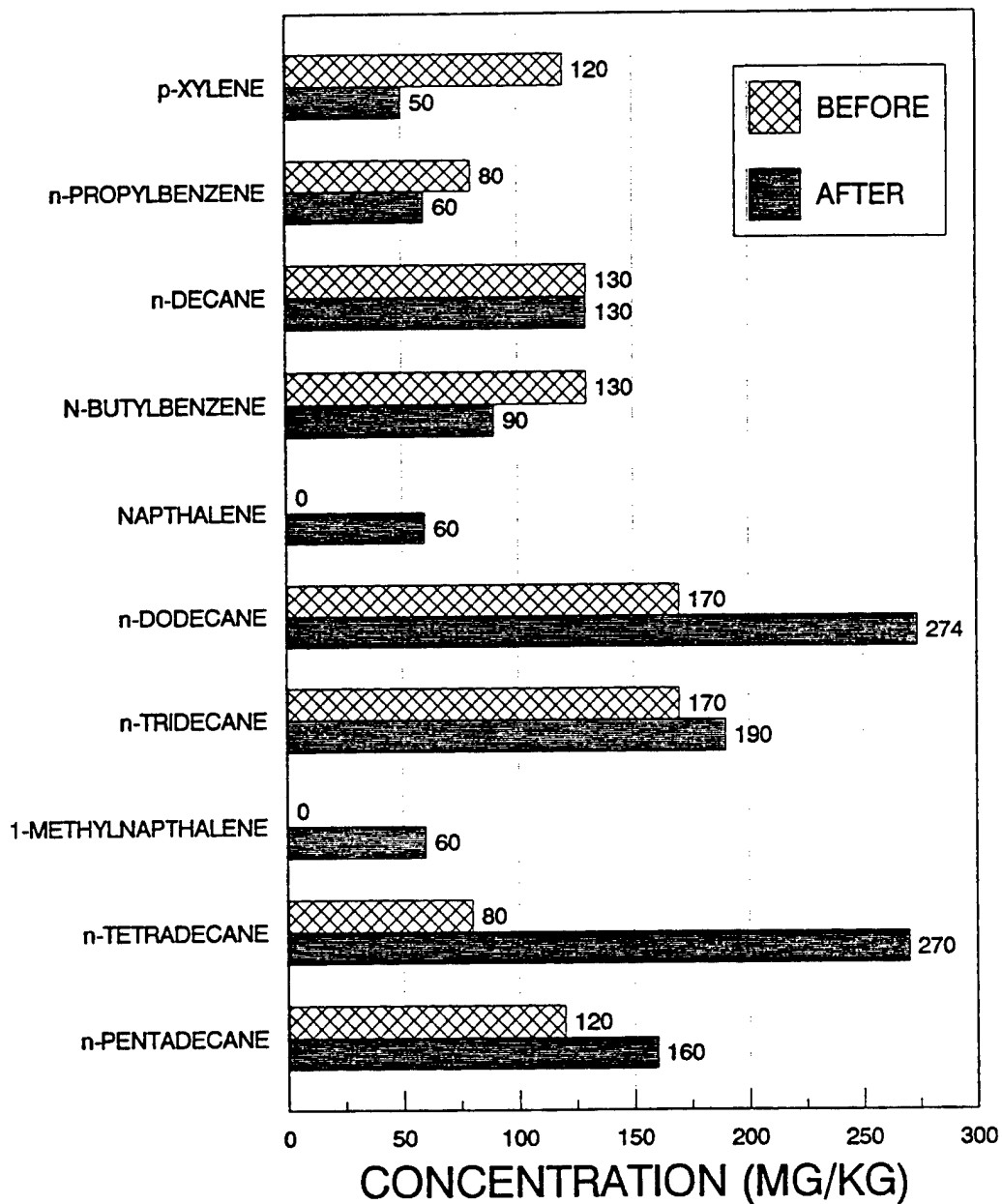
BEFORE DATA AVERAGED FROM 7/89 AND 9/89  
 AFTER DATA AVERAGED FROM 4/90

Figure 64. Specific Hydrocarbon Concentrations Before and After Treatment In Plot V1 (Concluded)



BEFORE DATA AVERAGED FROM 7/89 AND 9/89  
 AFTER DATA AVERAGED FROM 4/90

Figure 65. Specific Hydrocarbon Concentrations Before and After Treatment In Plot V2.



BEFORE DATA AVERAGED FROM 7/89 AND 9/89  
 AFTER DATA AVERAGED FROM 4/90

Figure 65. Specific Hydrocarbon Concentrations Before and After Treatment In Plot V2 (Concluded)

measurement of the discharge gas streams from Treatment Plots V1 and V2, agree surprisingly well with the actual level of soil remediation determined from soil samples (Table 9). This mass balance indicates that added water did not wash significant amounts of fuel from the site. Washing was not considered to be a significant removal mechanism because of the low aqueous solubility of jet fuel. The field test design did not allow measurement of the quantity of hydrocarbons removed by washing, however, by assuming an average pore water-hydrocarbon concentration of 43 mg/L [this was the average total hydrocarbon concentration measured in Wells V1-1, V1-2, V1-3, V2-1, V2-2, and V2-3 over the test period (Appendix D)], and water flow rate of 50 ml/min, approximately 0.1 mg/(kg day) would be removed by washing. This is well below measured rates of biodegradation or volatilization. This conclusion is supported by Reference 1 where it was shown that 190 pore volumes of water had no measurable washing effect on JP-4-contaminated soil.

## 2. Isotopic Analysis

To confirm biological degradation in the treatment plots, the sources of carbon dioxide in soil gases were determined by isotopic ratios (R) of  $^{13}\text{C}/^{12}\text{C}$ . The ratio of these two stable isotopes of carbon is characteristic of the source of carbon in a given gas sample. The isotopic ratios of an unknown are reported as a per-mil deviation from the standard using the " $\delta$ " notation:

$$\delta = \frac{R \text{ sample} - R \text{ std}}{R \text{ std}} \times 100 \quad (7)$$

Six samples of soil gas from the contaminated treatment plots, two samples of soil gas from the background plot, and one sample of atmospheric air were collected and analyzed. Values of  $\delta$  for the gas samples were compared (Figure 66) to known ranges of  $\delta$  for carbon dioxide resulting from the biodegradation of petroleum, coal, and organisms; carbon dioxide resulting from the abiotic decomposition of carbonate rock; and from atmospheric carbon dioxide. The per-mil deviations ( $\delta$ ) for samples collected at the field site

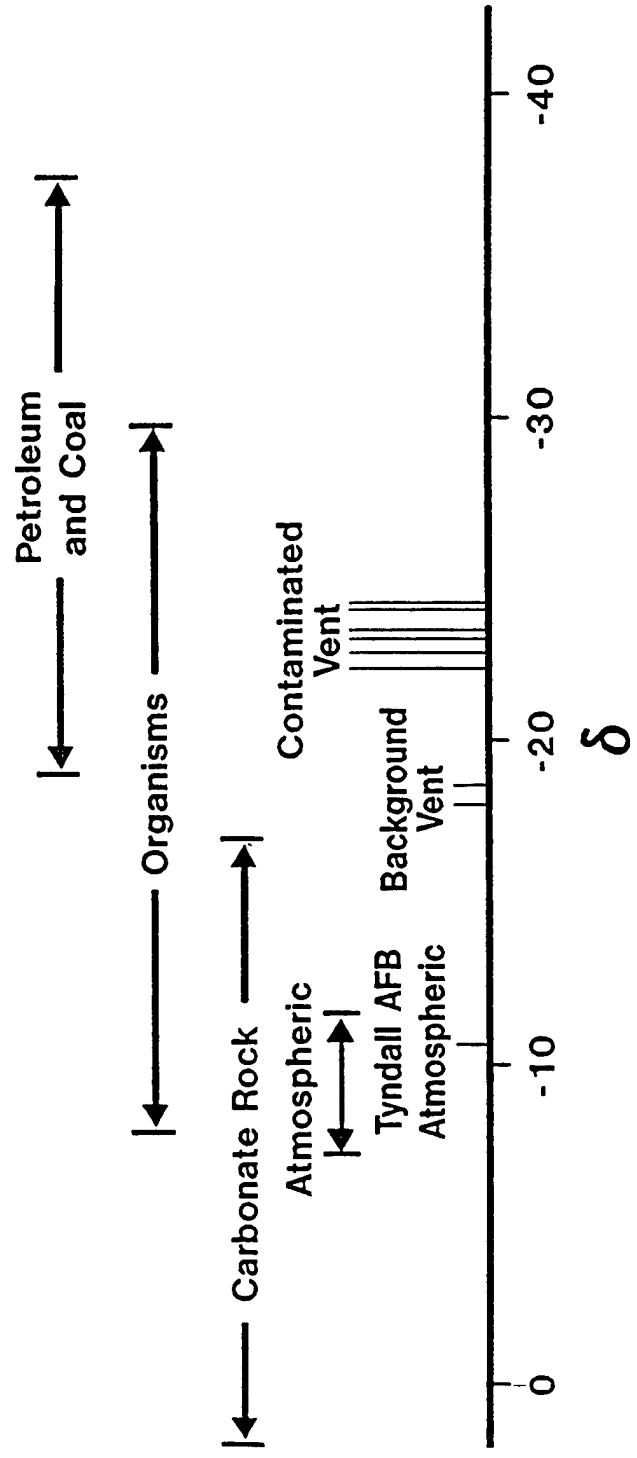


Figure 66. Comparison Of  $\delta$  for Gas Samples Compared to Known Ranges of  $\delta$  for Carbon Dioxide Resulting From Petroleum and Coal, Organisms, Carbonate Rock, and the Atmosphere.

agree with expected  $\delta$  values and support the conclusion that observed carbon dioxide is the result of biodegradation of the jet fuel.

### 3. Enumeration of Soil Microorganisms

Soils were analyzed for microbial enumeration prior to and at the conclusion of the soil venting process. Nutrient agar-platable bacteria were recovered from soil samples and are reported in colony forming units per dry gram of soil (CFU/g). Average (of 3 replicates) microbial counts are summarized in Table 10 together with the results of paired Students t-tests comparing initial and final counts. There were no significant differences between initial microbial counts and microbial counts following the field test period.



TABLE 10. SUMMARY OF INITIAL AND FINAL MICROBIAL COUNTS AND STUDENT T-TESTS

Plot Location	Average Initial Conc. (CFU/g)	SD ± (CFU/g)	Average Final Conc. (CFU/g)	SD ± (CFU/g)	Paired t-test (p) Comparing Initial-Final
V1	2.89 E+06	6.56 E+06	1.12 E+06	1.54 E+06	0.56
V2	4.16 E+05	9.38 E+05	4.52 E+05	5.37 E+05	0.95
V3	8.24 E+05	4.61 E+05	1.76 E+06	1.72 E+06	0.23
V4	7.75 E+05	7.54 E+05	1.36 E+06	1.65 E+06	0.36

## SECTION V

### CONCLUSIONS AND RECOMMENDATIONS

This field-scale investigation has demonstrated that soil venting is an effective source of oxygen for enhanced aerobic biodegradation of petroleum hydrocarbons (jet fuel) in the vadose zone. Operational data and in situ respiration tests indicated that moisture (6.5-9.8 percent) and nutrients were not a limiting factor in hydrocarbon biodegradation or, if limiting, did not stimulate hydrocarbon biodegradation in the field plots. Soil and water analyses indicated that nutrients were delivered to the treatment plots and passed through the vadose zone to groundwater.

Air flow tests documented that decreasing flow rates will increase the percent of hydrocarbon removal by biodegradation and decrease the percent of hydrocarbon removal by volatilization. Under optimal air flow conditions (0.5 air void volumes per day), 82 percent biodegradation was achieved. Biodegradation removal rates ranged from approximately 2 to 20 mg/(kg day), but stabilized values averaged about 5 mg/(kg day). The effects of soil temperature on biodegradation rates were shown to approximate effects predicted by the van't Hoff-Arrhenius equation.

Off-gas treatment studies documented that uncontaminated soil at this test site could be successfully used as a biological reactor for the mineralization of hydrocarbon vapors (off-gas) generated during remediation of fuel-contaminated soil using the enhanced biodegradation through soil venting technology investigated in this field study. The average off-gas biodegradation rate was 1.34 (SD  $\pm$  0.83) mg/(kg day), or 1.93 (SD  $\pm$  1.2) grams/(m<sup>3</sup> day). The percent of off-gas biodegradation was inversely associated with air flow rate (retention time), and associated positively with hydrocarbon loading rate, at 95 percent confidence. Based on data collected at the field site, a soil volume ratio of approximately 4 to 1, uncontaminated to contaminated soil, would be required to biodegrade the off-gas completely from a bioventing system operated in a manner similar to this field project. However, if air flow rates in contaminated soil were designed to maximize biodegradation and minimize volatilization, the ratio of uncontaminated to contaminated soil required would be proportionally less.

In situ respiration tests indicated that oxygen consumption rates followed zero-order kinetics, and that rates were linear down to about 2-4 percent oxygen. Therefore, it appears that air flow rates can be minimized to maintain oxygen levels between 2 and 4 percent without inhibiting biodegradation of fuel, with the added benefit that lower air flow rates will increase the percent of removal by biodegradation and decrease the percent of removal by volatilization.

Initial soil samples indicated that naturally available nitrogen and phosphorus were adequate for the amount of biodegradation measured, explaining the observation that nutrient addition had an insignificant effect on the rate of biodegradation. Acetylene reduction studies revealed an organic nitrogen fixation potential that could fix the observed organic nitrogen, under anaerobic conditions, in 5 to 8 years.

Soil moisture levels did not significantly change during the field study. Soil moisture levels ranged from 6.5 to 7.4 percent and 8.5 to 9.8 percent, respectively, in Treatment Plots V1 and V2. Neither venting nor moisture addition had a statistically significant effect on soil moisture. Separate AFESC-sponsored research indicates that maximum biodegradation occurs at a soil water content of 72 percent saturation, or approximately 100 percent of the in situ field capacity (63).

This research has provided adequate design parameters for a full-scale remediation project using enhanced biodegradation through soil venting. A full-scale project should attempt to biodegrade all contamination including any generated off-gas.

Figure 67 presents a configuration that may successfully remediate the contaminated site and the generated off-gas. An air extraction well is drilled in uncontaminated soil at a distance from the contaminated site that will provide adequate uncontaminated soil volume (4:1) to treat generated off-gas. Air injection wells are drilled, as needed, into and on the opposite side of the contaminated area in a manner that will provide a relatively even distribution of air to the contaminated soil. It may be possible to design a system that will provide more air to more contaminated areas. Soil gas monitoring wells are installed in the contaminated area and, in the uncontaminated area, used as an off-gas treatment reactor to monitor total hydrocarbons, carbon dioxide, and oxygen. Air flows are adjusted to assure

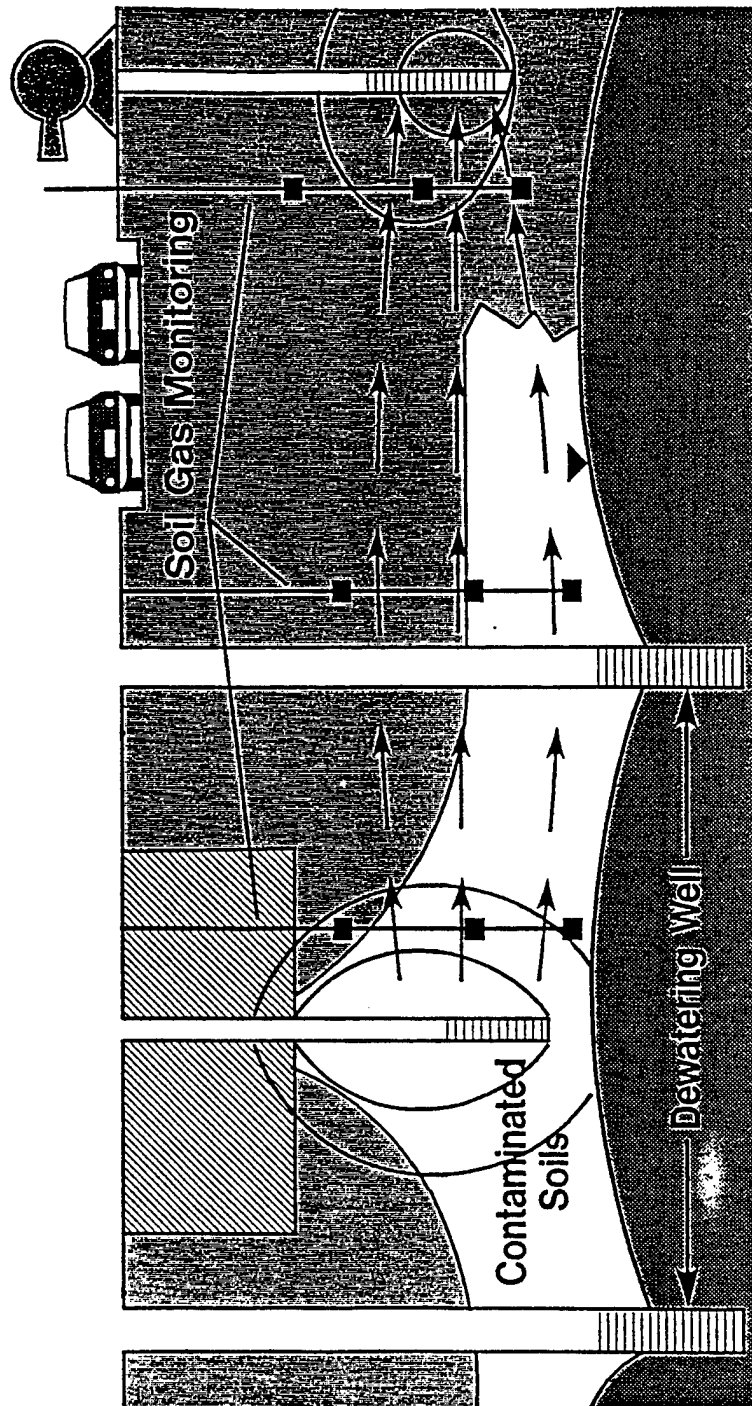


Figure 67. Potential Configuration for Enhanced Bioreclamation Through Soil Venting  
 (Air Withdrawn From Clean Soil)

aerobic conditions in the contaminated and off-gas treatment areas while ensuring that only carbon dioxide, not hydrocarbons, are emitted from the blower. A strategy for design should include as a minimum the following:

1. In addition to a conventional site investigation, initial soil samples should be collected to determine the volume of contaminated soil, the total hydrocarbon, total organic nitrogen (TKN), and total phosphorus concentrations.
2. Initial soil gas analyses should be conducted to delineate hydrocarbon,  $O_2$ , and  $CO_2$  distributions.
3. Field treatability tests to determine in situ respiration rates and gas permeability levels should be conducted to demonstrate biodegradation and to determine rates for design.
4. C:N:P ratios should be determined assuming no nutrient recycle, a C:N:P ratio of 300:10:1 should be adequate, realizing that only one-third of the hydrocarbons are converted to cell mass and two-thirds to carbon dioxide. Wider C:N:P ratios should not eliminate the site as a potential candidate for this technology.
5. Based upon the field treatability tests, an air delivery system should be designed to provide sufficient, but not excess, air to the site.
6. Soil gas should be monitored and adjusted to assure minimum air flow rates to maintain aerobic conditions (2-4 percent  $O_2$ ) and minimize or eliminate hydrocarbons in the blower discharge.
7. Add moisture only if moisture is significantly less than required for biodegradation. Add nutrients only if C:N:P ratios are not satisfied and biodegradation rates are significantly less than reported in this research and if nutrients appear to be limiting. If nitrogen is limiting, consideration may be given to shutting down the air delivery system temporarily and enhancing anaerobic nitrogen fixation.
8. Depending on seasonal temperature fluctuations, operation during periods of maximum soil temperature may be optimum.
9. Manipulate the water table as required for air/contaminant contact.

## SECTION VI

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APPENDIX A  
ENGINEERING CALCULATIONS

Calculations Supporting  
Air Flow Rates

Volume of Vents (not including gravel):

- Treatment Vent (per vent)

$$L \times W \times H = V$$

$$4.9 \text{ meters} \times 2.4 \text{ meters} \times 1.7 \text{ meters} = 20 \text{ m}^3 \\ (16 \text{ feet} \times 8 \text{ feet} \times 5.5 \text{ feet} = 704 \text{ ft}^3)$$

- Background Vent (per vent)

$$2.4 \text{ meters} \times 1.2 \text{ meters} \times 1.1 \text{ meter} = 3.2 \text{ m}^3 \\ (8 \text{ feet} \times 4 \text{ feet} \times 3.5 \text{ feet} = 112 \text{ ft}^3)$$

Assuming an air-filled void volume of 0.20. With a variable flow of 0.1 - 5 pore volumes/day, then the range in rate of air movement is as follows:

- Treatment Vent

$$0.4 \text{ to } 19.9 \text{ m}^3/\text{day} \text{ (14 to } 704 \text{ ft}^3/\text{day)}$$

$$0.275 \text{ to } 14 \text{ liters/minute [0.01 to } 0.49 \text{ cubic feet per minute (cfm)]}$$

- Background Vent

$$.06 \text{ to } 3.2 \text{ m}^3/\text{day} \text{ (2.2 to } 112 \text{ ft}^3/\text{day)}$$

$$0.044 \text{ to } 2.2 \text{ liters/minute (0.0016 to } 0.078 \text{ cfm)}$$

Calculations Supporting  
Water Flow Rates

Surface Area of Vents:

- Treatment Vents

$$L \times W$$

$$4.88 \text{ meters} \times 2.44 \text{ meters} = 11.9 \text{ m}^2 \\ (16 \text{ feet} \times 8 \text{ feet} = 128 \text{ ft}^2)$$

- Background Vent

$$2.44 \text{ meters} \times 1.22 \text{ meters} = 3 \text{ m}^2 \text{ (8 feet} \times 4 \text{ feet} = 32 \text{ ft}^2)$$

Assume a surface infiltration rate of 43 cm to 432 cm/year (17 to 170 inches/year)

= .12 cm/day to 1.12 cm/day (0.047 to 0.47 inches/day)

= .0012 meters/day to .0112 meters/day (0.0039 to 0.039 feet/day)

The flow rates may be calculated as follows:

- Treatment Vents

$11.9 \text{ m}^2 \times .0012 \text{ to } .0112 \text{ meters/day}$   
 $(128 \text{ ft}^2 \times 0.0039 \text{ to } 0.039 \text{ feet/day})$

= 0.014 to .14  $\text{m}^3/\text{day}$  (0.50 - 5.0  $\text{ft}^3/\text{day}$ )

= 14 to 140 liters/day (3.7 -37 gallons/day)

= 10 to 100 mL/minute (0.0026 - 0.026 gallons/minute)

- Background Vents

$3 \text{ m}^2 \times .0012 \text{ to } .0112 \text{ meters/day}$   
 $(32 \text{ ft}^2 \times 0.0039 - 0.039 \text{ feet/day})$

= .0036 to .036  $\text{m}^3/\text{day}$  (0.12 - 1.2  $\text{ft}^3/\text{day}$ )

= 3.6 to 36 liters/day (0.94 - 9.4 gallons/day)

= 2.5 to 25 mL/minute (0.00065 - 0.0065 gallons/minute)

### Calculations Supporting Nutrient Addition Rates

- Treatment Vents (per vent)

Volume = 20  $\text{m}^3$  (704  $\text{ft}^3$ )

Assume  $\approx 1600 \text{ kg}/\text{m}^3$  (100  $\text{lb}/\text{ft}^3$ ) density of soil

Mass of soil  $\sim 32,000 \text{ kg}$  (70,400 lbs)

Assuming a contamination level of 20,000 mg/kg (2  $\text{lb}/\text{ft}^3$ ) of JP-4.

Then the total JP-4 mass  $\sim 640 \text{ kg}$  (1408 lbs)

Using nutrient ratio of C:N:P  
100:10:1 (Reference 28)

Then approximately 64 kg (141 lbs) N and 6.4 (14 lbs) P are needed over a 7-month period for the test.

Nutrient delivery to treatment plots is summarized as follows:

- Treatment Vents (per vent)
  - 64 kg (141 lbs) N = 245 kg (539 lbs)  $\text{NH}_4\text{Cl}$ /7 months  
 = 1.15 kg (2.57 lbs)  $\text{NH}_4\text{Cl}$ /day/treatment vent
  - 6.4 kg (14 lbs) P = 21 kg (46 lbs) Trimetaphosphate (TMP)/7 months  
 = 100 grams (0.22 lbs) TMP/day/treatment vent
- $\text{KNO}_3$  was added as a 0.18 grams/liter solution for additional nutrient needs.
  - $\text{KNO}_3 = 0.18 \text{ grams/liter} @ 20 \text{ mL/minute} = 5.18 \text{ grams}$   
 (0.011 lb)  $\text{KNO}_3$ /day

Mass Balance Approach for Determining Rate Constants (k) in Off-Gas Treatment Plot V3

Figure A-1 illustrates the mass balance approach to calculating leakage and oxygen consumption rate (k percent/minute) in Off-Gas Treatment Plot V3.

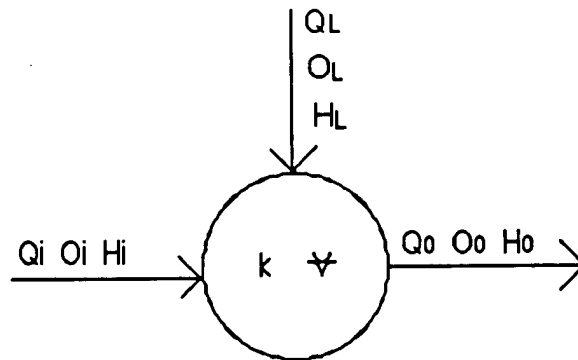


Figure A-1. Mass Balance Schematic for Off-Gas Treatment Plot V3.

- $Q_i$  = Flow from V1 into V3, unknown, liters/minute
- $Q_L$  = Leakage flow, unknown, liters/minute
- $Q_o$  = Flow discharge V3, unknown, liters/minute

- $O_i$  = Oxygen inflow from V1 into V3, known, percent  
 $O_L$  = Oxygen from leakage, known, (percent), assumed to equal V4 oxygen  
 $O_o$  = Oxygen discharged from V3, known, percent  
 $H_i$  = Hydrocarbons inflow from V1 into V3, known, percent by volume  
 $H_L$  = Hydrocarbons from leakage, assumed to be 0 percent by volume  
 $H_o$  = Hydrocarbons discharged from V3, known, percent by volume  
 $V$  = V3 soil volume, assumed to be  
     2.44 meters x 1.22 meters x 1.07 meters x .31 x  
     1000 liters/m<sup>3</sup> = 983.27  
 $K$  = Zero order oxygen decay constant, unknown, but may be estimated from shutdown data, percent/minute.

Mass balance equations:

$$Q_o O_o = Q_i O_i + Q_L O_L - (KV) \quad (A-1)$$

$$Q_o H_o = Q_i H_i - KVX \quad (A-2)$$

$$Q_o = Q_i + Q_L \quad (A-3)$$

Where X = ratio of hydrocarbon mineralized to oxygen removed = .1053

Allowing  $Q_o = 1$  and rewriting Equation A-1

$$O_o = a O_i + b O_L - KD \quad (A-4)$$

Where: a = fraction of flow from V1  
 b = fraction of flow from outside leakage  
 D = Detention time

Rewriting Equation A-2:

$$H_o = a H_i - KD (.1053) \quad (A-5)$$

Rewriting Equation A-3:

$$1 = a + b \quad (A-6)$$

$$b = 1 - a \quad (A-7)$$

Substituting into Equation A-4:

$$O_o = a O_i + (1-a) O_L - KD \quad (A-8)$$



Rewriting Equation A-5:

$$k = \frac{aH_i - H_o}{D (.1053)} \quad (\text{A-9})$$

Substituting into Equation A-8:

$$O_o = aO_i + (1-a)O_L - \frac{(aH_i - H_o) D}{D(.1053)} \quad (\text{A-10})$$

$$O_o = aO_i + O_L - aO_L - a \frac{H_i - H_o}{(.1053)} \quad (\text{A-11})$$

$$O_o - O_L = a(O_i - O_L - \frac{H_i - H_o}{(.1053)}) \quad (\text{A-12})$$

$$a = \frac{O_o - O_L}{O_i + O_L - \frac{H_i - H_o}{(.1053)}} \quad (\text{A-13})$$

Rewriting Equation A-9:

$$K = \frac{a H_i - H_o}{\frac{983 \text{ liters } (.1053)}{\text{Flow Rate (liters/minute)}}} \quad (\text{A-14})$$

APPENDIX B  
OPERATIONAL DATA

TABLE B-1. OPERATIONAL DATA FOR TREATMENT PLOT VI

Date m/d/y h:mm	Venting Time (days)	CO2 (%)	O2 (%)	THC (ppm)	O2+C02 (%)	Average Rotameter	Avg Air Flow (LPM)	Int Vol Air (L)	Cumul Vol Air (L)	Cumul O2 Prov (g)	Inter O2 Disch (g)	Cumul O2 Disch (g)	Cumul O2 Used (g)	
10/4/89 10:05	0.00	15.60	1.4	20640	17.0	12.9	9.8	12962	12962	3244	1070	1070	2174	
10/5/89 8:07	0.92	6.50	11	21261	17.5	9.0	5.4	40413	53375	13357	4088	5158	8199	
10/10/89 14:00	6.16	13.89	4.2	27891	18.1	6.7	3.3	8985	62360	15606	478	5637	9969	
10/12/89 12:00	8.08	15.54	3.8	8087	19.3	11.9	8.6	49430	111790	27975	4211	9848	18128	
10/16/89 12:00	12.08	9.46	9	15919	18.5	11.9	8.6	49568	161358	40380	7126	16974	23406	
10/20/89 12:00	16.08	7.49	12.6	13106	20.1	14.1	11.3	63619	224976	56300	10840	27813	28487	
10/24/89 9:35	19.98	5.58	13	10516	18.6	14.5	11.9	452	225428	56413	78	27891	28522	
10/24/89 10:13	20.01	Blowers off for Shutdown Test 1												
10/26/89 12:00	20.01	Blowers on												
10/27/89 11:11	20.97	8.99	9.1	10288	18.1	13.4	10.4	14433	239862	60025	1748	29640	30386	
10/31/89 12:00	25.01	6.11	12.6	6234	18.7	13.3	10.4	60127	299988	77197	8684	38324	38873	
11/3/89 12:00	28.01	8.68	10.5	6831	19.2	13.3	10.3	44659	344648	89149	6866	45190	43959	
11/6/89 12:00	31.01	5.72	14	5988	19.7	12.9	9.8	42304	386952	99060	6898	52088	46972	
11/9/89 12:00	34.01	7.29	13	6148	20.3	12.7	9.5	41011	427963	111270	7370	59458	51813	
11/14/89 15:00	39.13	6.66	15	6618	21.7	11.6	8.2	60715	488678	126405	11315	70772	55633	
11/16/89 15:00	41.13	5.32	14.8	5439	20.1	10.9	7.4	21373	510051	136014	4239	75011	61002	
11/21/89 15:00	46.13	4.30	15	4385	19.3	11.1	7.7	55233	565284	146974	10955	85966	61008	
11/24/89 14:00	49.09	4.80	15	2703	19.8	9.3	5.7	24266	589550	160358	4845	90811	69547	
11/28/89 12:43	53.04	4.50	14.7	4908	19.2	9.1	5.5	31442	620992	162286	6215	97026	65260	
11/28/89 15:11	53.14	Blowers off for Shutdown Test 2												
12/1/89 14:00	53.14	Blowers on												
12/2/89 17:58	54.30	9.18	10	3389	19.2	7.8	4.2	7013	628744	169342	934	98104	71237	
12/7/89 12:00	59.05	4.40	15.8	2920	20.2	7.7	4.2	28469	657213	177009	4888	102993	74017	
12/11/89 12:00	63.05	4.50	15.5	2304	20.0	7.6	4.0	23274	680487	181463	4849	107841	73622	
12/13/89 14:30	65.16	4.40	15.8	2103	20.2	7.9	4.3	12946	693433	189538	2697	110538	79000	
12/15/89 11:30	67.03	4.50	16	2049	20.5	7.9	4.3	11638	705071	189899	2463	113001	76898	
12/22/89 12:00	74.05	3.40	16.5	2049	19.9	7.7	4.1	41879	746950	209146	9059	122060	87086	
12/27/89 12:00	79.05	2.90	17.7	1498	20.6	7.6	4.0	28894	775844	215167	6577	128637	86531	
12/29/89 12:00	81.05	2.80	17.5	1183	20.3	7.5	4.0	11426	787270	209939	2677	131314	78625	

TABLE B-1. OPERATIONAL DATA FOR TREATMENT PLOT VI (CONTINUED)

Date m/d/y h:mm	Venting Time (days)	CO2 (%)	O2 (%)	THC(ppm)	O2+C02 (%)	Average Rotameter	Avg Air Flow (LPM)	Int Vol Air (L)	Cumul Vol Air (L)	Cumul O2 Prov (g)	Inter O2 Disch (g)	Cumul O2 Disch (g)	Cumul O2 Used (g)
1/2/90 12:00	85.05	2.60	17.3	1500	19.9	7.8	3.3	18889	806158	217125	4375	135689	81437
1/3/90 14:28	86.16	2.80	18.1	1856	20.9	7.9	3.3	5286	811445	221795	1245	136934	84861
1/3/90 15:33	86.20	Blowers off for Shutdown Test 3				7.9	3.3	216	811661	221854	52	136986	84868
1/8/90 13:30	86.20	Blowers on											
1/10/90 11:43	88.13	3.20	17.5	1999	20.7	14.2	8.1	22401	834062	224641	5218	142204	82436
1/12/90 8:56	90.01		17.8	1583		14.2	8.1	21917	855979	230544	5149	147354	83190
1/16/90 10:00	94.06	3.30	16.7	2113	20.0	9.0	4.2	24577	880556	237163	5643	152997	84166
1/19/90 8:00	96.97	4.10	15.8	1690	19.9	9.0	4.2	17724	898280	241937	3834	156831	85106
1/22/90 10:30	100.08	4.80	15.5	1822	20.3	9.0	4.2	18863	917144	247017	3930	160760	86257
1/25/90 6:00	102.89	Blowers off for Shutdown Test 3A				9.0	4.2	17091	934235	251621	3526	164287	87334
1/26/90 15:00	102.89	Blowers on											
2/1/90 16:30	108.95	7.00	12.3	1934	19.3	5.5	2.0	17085	951320	257491	2797	167084	90407
2/4/90 16:30	111.95	8.00	10.8	2247	18.8	5.5	2.0	8454	959774	262338	1300	168384	93955
2/9/90 8:00	116.60	8.00	10.2	2337	18.2	5.5	2.0	13093	972867	262025	1830	170214	91812
2/12/90 15:00	119.89	7.80	10.6	1679	18.4	5.5	2.0	9276	982143	263214	1284	171498	91717
2/21/90 8:00	128.60	9.40	6.9	1886	16.3	3.7	1.1	13625	995769	266866	1587	173085	93781
2/24/90 10:30	131.70	8.50	8.9	2543	17.4	3.7	1.1	4857	1000625	268168	511	173596	94572
2/28/90 10:00	135.68	7.30	10.2	1852	17.5	3.7	1.1	6226	1006851	269836	791	174387	95449
3/3/90 10:35	138.71	4.80	15.3	1489	20.1	7.5	3.1	13429	1020280	273435	2279	176666	96769
3/7/90 11:49	142.76	4.10	15.6	1550	19.7	9.0	4.0	23560	1043840	279749	4845	181511	98238
3/8/90 9:00	143.64	4.50	15.3	1368	19.8	9.0	4.0	5133	1048972	281125	1056	182567	98558
3/8/90 11:35	143.75	Blowers off for Shutdown Test 4				9.0	4.0	626	1049598	281292	127	182694	98598
3/10/90 18:05	143.75	Blowers on											
3/10/90 18:40	143.77	8.80	4.9	2058	13.7	9.0	4.0	141	1049740	281330	9	182704	98627
3/11/90 18:25	144.76	6.80	12.5	1308	19.3	9.0	4.0	5755	1055494	282872	666	183370	99502
3/12/90 8:45	145.36	6.40	12.8	1937	19.2	9.0	4.0	3473	1058967	283803	585	183955	99848
3/13/90 8:00	146.33	6.00	13.4	2119	19.4	9.0	4.0	5633	1064601	285313	982	184937	100376
3/25/90 8:30	158.35	4.60	14.5	1471	19.1	9.0	4.0	69904	1134504	304047	12980	197918	106130
3/30/90 8:30	163.35	5.90	13.2	1359	19.1	9.0	4.0	29076	1163580	311839	5360	203278	108562
4/9/90 10:00	173.41	4.70	15	1359	19.7	9.0	4.0	58515	1222096	327522	10983	214261	113261
4/13/90 9:30	177.39	4.60	15.2	1599	19.8	9.0	4.0	23140	1245235	333723	4651	218912	114811
4/24/90 9:30	188.39	6.10	12.7	1599	18.8	9.0	4.0	63967	1309202	350866	11878	230790	120077
4/24/90 13:00	188.54	Blowers off for Shutdown Test 5				9.0	4.0	848	1310051	351094	143	230933	120160
5/2/90 9:30	196.39	Blowers on											

TABLE B-1. OPERATIONAL DATA FOR TREATMENT PLOT VI (CONTINUED)

Date m/d/y h:mm	Hexane Eq. CO <sub>2</sub> (g)	Hexane Eq. O <sub>2</sub> (g)	Hexane Eq. THC (g)	% Biol Deg CO <sub>2</sub> Basis	% Biol Deg O <sub>2</sub> Basis	Cum Hex Eq CO <sub>2</sub> (g)	Cum Hex Eq O <sub>2</sub> (g)	Cum Hex Eq THC (g)	Cum Hex Eq O <sub>2</sub> & THC (g)	Cum Hex Eq CO <sub>2</sub> & THC (g)	Cum % Bio Deg CO <sub>2</sub> Basis	Cum % Biol Deg O <sub>2</sub> Basis
10/4/89 10:05												
10/5/89 8:07	730	615	971	42.9	38.8	730	615	971	1587	1702	42.9	38.8
10/10/89 14:00	2071	1704	3553	36.8	32.4	2801	2319	4524	6844	7326	38.2	33.9
10/12/89 12:00	703	501	578	54.9	46.4	3504	2820	5103	7923	8607	40.7	35.6
10/16/89 12:00	3213	2308	2122	60.2	52.1	6717	5128	7225	12353	13942	48.2	41.5
10/20/89 12:00	2033	1493	2573	44.1	36.7	8750	6622	9799	16420	18548	47.2	40.3
10/24/89 9:35	1873	1437	2688	41.1	34.8	10623	8059	12487	20545	23109	46.0	39.2
10/24/89 10:13	11	10	17	38.7	36.7	10633	8069	12504	20572	23137	46.0	39.2
10/26/89 12:00												
10/27/89 11:11	636	527	531	54.5	49.8	11269	8596	13035	21631	24304	46.4	39.7
10/31/89 12:00	2240	1913	1777	55.8	51.8	13509	10509	14812	25321	28321	47.7	41.5
11/3/89 12:00	1649	1320	1044	61.2	55.8	15159	11829	15855	27685	31014	48.9	42.7
11/6/89 12:00	1437	1107	970	59.7	53.3	16595	12937	16825	29762	33421	49.7	43.5
11/9/89 12:00	1224	927	890	57.9	51.0	17820	13863	17716	31579	35535	50.1	43.9
11/14/89 15:00	2019	1257	1386	59.3	47.6	19839	15121	19102	34223	38941	50.9	44.2
11/16/89 15:00	649	410	461	58.5	47.1	20488	15531	19563	35094	40050	51.2	44.3
11/21/89 15:00	1255	957	970	56.4	49.6	21743	16488	20533	37021	42276	51.4	44.5
11/24/89 14:00	557	493	308	64.4	61.6	22300	16981	20841	37822	43141	51.7	44.9
11/28/89 12:43	703	562	428	62.2	56.8	23003	17544	21269	38813	44272	52.0	45.2
11/28/89 15:11	16	14	13	55.0	51.2	23019	17557	21282	38839	44301	52.0	45.2
12/1/89 14:00												
12/2/89 17:58	355	269	85	80.7	76.0	23373	17827	21367	39194	44740	52.2	45.5
12/7/89 12:00	1034	783	321	76.3	70.9	24407	18609	21688	40298	46096	52.9	46.2
12/11/89 12:00	548	381	217	71.6	63.7	24955	18990	21906	40896	46861	53.3	46.4
12/13/89 14:30	305	236	102	74.9	69.9	25260	19227	22008	41235	47268	53.4	46.6
12/15/89 11:30	281	188	86	76.5	68.6	25541	19415	22094	41510	47636	53.6	46.8
12/22/89 12:00	936	749	307	75.3	70.9	26478	20164	22401	42566	48879	54.2	47.4
12/27/89 12:00	474	403	183	72.1	68.7	26951	20567	22585	43152	49536	54.4	47.7
12/29/89 12:00	160	103	55	74.5	65.3	27112	20670	22639	43310	49751	54.5	47.7

TABLE B-1. OPERATIONAL DATA FOR TREATMENT PLOT VI (CONTINUED)

Date m/d/y h:mm	Hexane Eq. CO <sub>2</sub> (g)	Hexane Eq. O <sub>2</sub> (g)	Hexane Eq. THC (g)	% Biol Deg CO <sub>2</sub> Basis	% Biol Deg O <sub>2</sub> Basis	Cum Hex Eq CO <sub>2</sub> (g)	Cum Hex Eq O <sub>2</sub> (g)	Cum Hex Eq THC (g)	Cum Hex Eq O <sub>2</sub> & THC (g)	Cum Hex Eq CO <sub>2</sub> & THC (g)	Cum % Bio CO <sub>2</sub> Basis	Cum % Biol Deg O <sub>2</sub> Basis
1/2/90 12:00	248	199	91	73.2	68.7	27359	20869	22730	43600	50089	54.6	47.9
1/3/90 14:28	76	56	32	70.4	63.7	27435	20925	22762	43687	50197	54.7	47.9
1/3/90 15:33	3	2	1	69.2	57.6	27438	20927	22763	43690	50202	54.7	47.9
1/8/90 13:30												
1/10/90 11:43	374	236	160	70.0	59.6	27812	21163	22923	44087	50736	54.8	48.0
1/12/90 8:56	157	219	140	52.8	60.9	27969	21382	23064	44446	51033	54.8	48.1
1/16/90 10:00	154	273	162	48.6	62.7	28123	21655	23226	44881	51349	54.8	48.2
1/19/90 8:00	317	264	121	72.4	68.6	28440	21919	23347	45266	51787	54.9	48.4
1/22/90 10:30	422	323	119	78.1	73.2	28862	22242	23465	45707	52327	55.2	48.7
1/25/90 6:00	418	302	111	78.9	73.1	29279	22544	23577	46121	52856	55.4	48.9
1/26/90 15:00												
2/1/90 16:30	642	515	118	84.4	81.3	29921	23059	23695	46754	53616	55.8	49.3
2/4/90 16:30	348	285	63	84.6	81.8	30269	23344	23758	47102	54027	56.0	49.6
2/9/90 8:00	554	468	107	83.8	81.4	30823	23812	23866	47678	54689	56.4	49.9
2/12/90 15:00	393	339	67	85.5	83.6	31217	24151	23932	48083	55149	56.6	50.2
2/21/90 8:00	651	587	87	88.2	87.1	31868	24739	24019	48758	55887	57.0	50.7
2/24/90 10:30	251	230	38	86.7	85.7	32118	24969	24058	49027	56176	57.2	50.9
2/28/90 10:00	268	250	49	84.5	83.6	32386	25219	24107	49325	56493	57.3	51.1
3/3/90 10:35	437	382	80	84.5	82.6	32823	25601	24187	49787	57010	57.6	51.4
3/7/90 11:49	542	430	128	80.9	77.1	33365	26031	24315	50346	57680	57.8	51.7
3/8/90 9:00	113	94	27	80.9	77.8	33478	26125	24342	50466	57820	57.9	51.8
3/8/90 11:35	15	12	3	82.6	79.4	33493	26136	24345	50481	57838	57.9	51.8
3/10/90 18:05												
3/10/90 18:40	6	8	1	86.2	88.4	33499	26144	24346	50490	57845	57.9	51.8
3/11/90 18:25	230	241	35	86.9	87.4	33730	26385	24380	50765	58110	58.0	52.0
3/12/90 8:45	114	94	20	85.0	82.3	33844	26478	24401	50879	58244	58.1	52.0
3/13/90 8:00	172	142	41	80.8	77.7	34015	26621	24441	51062	58457	58.2	52.1
3/25/90 8:30	1795	1593	449	80.0	78.0	35811	28213	24890	53103	60701	59.0	53.1
3/30/90 8:30	738	673	147	83.4	82.1	36549	28886	25037	53924	61586	59.3	53.6
4/9/90 10:00	1573	1322	284	84.7	82.3	38121	30209	25322	55530	63443	60.1	54.4
4/13/90 9:30	532	427	122	81.3	77.7	38653	30636	25444	56080	64097	60.3	54.6
4/24/90 9:30	1585	1337	366	81.3	78.5	40239	31972	25810	57782	66049	60.9	55.3
4/24/90 13:00	25	22	5	83.7	81.7	40263	31994	25815	57809	66078	60.9	55.3
5/2/90 9:30												

TABLE B-1. OPERATIONAL DATA FOR TREATMENT PLOT VI (CONTINUED)

Date m/d/y h:mm	Hexane Eq. CO <sub>2</sub> (g/day)	Hexane Eq. O <sub>2</sub> (g/day)	Hexane Eq. THC (g/day)	Hexane Eq. O <sub>2</sub> (g/day)	Tot Hexane Eq. CO <sub>2</sub> &THC (g/day)	Hexane Eq. CO <sub>2</sub> (mg/(kg day))	Hexane Eq. THC (mg/(kg day))	Hexane Eq. O <sub>2</sub> (mg/(kg day))	Hexane Eq. THC (mg/(kg day))	Tot Hexane Eq. CO <sub>2</sub> &THC (mg/(kg day))
10/4/89 10:05										
10/5/89 8:07	795.5	669.9	1058.2	1728.1	1853.8	27.7	23.3	36.8	60.1	60.1
10/10/89 14:00	394.9	325.0	677.4	1002.3	1072.2	13.7	11.3	23.5	34.8	34.8
10/12/89 12:00	366.6	261.3	301.7	562.9	668.3	12.7	9.1	10.5	19.6	19.6
10/16/89 12:00	803.3	577.0	530.6	1107.6	1333.9	27.9	20.1	18.4	38.5	38.5
10/20/89 12:00	508.2	373.3	643.3	1016.6	1151.5	17.7	13.0	22.4	35.3	35.3
10/24/89 9:35	480.3	368.6	689.4	1058.0	1169.6	16.7	12.8	24.0	36.8	36.8
10/24/89 10:13	406.6	374.1	644.3	1018.4	1051.0	14.1	13.0	22.4	35.4	35.4
10/26/89 12:00										
10/27/89 11:11	658.1	545.8	549.9	1095.7	1208.0	22.9	19.0	19.1	38.1	38.1
10/31/89 12:00	555.4	474.3	440.5	914.7	995.9	19.3	16.5	15.3	31.8	31.8
11/3/89 12:00	549.7	440.0	347.9	787.9	897.6	19.1	15.3	12.1	27.4	27.4
11/6/89 12:00	478.9	369.0	323.3	692.4	802.3	16.6	12.8	11.2	24.1	24.1
11/9/89 12:00	408.0	308.9	296.8	605.6	704.8	14.2	10.7	10.3	21.1	21.1
11/14/89 15:00	394.0	245.4	270.5	515.9	664.5	13.7	8.5	9.4	17.9	17.9
11/16/89 15:00	324.4	205.2	230.5	435.7	554.9	11.3	7.1	8.0	15.1	15.1
11/21/89 15:00	251.0	191.3	194.1	385.4	445.1	8.7	6.7	6.7	13.4	13.4
11/24/89 14:00	188.3	166.8	104.0	270.8	292.3	6.5	5.8	3.6	9.4	9.4
11/28/89 12:43	178.1	142.5	108.5	251.0	286.6	6.2	5.0	3.8	8.7	8.7
11/28/89 15:11	154.3	132.7	126.2	258.9	280.5	5.4	4.6	4.4	9.0	9.0
12/1/89 14:00										
12/2/89 17:58	304.4	231.2	73.0	304.1	377.4	10.6	8.0	2.5	10.6	10.6
12/7/89 12:00	217.6	164.7	67.6	232.3	285.2	7.6	5.7	2.4	8.1	8.1
12/11/89 12:00	137.0	95.3	54.4	149.7	191.4	4.8	3.3	1.9	5.2	5.2
12/13/89 14:30	144.9	112.4	48.5	160.9	193.4	5.0	3.9	1.7	5.6	5.6
12/15/89 11:30	149.9	100.5	46.1	146.6	196.0	5.2	3.5	1.6	5.1	5.1
12/22/89 12:00	133.4	106.7	43.7	150.4	177.1	4.6	3.7	1.5	5.2	5.2
12/27/89 12:00	94.8	80.5	36.7	117.2	131.4	3.3	2.8	1.3	4.1	4.1
12/29/89 12:00	80.0	51.6	27.4	79.0	107.4	2.8	1.8	1.0	2.7	2.7

TABLE B-1. OPERATIONAL DATA FOR TREATMENT PLOT VI (CONTINUED)

Date m/d/y h:mm	Hexane Eq. CO <sub>2</sub> (g/day)	Hexane Eq. O <sub>2</sub> (g/day)	Hexane Eq. THC (g/day)	Hexane Eq. O <sub>2</sub> &THC (g/day)	Tot Hexane Eq. CO <sub>2</sub> &THC (g/day)	Hexane Eq. CO <sub>2</sub> (mg/(kg day))	Hexane Eq. THC (mg/(kg day))	Hexane Eq. O <sub>2</sub> (mg/(kg day))	Hexane Eq. THC (mg/(kg day))	Hexane Eq. O <sub>2</sub> &THC (mg/(kg day))	Tot Hexane Eq. O <sub>2</sub> &THC (mg/(kg day))
1/2/90 12:00	61.9	49.8	22.7	72.5	84.6	2.2	1.7	0.8	2.5	2.5	2.5
1/3/90 14:28	68.6	50.5	28.8	79.3	97.4	2.4	1.8	1.0	2.8	2.8	2.8
1/3/90 15:33	71.5	43.3	31.8	75.2	103.3	2.5	1.5	1.1	2.6	2.6	2.6
1/8/90 13:30											
1/10/90 11:43	194.2	122.7	83.2	205.8	277.4	6.8	4.3	2.9	7.2	7.2	7.2
1/12/90 8:56	83.2	116.1	74.5	190.6	157.7	2.9	4.0	2.6	6.6	6.6	6.6
1/16/90 10:00	38.0	67.5	40.2	107.7	78.2	1.3	2.3	1.4	3.7	3.7	3.7
1/19/90 8:00	108.7	90.4	41.3	131.7	150.0	3.8	3.1	1.4	4.6	4.6	4.6
1/22/90 10:30	135.9	104.1	38.2	142.3	174.1	4.7	3.6	1.3	4.9	4.9	4.9
1/25/90 6:00	148.5	107.6	39.6	147.2	188.2	5.2	3.7	1.4	5.1	5.1	5.1
1/26/90 15:00											
2/1/90 16:30	105.9	84.9	19.5	104.4	125.4	3.7	3.0	0.7	3.6	3.6	3.6
2/4/90 16:30	115.9	95.0	21.1	116.1	137.0	4.0	3.3	0.7	4.0	4.0	4.0
2/9/90 8:00	119.3	100.8	23.1	123.9	142.4	4.1	3.5	0.8	4.3	4.3	4.3
2/12/90 15:00	119.5	102.9	20.2	123.2	139.7	4.2	3.6	0.7	4.3	4.3	4.3
2/21/90 8:00	74.8	67.5	10.0	77.4	84.7	2.6	2.3	0.3	2.7	2.7	2.7
2/24/90 10:30	80.8	74.2	12.4	86.6	93.2	2.8	2.6	0.4	3.0	3.0	3.0
2/28/90 10:00	67.3	62.7	12.3	75.0	79.6	2.3	2.2	0.4	2.6	2.6	2.6
3/3/90 10:35	144.5	126.2	26.5	152.8	171.1	5.0	4.4	0.9	5.3	5.3	5.3
3/7/90 11:49	133.7	106.2	31.6	137.8	165.3	4.6	3.7	1.1	4.8	4.8	4.8
3/8/90 9:00	128.5	106.2	30.4	136.6	158.8	4.5	3.7	1.1	4.7	4.7	4.7
3/8/90 11:35	135.2	109.5	28.5	138.0	163.7	4.7	3.8	1.0	4.8	4.8	4.8
3/10/90 18:05											
3/10/90 18:40	267.0	326.3	42.8	369.1	309.8	9.3	11.3	1.5	12.8	12.8	12.8
3/11/90 18:25	232.7	243.1	35.0	278.1	267.7	8.1	8.5	1.2	9.7	9.7	9.7
3/12/90 8:45	191.0	156.6	33.8	190.3	224.8	6.6	5.4	1.2	6.6	6.6	6.6
3/13/90 8:00	177.1	146.7	42.2	188.9	219.3	6.2	5.1	1.5	6.6	6.6	6.6
3/25/90 8:30	149.3	132.5	37.3	169.8	186.7	5.2	4.6	1.3	5.9	5.9	5.9
3/30/90 8:30	147.6	134.7	29.4	164.1	177.0	5.1	4.7	1.0	5.7	5.7	5.7
4/9/90 10:00	156.3	131.4	28.3	159.7	184.6	5.4	4.6	1.0	5.6	5.6	5.6
4/13/90 9:30	133.7	107.3	30.8	138.1	164.5	4.6	3.7	1.1	4.8	4.8	4.8
4/24/90 9:30	144.1	121.5	33.3	154.8	177.4	5.0	4.2	1.2	5.4	5.4	5.4
4/24/90 13:00	170.2	148.9	33.3	182.2	203.4	5.9	5.2	1.2	6.3	6.3	6.3
5/2/90 9:30											



TABLE B-1. OPERATIONAL DATA FOR TREATMENT PLOT VI (CONTINUED)

Date m/d/y h:mm	Tot Hexane Eq.		Ambient Mean		Soil Mean Temp °C
	CO2&THC (mg/(kg day))	Temp °C	Temp °C	Temp °C	
10/4/89 10:05		25.0			
10/5/89 8:07	64.4	23.6			
10/10/89 14:00	37.3	19.4			
10/12/89 12:00	23.2	23.3			
10/16/89 12:00	46.4	26.1			
10/20/89 12:00	40.0	9.2			
10/24/89 9:35	40.7	19.2			
10/24/89 10:13	36.5	19.2			
10/26/89 12:00					
10/27/89 11:11	42.0	20.0			
10/31/89 12:00	34.6	20.6			
11/3/89 12:00	31.2	15.6			
11/6/89 12:00	27.9	18.3			
11/9/89 12:00	24.5	17.8			
11/14/89 15:00	23.1	20.0			
11/16/89 15:00	19.3	15.0			
11/21/89 15:00	15.5	20.6			
11/24/89 14:00	10.2	11.1			
11/28/89 12:43	10.0	20.0			
11/28/89 15:11	9.8	20.0			
12/1/89 14:00					
12/2/89 17:58	13.1	12.8			
12/7/89 12:00	9.9	20.6			
12/11/89 12:00	6.7	13.9			
12/13/89 14:30	6.7	8.3			
12/15/89 11:30	6.8	13.9			
12/22/89 12:00	6.2	0.6			
12/27/89 12:00	4.6	12.8			
12/29/89 12:00	3.7	13.9			

TABLE B-1. OPERATIONAL DATA FOR TREATMENT PLOT VI (CONCLUDED)

Date m/d/y h:mm	Tot Hexane Eq. CO2&THC (mg/(kg day))	Ambient Mean Temp °C	Soil Mean Temp °C
1/2/90 12:00	2.9	8.9	
1/3/90 14:28	3.4	15.0	17.7
1/3/90 15:33	3.6	15.0	
1/8/90 13:30		13.3	
1/10/90 11:43	9.6	14.4	
1/12/90 8:56	5.5	11.1	
1/16/90 10:00	2.7	16.7	
1/19/90 8:00	5.2	18.3	
1/22/90 10:30	6.1	11.1	
1/25/90 6:00	6.5	16.1	18.5
1/26/90 15:00		8.9	
2/1/90 16:30	4.4	16.7	
2/4/90 16:30	4.8	15.0	
2/9/90 8:00	5.0	20.0	
2/12/90 15:00	4.9	15.0	
2/21/90 8:00	2.9	16.7	
2/24/90 10:30	3.2	11.7	
2/28/90 10:00	2.8	15.0	
3/3/90 10:35	5.9	13.9	
3/7/90 11:49	5.7	21.7	
3/8/90 9:00	5.5	20.0	
3/8/90 11:35	5.7	20.0	
3/10/90 18:05		20.6	
3/10/90 18:40	10.8	20.6	
3/11/90 18:25	9.3	21.7	
3/12/90 8:45	7.8	21.1	22.0
3/13/90 8:00	7.6	21.1	
3/25/90 8:30	6.5	20.0	
3/30/90 8:30	6.2	22.2	
4/9/90 10:00	6.4	18.9	
4/13/90 9:30	5.7	17.2	
4/24/90 9:30	6.2	22.2	
4/24/90 13:00	7.1	22.2	26.0
5/2/90 9:30			

TABLE B-2. OPERATIONAL DATA FOR TREATMENT PLOT V2

Date m/d/y h:mm	Venting Time (days)	CO2 (%)	O2 (%)	THC (ppm)	O2+CO2 (%)	Average Rotameter	Avg Air Flow (LPM)	Int Vol Air (L)	Cumul Vol Air (L)	Cumul O2 Prov (g)	Inter O2 Disch (g)	Cumul O2 Disch (g)	Cumul O2 Used (g)	
10/4/89 10:40	0.00	16.17	6	6414	22.2	13.5	10.3	15970	15970	3996	1807	1807	2189	
10/5/89 12:00	1.08	7.00	11	10528	18.0	8.5	4.8	35172	51142	12798	4097	5904	6895	
10/10/89 14:00	6.16	10.42	6.5	23623	16.9	6.0	3.0	8294	59435	14874	773	6676	8197	
10/12/89 12:00	8.08	10.77	7.5	10262	18.3	12.1	8.6	49272	108707	27204	6493	13169	14035	
10/16/89 12:00	12.08	6.90	12.3	24233	19.2	11.3	7.6	43804	152511	38166	7930	21099	17067	
10/20/89 12:00	16.08	4.65	14.9	14298	19.6	8.0	4.4	24726	177238	44354	4674	25773	18581	
10/24/89 8:57	19.95	5.10	13.5	11583	18.6	8.0	4.4	337	177575	44438	61	25834	18604	
10/24/89 10:13	20.01	Blowers off for Shutdown Test 1												
10/26/89 12:00	20.01	Blowers on												
10/27/89 10:48	20.96	8.21	9	13869	17.2	13.4	10.1	13814	191389	47895	1655	27489	20406	
10/31/89 12:00	25.01	6.11	11.2	8539	17.3	13.2	9.9	57977	249366	64170	7795	35283	28887	
11/3/89 12:00	28.01	8.68	10	13957	18.7	13.2	9.9	42890	292256	75597	6052	41335	34262	
11/6/89 12:00	31.01	7.10	12.5	12425	19.6	13.3	10.0	43284	335540	85898	6482	47817	38082	
11/9/89 12:00	34.01	8.77	10.7	8185	19.5	13.3	10.0	43341	378881	98509	6692	54509	44000	
11/14/89 15:00	39.13	4.79	15.8	7136	20.6	13.2	9.9	73078	451959	116907	12889	67398	49509	
11/16/89 15:00	41.13	5.52	14	4058	19.5	13.3	10.1	28969	480928	128247	5746	73143	55104	
11/21/89 15:00	46.13	5.32	13.2	5273	18.5	13.4	10.2	73276	554204	144093	13265	86409	57684	
11/24/89 14:00	49.09	4.90	13.8	3952	18.7	13.4	10.2	43299	597503	162521	7781	94190	68331	
11/28/89 13:50	53.08	5.47	13	6354	18.5	13.4	10.2	58367	655870	171401	10411	104600	66800	
11/28/89 15:11	53.14	Blowers off for Shutdown Test 2												
12/1/89 14:00	53.14	Blowers on												
12/2/89 17:46	54.30	6.84	13	4142	19.8	13.4	10.1	16889	673572	181415	2923	107664	73752	
12/7/89 12:00	59.05	4.90	15	3517	19.9	13.4	10.1	69393	742965	200105	12932	120596	79510	
12/11/89 12:00	63.05	3.40	16.7	2893	20.1	13.3	10.0	57411	800376	213434	12113	132708	80725	
12/13/89 14:30	65.16	2.90	17.1	2813	20.0	13.2	9.9	29925	830301	226949	6732	139440	87509	
12/15/89 11:30	67.03	3.30	17.3	2090	20.6	13.3	10.0	26982	857283	230895	6178	145618	85277	
12/22/89 12:00	74.05	2.60	16.8	2090	19.4	13.2	9.9	100242	957526	268107	22750	168368	99739	
12/27/89 12:00	79.05	2.60	17.9	2267	20.5	13.2	10.0	71670	1029196	285430	16552	184920	100510	
12/29/89 12:00	81.05	2.30	17.7	1518	20.0	13.3	10.1	28969	1058165	282177	6864	191784	90393	

TABLE B-2. OPERATIONAL DATA FOR TREATMENT PLOT V2 (CONTINUED)

Date m/d/y h:mm	Venting Time (days)	CO2 (%)	O2 (%)	THC (ppm)	O2+C02 (%)	Average Rotameter Flow (LPM)	Avg Air Flow (LPM)	Int Vol Air (L)	Cumul Vol Air (L)	Cumul O2 Prov (g)	Inter O2 Disch (g)	Cumul O2 Disch (g)	Cumul O2 Used (g)
1/2/90 12:00	85.05	1.90	18.2	1600	20.1	13.3	10.0	57788	1115953	300563	13808	205592	94971
1/3/90 14:32	86.16	2.40	18.3	1915	20.7	13.3	10.0	15868	1131821	309364	3855	209447	99918
1/3/90 15:33	86.20	Blowers off for Shutdown Test 3											
1/8/90 13:30	86.20	Blowers on											
1/12/90 9:40	90.04	3.00	17.5	1758	20.5	13.8	8.0	44480	1176889	316975	10361	219951	97024
1/16/90 10:00	94.06	3.60	16.2	2061	19.8	9.0	4.3	24820	1201709	323660	5567	225518	98142
1/19/90 8:00	96.97	4.20	14.7	2244	18.9	9.0	4.3	18212	1219922	328566	3745	229264	99302
1/22/90 10:30	100.08	5.20	15.4	2270	20.6	9.0	4.3	19414	1239336	333795	3889	233153	100641
1/25/90 6:00	102.89	Blowers off for Shutdown Test 3A											
1/26/90 15:00	102.89	Blowers on											
2/1/90 16:30	108.95	6.80	12.2	2300	18.8	5.5	2.1	17954	1274795	345045	2916	239657	105387
2/4/90 16:30	111.95	6.90	12.9	2276	19.8	5.5	2.1	8885	1283680	350872	1484	241141	109731
2/9/90 8:00	116.60	8.60	7.9	2750	16.5	5.5	2.1	13759	1297439	345984	1905	243046	102937
2/12/90 15:00	119.89	9.10	7.9	2877	17.0	5.5	2.1	9748	1307187	350326	1025	244071	106255
2/21/90 8:00	128.60	6.70	11.8	2430	18.5	3.7	1.0	13022	1320209	353816	1707	245779	108037
2/24/90 10:30	131.70	6.00	13	2046	19.0	3.7	1.0	4642	1324851	355060	766	246545	108515
2/28/90 10:00	135.68	6.10	12	2107	18.1	3.7	1.0	5950	1330801	356655	990	247535	109120
3/3/90 10:35	138.71	4.70	15.2	1870	19.9	7.5	3.3	14393	1345194	360512	2606	250141	110372
3/7/90 11:53	142.76	4.90	14.2	1887	19.1	9.0	4.3	25233	1370428	367275	4937	255078	112197
3/8/90 9:25	143.66	4.70	15	2174	19.7	9.0	4.3	5584	1376012	368771	1085	256163	112608
3/8/90 11:35	143.75	Blowers off for Shutdown Test 4											
3/10/90 18:05	143.75	Blowers on											
3/10/90 18:45	143.78	9.80	3.1	3069	12.9	9.0	4.3	173	1376747	368968	7	256283	112686
3/11/90 18:30	144.77	7.70	10.1	2334	17.8	9.0	4.3	6159	1382906	370619	541	256824	113795
3/12/90 8:55	145.37	7.20	10.7	2782	17.9	9.0	4.3	3739	1386645	371621	518	257341	114279
3/13/90 8:10	146.33	6.80	11.2	2638	18.0	9.0	4.3	6029	1392674	373237	879	258220	115017
3/25/90 8:30	158.35	4.60	14.8	2110	19.4	9.0	4.3	74774	1467448	393276	12939	271159	122117
3/30/90 8:30	163.35	5.90	12.5	2238	18.4	9.0	4.3	31120	1498568	401616	5654	276814	124803
4/9/90 10:00	173.41	5.00	14.7	1966	19.7	9.0	4.3	62629	1561197	418401	11338	288152	130249
4/13/90 9:30	177.39	4.90	13.8	2078	18.7	9.0	4.3	24766	1585964	425038	4698	292849	132189
4/24/90 9:30	188.39	7.50	10.8	2302	18.3	9.0	4.3	68464	1654428	443387	11209	304059	139328
4/24/90 13:00	188.54	Blowers off for Shutdown Test 5											
5/2/90 9:30	196.39	Blowers on											

TABLE B-2. OPERATIONAL DATA FOR TREATMENT PLOT V2 (CONTINUED)

Date m/d/y h:mm	Hexane Eq. CO2 (g)	Hexane Eq. O2 (g)	Hexane Eq. THC (g)	% Biol Deg CO2 Basis	% Biol Deg O2 Basis	Cum Hex Eq CO2 (g)	Cum Hex Eq O2 (g)	Cum Hex Eq THC (g)	Cum Hex Eq O2&THC (g)	Cum Hex Eq CO2&THC (g)	Cum % Bio Deg CO2 Basis	Cum % Biol Deg O2 Basis
10/4/89 10:05												
10/5/89 8:07	951	619	484	66.3	56.1	951	619	484	1103	1435	66.3	56.1
10/10/89 14:00	1491	1331	2148	41.0	38.3	2442	1950	2632	4583	5074	48.1	42.6
10/12/89 12:00	445	369	503	46.9	42.3	2886	2319	3135	5454	6021	47.9	42.5
10/16/89 12:00	2125	1651	3040	41.1	35.2	5011	3970	6175	10146	11186	44.8	39.1
10/20/89 12:00	1090	858	3019	26.5	22.1	6102	4828	9194	14022	15296	39.9	34.4
10/24/89 9:35	483	428	1145	29.7	27.2	6584	5256	10339	15595	16923	38.9	33.7
10/24/89 10:13	7	7	14	33.5	32.5	6592	5263	10353	15616	16944	38.9	33.7
10/26/89 12:00												
10/27/89 11:11	544	510	685	44.3	42.7	7136	5773	11038	16811	18174	39.3	34.3
10/31/89 12:00	2024	2009	2324	46.6	46.4	9160	7781	13362	21143	22522	40.7	36.8
11/3/89 12:00	1583	1421	1726	47.8	45.2	10743	9203	15088	24290	25831	41.6	37.9
11/6/89 12:00	1648	1296	2043	44.7	38.8	12391	10499	17130	27629	29521	42.0	38.0
11/9/89 12:00	1663	1289	1598	51.0	44.7	14054	11788	18728	30516	32782	42.9	38.6
11/14/89 15:00	2345	1720	2003	53.9	46.2	16399	13508	20731	34239	37130	44.2	39.5
11/16/89 15:00	735	556	580	55.9	49.0	17134	14064	21311	35375	38445	44.6	39.8
11/21/89 15:00	1932	1628	1223	61.2	57.1	19066	15692	22534	38226	41600	45.8	41.1
11/24/89 14:00	1139	1125	714	61.5	61.2	20205	16817	23248	40065	43453	46.5	42.0
11/28/89 12:43	1491	1363	1076	58.1	55.9	21697	18180	24324	42504	46021	47.1	42.8
11/28/89 15:11	22	20	18	54.5	52.2	21719	18200	24343	42543	46061	47.2	42.8
12/1/89 14:00												
12/2/89 17:58	618	458	250	71.2	64.7	22337	18658	24593	43251	46930	47.6	43.1
12/7/89 12:00	2139	1620	951	69.2	63.0	24475	20278	25543	45821	50019	48.9	44.3
12/11/89 12:00	1249	897	658	65.5	57.7	25725	21175	26202	47377	51927	49.5	44.7
12/13/89 14:30	473	406	305	60.8	57.0	26198	21581	26507	48088	52705	49.7	44.9
12/15/89 11:30	434	305	237	64.7	56.3	26632	21886	26744	48629	53376	49.9	45.0
12/22/89 12:00	1644	1491	749	68.7	66.5	28276	23377	27493	50870	55769	50.7	46.0
12/27/89 12:00	940	931	559	62.7	62.5	29216	24308	28052	52360	57268	51.0	46.4
12/29/89 12:00	337	240	196	63.2	55.0	29553	24548	28248	52796	57800	51.1	46.5

TABLE B-2. OPERATIONAL DATA FOR TREATMENT PLOT V2 (CONTINUED)

Date m/d/y h:mm	Hexane Eq. CO2 (g)	Hexane Eq. O2 (g)	Hexane Eq. THC (g)	% Biol Deg CO2 Basis	% Biol Deg O2 Basis	Cum Hex Eq CO2 (g)	Cum Hex Eq O2 (g)	Cum Hex Eq THC (g)	Cum Hex Eq O2&THC (g)	Cum Hex Eq CO2&THC (g)	Cum % Bio Deg CO2 Basis	Cum % Biol Deg O2 Basis
1/2/90 12:00	551	490	322	63.1	60.3	30104	25038	28570	53608	58674	51.3	46.7
1/3/90 14:28	175	134	100	63.7	57.4	30279	25172	28670	53842	58949	51.4	46.8
1/3/90 15:33	7	5	4	64.6	54.7	30286	25177	28674	53851	58960	51.4	46.8
1/8/90 13:30												
1/10/90 11:43	690	469	280	71.1	62.6	30976	25646	28954	54600	59930	51.7	47.0
1/12/90 8:56	400	322	170	70.2	65.5	31375	25968	29123	55092	60499	51.9	47.1
1/16/90 10:00	347	326	140	71.2	69.9	31723	26294	29264	55558	60986	52.0	47.3
1/19/90 8:00	463	377	157	74.7	70.6	32186	26671	29420	56091	61606	52.2	47.5
1/22/90 10:30	470	316	71	86.9	81.7	32655	26987	29491	56478	62147	52.5	47.8
1/25/90 6:00												
1/26/90 15:00	653	271	73	89.9	78.8	33308	27258	29565	56822	62873	53.0	48.0
2/1/90 16:30	331	266	73	82.0	78.5	33640	27524	29637	57161	63277	53.2	48.2
2/4/90 16:30	562	497	124	82.0	80.1	34201	28021	29761	57782	63962	53.5	48.5
2/9/90 8:00	469	448	98	82.7	82.0	34670	28469	29859	58328	64529	53.7	48.8
2/12/90 15:00	568	508	124	82.1	80.4	35238	28977	29983	58959	65221	54.0	49.1
2/21/90 8:00	168	142	37	81.9	79.2	35406	29118	30020	59138	65425	54.1	49.2
2/24/90 10:30	190	173	44	81.1	79.6	35596	29291	30064	59355	65660	54.2	49.3
2/28/90 10:00	413	363	102	80.1	78.0	36008	29654	30166	59820	66175	54.4	49.6
3/3/90 10:35	633	532	170	78.9	75.8	36641	30186	30336	60522	66977	54.7	49.9
3/7/90 11:49	140	120	41	77.5	74.7	36781	30306	30377	60682	67158	54.8	49.9
3/8/90 9:00	14	11	4	75.9	72.0	36795	30317	30381	60698	67176	54.8	49.9
3/8/90 11:35												
3/10/90 18:05	9	11	2	82.5	85.1	36804	30328	30383	60711	67187	54.8	50.0
3/10/90 18:40	281	306	60	82.5	83.7	37085	30634	30442	61077	67528	54.9	50.2
3/11/90 18:25	142	132	34	80.6	79.5	37227	30766	30477	61243	67704	55.0	50.2
3/12/90 8:45	212	201	58	78.4	77.5	37440	30967	30535	61502	67975	55.1	50.4
3/13/90 8:00	2099	1971	635	76.8	75.6	39539	32938	31170	64108	70709	55.9	51.4
3/25/90 8:30	790	744	242	76.5	75.5	40328	33683	31412	65095	71741	56.2	51.7
3/30/90 8:30	1739	1533	471	78.7	76.5	42068	35216	31883	67099	73951	56.9	52.5
4/9/90 10:00	614	536	179	77.4	75.0	42682	35752	32062	67814	74744	57.1	52.7
4/13/90 9:30	2044	1856	536	79.2	77.6	44726	37608	32599	70207	77325	57.8	53.6
4/24/90 9:30	34	30	7	82.0	79.9	44760	37638	32606	70244	77366	57.9	53.6
5/2/90 9:30												

TABLE B-2. OPERATIONAL DATA FOR TREATMENT PLOT V2 (CONTINUED)

Date m/d/y h:mm	Hexane Eq. CO2 (g/day)	Hexane Eq. O2 (g/day)	Hexane Eq. THC (g/day)	Hexane Eq. O2&THC (g/day)	Tot Hexane Eq. CO2&THC (g/day)	Hexane Eq. CO2 (mg/(kg day))	Hexane Eq. O2 (mg/(kg day))	Hexane Eq. THC (mg/(kg day))	Hexane Eq. O2&THC (mg/(kg day))	Tot Hexane Eq. O2&THC (mg/(kg day))
10/4/89 10:05										
10/5/89 8:07	880.6	573.6	448.1	1021.7	1328.7	30.6	19.9	15.6	15.6	35.5
10/10/89 14:00	293.3	261.8	422.7	684.5	715.9	10.2	9.1	14.7	14.7	23.8
10/12/89 12:00	232.0	192.3	262.3	454.5	494.2	8.1	6.7	9.1	9.1	15.8
10/16/89 12:00	531.2	412.8	760.0	1172.9	1291.2	18.5	14.4	26.4	26.4	40.8
10/20/89 12:00	272.6	214.4	754.7	969.2	1027.4	9.5	7.5	26.2	26.2	33.7
10/24/89 9:35	124.7	110.6	295.5	406.1	420.2	4.3	3.8	10.3	10.3	14.1
10/24/89 10:13	133.2	127.4	264.5	392.0	397.8	4.6	4.4	9.2	9.2	13.6
10/26/89 12:00										
10/27/89 11:11	572.7	536.6	721.5	1258.1	1294.2	19.9	18.7	25.1	25.1	43.7
10/31/89 12:00	499.8	495.9	573.8	1069.7	1073.6	17.4	17.2	19.9	19.9	37.2
11/3/89 12:00	527.7	473.8	575.3	1049.0	1103.0	18.3	16.5	20.0	20.0	36.5
11/6/89 12:00	549.4	431.9	680.9	1112.8	1230.2	19.1	15.0	23.7	23.7	38.7
11/9/89 12:00	554.4	429.8	532.6	962.4	1086.9	19.3	14.9	18.5	18.5	33.5
11/14/89 15:00	457.6	335.6	390.8	726.4	848.4	15.9	11.7	13.6	13.6	25.3
11/16/89 15:00	367.5	278.2	290.0	568.2	657.5	12.8	9.7	10.1	10.1	19.8
11/21/89 15:00	386.4	325.6	244.6	570.2	631.0	13.4	11.3	8.5	8.5	19.8
11/24/89 14:00	385.0	380.3	241.5	621.8	626.5	13.4	13.2	8.4	8.4	21.6
11/28/89 12:43	373.5	341.3	269.4	610.7	642.9	13.0	11.9	9.4	9.4	21.2
11/28/89 15:11	393.7	359.1	328.4	687.4	722.1	13.7	12.5	11.4	11.4	23.9
12/1/89 14:00										
12/2/89 17:58	534.3	395.8	216.3	612.1	750.6	18.6	13.8	7.5	7.5	21.3
12/7/89 12:00	449.3	340.4	199.7	540.1	649.0	15.6	11.8	6.9	6.9	18.8
12/11/89 12:00	312.4	224.3	164.6	388.9	476.9	10.9	7.8	5.7	5.7	13.5
12/13/89 14:30	224.7	192.8	145.2	338.0	369.9	7.8	6.7	5.0	5.0	11.7
12/15/89 11:30	231.7	162.6	126.2	288.8	357.9	8.1	5.7	4.4	4.4	10.0
12/22/89 12:00	234.1	212.4	106.7	319.1	340.9	8.1	7.4	3.7	3.7	11.1
12/27/89 12:00	188.0	186.2	111.7	297.9	299.7	6.5	6.5	3.9	3.9	10.4
12/29/89 12:00	168.4	120.0	98.1	218.1	266.5	5.9	4.2	3.4	3.4	7.6

TABLE B-2. OPERATIONAL DATA FOR TREATMENT PLOT V2 (CONTINUED)

Date m/d/y h:mm	Hexane Eq. CO <sub>2</sub> (g/day)	Hexane Eq. O <sub>2</sub> (g/day)	Hexane Eq. THC (g/day)	Hexane Eq. O <sub>2</sub> &THC (g/day)	Tot Hexane Eq. CO <sub>2</sub> &THC (g/day)	Tot Hexane Eq. CO <sub>2</sub> (mg/kg day)	Hexane Eq. O <sub>2</sub> (mg/kg day)	Hexane Eq. THC (mg/kg day)	Hexane Eq. O <sub>2</sub> (mg/kg day)	Hexane Eq. THC (mg/kg day)	Tot Hexane Eq. O <sub>2</sub> &THC (mg/kg day)
1/2/90 12:00	137.8	122.4	80.6	203.0	218.4	4.8	4.3	2.8	4.3	2.8	7.1
1/3/90 14:28	158.3	121.6	90.2	211.8	248.5	5.5	4.2	3.1	4.2	3.1	7.4
1/3/90 15:33	173.9	115.1	95.1	210.2	269.0	6.0	4.0	3.3	4.0	3.3	7.3
1/8/90 13:30	179.5	122.1	72.9	195.0	252.4	6.2	4.2	2.5	4.2	2.5	6.8
1/10/90 11:43	99.5	80.3	42.2	122.6	141.8	3.5	2.8	1.5	2.8	1.5	4.3
1/12/90 8:56	119.1	111.7	48.1	159.8	167.2	4.1	3.9	1.7	3.9	1.7	5.6
1/16/90 10:00	149.2	121.3	50.5	171.8	199.7	5.2	4.2	1.8	4.2	1.8	6.0
1/19/90 8:00	167.0	112.5	25.3	137.8	192.3	5.8	3.9	0.9	3.9	0.9	4.8
1/22/90 10:30	107.7	44.7	12.1	56.8	119.8	3.7	1.6	0.4	1.6	0.4	2.0
1/26/90 15:00	110.4	88.7	24.2	112.9	134.6	3.8	3.1	0.8	3.1	0.8	3.9
2/1/90 16:30	121.0	107.1	26.6	133.7	147.6	4.2	3.7	0.9	3.7	0.9	4.6
2/4/90 16:30	142.4	136.1	29.8	165.9	172.2	4.9	4.7	1.0	4.7	1.0	5.8
2/9/90 8:00	65.2	58.3	14.2	72.5	79.4	2.3	2.0	0.5	2.0	0.5	2.5
2/12/90 15:00	54.0	45.6	12.0	57.6	66.0	1.9	1.6	0.4	1.6	0.4	2.0
2/21/90 8:00	47.8	43.4	11.1	54.5	58.9	1.7	1.5	0.4	1.5	0.4	1.9
2/24/90 10:30	136.4	120.1	33.9	153.9	170.3	4.7	4.2	1.2	4.2	1.2	5.4
2/28/90 10:00	156.1	131.2	41.8	173.1	197.9	5.4	4.6	1.5	4.6	1.5	6.0
3/3/90 10:35	156.1	133.6	45.2	178.8	201.3	5.4	4.6	1.6	4.6	1.6	6.2
3/7/90 11:49	152.1	124.2	48.4	172.6	200.6	5.3	4.3	1.7	4.3	1.7	6.0
3/8/90 9:00	322.9	391.4	68.3	459.7	391.2	11.2	13.6	2.4	13.6	2.4	16.0
3/10/90 18:05	284.4	309.4	60.2	369.5	344.5	9.9	10.8	2.1	10.8	2.1	12.8
3/10/90 18:40	236.0	220.3	56.9	277.3	293.0	8.2	7.7	2.0	7.7	2.0	9.6
3/11/90 18:25	219.3	207.4	60.3	267.8	279.6	7.6	7.2	2.1	7.2	2.1	9.3
3/12/90 8:45	174.7	164.1	52.9	216.9	227.6	6.1	5.7	1.8	5.7	1.8	7.5
3/13/90 8:00	158.0	148.8	48.4	197.2	206.4	5.5	5.2	1.7	5.2	1.7	6.9
3/25/90 8:30	172.8	152.3	46.8	199.1	219.7	6.0	5.3	1.6	5.3	1.6	6.9
3/30/90 8:30	154.3	134.8	45.0	179.8	199.3	5.4	4.7	1.6	4.7	1.6	6.3
4/9/90 10:00	185.9	168.7	48.8	217.5	234.6	6.5	5.9	1.7	5.9	1.7	7.6
4/13/90 9:30	234.2	203.9	51.3	255.2	285.4	8.1	7.1	1.8	7.1	1.8	8.9
4/24/90 9:30											
5/2/90 9:30											



TABLE B-2. OPERATIONAL DATA FOR TREATMENT PLOT V2 (CONTINUED)

Date m/d/y h:mm	Tot Hexane Eq. CO2&THC (mg/(kg day))	Ambient Mean		Soil Mean	
		Temp °C	Temp °C	Temp °C	Temp °C
10/4/89 10:05		25.0			
10/5/89 8:07	46.2	23.6			
10/10/89 14:00	24.9	19.4			
10/12/89 12:00	17.2	23.3			
10/16/89 12:00	44.9	26.1			
10/20/89 12:00	35.7	9.2			
10/24/89 9:35	14.6	19.2			
10/24/89 10:13	13.8	19.2			
10/26/89 12:00					
10/27/89 11:11	45.0	20.0			
10/31/89 12:00	37.3	20.6			
11/3/89 12:00	38.3	15.6			
11/6/89 12:00	42.8	18.3			
11/9/89 12:00	37.8	17.8			
11/14/89 15:00	29.5	20.0			
11/16/89 15:00	22.9	15.0			
11/21/89 15:00	21.9	20.6			
11/24/89 14:00	21.8	11.1			
11/28/89 12:43	22.4	20.0			
11/28/89 15:11	25.1	20.0			
12/1/89 14:00					
12/2/89 17:58	26.1	12.8			
12/7/89 12:00	22.6	20.6			
12/11/89 12:00	16.6	13.9			
12/13/89 14:30	12.9	8.3			
12/15/89 11:30	12.4	13.9			
12/22/89 12:00	11.8	0.6			
12/27/89 12:00	10.4	12.8			
12/29/89 12:00	9.3	13.9			

TABLE B-2. OPERATIONAL DATA FOR TREATMENT PLOT V2 (CONCLUDED)

Date m/d/y h:mm	Tot Hexane Eq. CO2&THC (mg/(kg day))	Ambient Mean Temp °C	Soil Mean Temp °C
1/2/90 12:00	7.6	8.9	
1/3/90 14:28	8.6	15.0	
1/3/90 15:33	9.4	15.0	17.7
1/8/90 13:30		13.3	
1/10/90 11:43	8.8	14.4	
1/12/90 8:56	4.9	11.1	
1/16/90 10:00	5.8	16.7	
1/19/90 8:00	6.9	18.3	
1/22/90 10:30	6.7	11.1	
1/25/90 6:00		16.1	18.5
1/26/90 15:00	4.2	8.9	
2/1/90 16:30	4.7	16.7	
2/4/90 16:30	5.1	15.0	
2/9/90 8:00	6.0	20.0	
2/12/90 15:00	2.8	15.0	
2/21/90 8:00	2.3	16.7	
2/24/90 10:30	2.0	11.7	
2/28/90 10:00	5.9	15.0	
3/3/90 10:35	6.9	13.9	
3/7/90 11:49	7.0	21.7	
3/8/90 9:00	7.0	20.0	
3/8/90 11:35		20.0	
3/10/90 18:05	13.6	20.6	
3/10/90 18:40	12.0	20.6	
3/11/90 18:25	10.2	21.7	
3/12/90 8:45	9.7	21.1	22.0
3/13/90 8:00	7.9	21.1	
3/25/90 8:30	7.2	20.0	
3/30/90 8:30	7.6	22.2	
4/9/90 10:00	6.9	18.9	
4/13/90 9:30	8.2	17.2	
4/24/90 9:30	9.9	22.2	
5/2/90 9:30			



TABLE B-3. OPERATIONAL DATA FOR OFF-GAS TREATMENT PLOT V3 DISCHARGE

Date	Venting	O2+C02	Average	Avg Air	Int Vol	Cumul	Hexane Eq.	Cum Hex Eq				
m/d/y h:mm	Time (days)	CO2 (%)	O2 (%)	THC (ppm)	(%)	Rotameter	Flow (LPM)	Air (L)	Vol Air (L)	THC (g)	THC (g)	
10/4/89	12:03	0.08	1.9	17.5	88.0	19.4						
10/10/89	14:00	6.16	3.2	16.2	1900.0	19.4	90	0.90	7881	7881	28.0	28
10/12/89	12:00	8.08	3.5	15.9	220.0	19.4	67	0.60	1656	9537	6.3	34
10/16/89	12:00	12.08	3.1	16.0	430.0	19.1	52	0.50	2880	12417	3.3	38
10/20/89	12:00	16.08	2.2	18.0	13.0	20.2	54	0.50	2880	15297	2.3	40
10/24/89	8:08	19.92	2.1	18.5	14.0	20.6	50	0.50	2764	18061	0.1	40
10/24/89	10:13	20.01	Blowers off for Shutdown Test 1				50	0.50	63	18124	0.0	40
10/26/89	12:00	20.01	Blowers on									
10/27/89	10:00	20.92	2.6	17.2	73.0	19.8	108	1.10	1452	19576	0.4	40
10/31/89	12:00	25.01	2.8	17.0	97.0	19.8	106	1.00	5880	25456	1.8	42
11/3/89	12:00	28.01	2.6	18.0	115.0	20.6	102	1.00	4320	29776	1.6	44
11/6/89	12:00	31.01	1.7	19.0	150.0	20.7	106	1.00	4320	34096	2.0	46
11/9/89	12:00	34.01	2.0	19.0	1050.0	21.0	106	1.00	4320	38416	9.3	55
11/14/89	15:00	39.13	2.0	19.0	530.0	21.0	106	1.00	7380	45796	20.9	76
11/16/89	15:00	41.13	2.0	18.5	90.0	20.5	104	1.00	2880	48676	3.2	79
11/21/89	15:00	46.13	1.3	19.4	265.0	20.7	107	1.00	7200	55876	4.6	84
11/24/89	14:00	49.09	1.3	19.7	400.0	21.0	108	1.00	4260	60136	5.1	89
11/28/89	14:25	53.11	1.6	18.7	5.0	20.3	107	1.00	5785	65921	4.2	93
11/28/89	15:11	53.14	Blowers off for Shutdown Test 2				107	1.00	46	65967	0.0	93
12/1/89	14:00	53.14	Blowers on									
12/2/89	17:30	54.28	2.2	16.5	264.0	18.7	50	3.95	6510	72477	6.1	99
12/7/89	12:00	59.05	2.6	17.5	1459.0	20.1	50	3.95	27106	99583	83.5	183
12/11/89	12:00	63.05	4.5	15.5	1326.6	20.0	49	3.83	22043	121626	109.8	293
12/13/89	14:30	65.16	2.8	17.5	595.0	20.3	49	3.83	11595	133222	39.9	332
12/15/89	11:30	67.03	4.5	15.1	1143.5	19.6	45	3.36	9083	142304	28.2	361
12/22/89	12:00	74.05	2.6	17.5	1143.5	20.1	40	2.81	28432	170737	116.3	477
12/27/89	12:00	79.05	1.8	18.8	370.0	20.6	40	2.81	20248	190985	54.8	532
12/29/89	12:00	81.05	1.5	19.0	370.0	20.5	40	2.81	8099	199084	10.7	543
1/2/90	12:00	85.05	2.9	17.5	610.0	20.4	40	2.81	16199	215283	28.4	571
1/3/90	14:13	86.15	2.8	17.9	940.0	20.7	40	2.81	4424	219707	12.3	583
1/3/90	15:33	86.20	Blowers off for Shutdown Test 3				40	2.81	225	219932	0.8	584
1/8/90	13:30	86.20	Blowers on									
1/10/90	12:05	88.14	2.9	18.1	1230.9	21.0	70	6.57	18366	238298	80.9	665
1/12/90	10:10	90.06	2.8	17.7	950.0	20.5	70	6.57	18169	256467	70.9	736
1/16/90	10:00	94.06	3.3	17.0	905.0	20.3	45	3.36	19343	275810	64.2	800
1/19/90	8:00	96.97	4.0	16.0	1080.0	20.0	45	3.36	14129	289939	50.2	850
1/22/90	10:30	100.08	4.5	15.2	1000.0	19.7	45	3.36	15037	304976	55.9	906
1/24/90	14:00	102.22	3.9	16.1	1170.0	20.0	45	3.36	10395	315371	40.3	946
1/25/90	6:00	102.89	Blowers off for Shutdown Test 3A				45	3.36	3229	318600	13.5	960
1/26/90	15:00	102.89	Blowers on									
2/1/90	16:30	108.95	5.6	13.8	765.0	19.4	25	1.34	11669	330269	31.9	992
2/4/90	16:30	111.95	6.7	12.0	960.0	18.7	25	1.34	5774	336043	17.8	1010
2/12/90	15:00	119.89	7.4	10.7	283.3	18.1	25	1.34	15277	351320	34.0	1044
2/21/90	8:00	128.60	9.5	5.3	25.0	14.8	17.5	0.70	8775	360095	4.8	1048
2/24/90	10:30	131.70	6.7	11.8	20.0	18.5	18.1	0.75	3344	363439	0.3	1049
2/28/90	10:00	135.68	6.3	12.0	56.0	18.3	18.2	0.76	4334	367773	0.6	1049
3/3/90	10:35	138.71	5.1	15.0	390.0	20.1	42	3.03	13193	380966	10.5	1060
3/3/90	11:06	138.73	Blowers off (V3&V4) for SD Test 4				42	3.03	94	381060	0.1	1060
3/6/90	12:30	138.73	Blowers on (V3 & V4) Direct JP-4 injection									
3/7/90	11:07	139.67	2.8	17.8	2174.0	20.6	17.5	0.70	950	382009	7.4	1067
3/7/90	14:00	139.79	2.6	17.8	2206.0	20.4	17.5	0.70	121	382130	0.9	1068
3/8/90	11:50	140.70	2.5	17.8	1215.0	20.3	17.5	0.70	917	383047	5.6	1074
3/8/90	15:12	140.84	2.6	17.7	1087.0	20.3	17.5	0.70	141	383188	0.6	1074
3/8/90	18:08	140.96	2.7	17.8	1007.0	20.5	17.5	0.70	123	383312	0.5	1075
3/8/90	22:00	141.13	2.7	17.8	895.0	20.5	17.5	0.70	162	383474	0.6	1075
3/8/90	23:15	141.18	2.7	17.8	895.0	20.5	17.5	0.70	52	383526	0.2	1076
3/9/90	8:55	141.58	2.7	17.5	895.0	20.2	17.5	0.70	406	383932	1.3	1077
3/9/90	9:20	141.60	Blowers off (V3) for Shutdown Test 4a				17.5	0.70	17	383950	0.1	1077
3/12/90	9:15	141.60	Blowers on (V3)									
3/13/90	7:53	142.54	2.2	16.3	6.0	18.5	17.5	0.70	950	384900	0.0	1077
3/25/90	8:30	154.57	1.5	19.0	2.4	20.5	17.5	0.70	12117	397017	0.2	1077
3/30/90	8:30	159.57	1.8	19.0	1.8	20.8	17.5	0.70	5038	402055	0.0	1077
4/9/90	10:00	169.63	1.4	19.1	2.5	20.5	17.5	0.70	10139	412194	0.1	1077
4/13/90	9:30	173.61	1.3	19.2	2.5	20.5	17.5	0.70	4009	416203	0.0	1077
4/24/90	9:30	184.61	1.3	19.3	6.0	20.6	17.5	0.70	11084	427287	0.2	1078
4/24/90	13:00	184.76	Blowers off for Shutdown Test 5				17.5	0.70	147	427434	0.0	1078
5/2/90	9:30	184.76	Blowers on									

**TABLE B-4. OPERATIONAL DATA FOR OFF-GAS TREATMENT PLOT V3 INLET**

Date	Venting	O2+C02	Avg Air	Int Vol	Cumul	Hexane Eq.	Cum Hex Eq					
m/d/y h:mm	Time (days)	CO2 (%)	O2 (%)	THC (µL/L)	(%)	Flow (L/min)	Air (L)	Vol Air (L)	THC (g)	THC (g)		
10/4/89	11:25	0.06	13.8	4.6	12048	18.4						
10/10/89	14:00	6.16	3.6	15.5	7139	19.1	1.26	11082	11082	380.3	380	
10/12/89	12:00	8.08	2.9	17.5	2425	20.4	0.54	1497	12579	25.6	406	
10/16/89	12:00	12.08	4.3	15.2	8410	19.5	1.43	8238	20818	159.7	566	
10/20/89	12:00	16.08	3.7	16.5	5717	20.2	1.43	8261	29079	208.8	774	
10/24/89	7:28	19.89	2.4	18.0	150	20.4	1.89	10363	39442	108.8	883	
10/24/89	10:13	20.01	Blowers off for Shutdown Test 1				1.98	327	39769	0.2	883	
10/26/89	12:00	20.01	Blowers on									
10/27/89	10:15	20.93	4.6	14.5	4528	19.1	1.73	2309	42078	37.4	921	
10/31/89	12:00	25.01	3.8	16.0	3497	19.8	1.73	10118	52196	145.2	1066	
11/3/89	12:00	28.01	2.7	17.5	1341	20.2	1.72	7443	59639	64.4	1130	
11/6/89	12:00	31.01	1.7	19.0	250	20.7	1.63	7051	66690	20.1	1150	
11/9/89	12:00	34.01	2.6	18.0	1400	20.6	1.58	6835	73525	20.2	1171	
11/14/89	15:00	39.13	2.6	17.6	3511	20.2	1.37	10119	83644	88.9	1259	
11/16/89	15:00	41.13	2.7	17.8	1181	20.5	1.24	3562	87206	29.9	1289	
11/24/89	14:00	49.09	2.4	18.4	1360	20.8	0.95	10880	98086	49.4	1339	
11/28/89	14:39	53.12	2.2	18.1	1622	20.3	0.92	5347	103433	28.5	1367	
11/28/89	15:11	53.14	Blowers off for Shutdown Test 2				0.83	27	103460	0.2	1367	
12/1/89	14:00	53.14	Blowers on									
12/2/89	16:46	54.25	9.2	9.6	2558	18.8	4.18	6712	110172	61.4	1429	
12/7/89	12:00	59.05	5.0	14.7	2335	19.7	4.16	28768	138940	251.7	1681	
12/11/89	12:00	63.05	4.5	15.5	2545	20.0	4.04	23274	162215	203.1	1884	
12/13/89	14:30	65.16	4.4	16.0	2178	20.4	4.27	12946	175161	109.4	1993	
12/15/89	11:30	67.03	4.5	14.5	1741	19.0	4.31	11638	186799	81.6	2075	
12/22/89	12:00	74.05	3.4	17.0	1741	20.4	4.14	41879	228677	260.9	2336	
12/27/89	12:00	79.05	1.9	18.8	1400	20.7	4.01	28894	257572	162.3	2498	
12/29/89	12:00	81.05	1.3	19.4	530	20.7	3.97	11426	268997	39.4	2537	
1/2/90	12:00	85.05	3.0	17.3	1450	20.3	3.28	18889	287886	66.9	2604	
1/3/90	14:20	86.15	2.8	18.0	2188	20.8	3.33	5260	293146	34.2	2639	
1/3/90	15:33	86.20	Blowers off for Shutdown Test 3				3.33	243	293389	1.9	2640	
1/8/90	13:30	86.20	Blowers on									
1/10/90	12:03	88.14	3.0	17.6	2188	20.6	8.08	22563	315952	176.6	2817	
1/12/90	10:05	90.06	3.0	17.6	1495	20.6	8.08	22313	338264	147.0	2964	
1/16/90	10:00	94.06	3.3	17.0	1964	20.3	4.22	24286	362550	150.2	3114	
1/19/90	8:00	96.97	4.2	15.9	1485	20.1	4.22	17724	380274	109.3	3224	
1/22/90	10:30	100.08	4.9	15.5	1788	20.4	4.22	18863	399138	110.4	3334	
1/24/90	14:00	102.22	4.5	15.2	2296	19.7	4.22	13040	412178	95.2	3429	
1/25/90	6:00	102.89	Blowers off for Shutdown Test 3A				4.22	4051	416229	33.3	3463	
1/26/90	15:00	102.89	Blowers on									
2/1/90	16:30	108.95	6.8	12.1	1710	18.9	1.96	17085	433314	104.5	3567	
2/4/90	16:30	111.95	8.0	10.5	1739	18.5	1.96	8454	441768	52.1	3619	
2/12/90	15:00	119.89	7.9	10.8	2228	18.7	1.96	22369	464137	158.7	3778	
2/21/90	8:00	128.60	9.6	6.5	1828	16.1	1.09	13669	477806	99.2	3877	
2/24/90	10:30	131.70	8.5	9.2	1961	17.7	1.09	4857	482663	32.9	3910	
2/28/90	10:00	135.68	7.3	10.3	2374	17.6	1.09	6226	488889	48.3	3958	
3/3/90	11:00	138.72	4.7	15.5	1133	20.2	3.08	13490	502379	84.6	4043	
3/3/90	11:06	138.73	Blowers off (V3&V4) for Shutdown Test				3.08	19	502397	0.1	4043	
3/6/90	12:30	138.73	Blowers on (V3 & V4) Direct JP-4 injection									
3/7/90	11:05	139.67	0.2	20.3	10668	20.5	1.20	1626	504023	62.1	4105	
3/7/90	13:54	139.79	0.5	20.1	10668	20.6	1.20	203	504226	7.7	4113	
3/8/90	11:45	140.70	0.6	20.2	7316	20.8	1.20	1573	505799	50.6	4163	
3/8/90	15:26	140.85	0.5	20.5	8230	21.0	1.20	265	506065	7.4	4171	
3/8/90	18:02	140.96	0.6	20.3	7620	20.9	1.20	187	506252	5.3	4176	
3/8/90	21:57	141.12	0.4	20.6	7620	21.0	1.20	282	506534	7.7	4184	
3/8/90	23:20	141.18	0.7	20.3	7163	21.0	1.20	100	506633	2.6	4186	
3/9/90	8:50	141.58	0.6	20.4	7925	21.0	1.20	684	507317	18.5	4205	
3/9/90	9:20	141.60	Blowers off (V3) for Shutdown Test 4a				1.20	36	507353	1.0	4206	
3/12/90	9:15	141.60	Blowers on (V3)									
3/13/90	7:53	142.54	0.0	20.9	0	20.9						
3/25/90	8:30	154.57	0.0	20.9	0	20.9						
3/30/90	8:30	159.57	0.0	20.9	0	20.9						
4/9/90	10:00	169.63	0.0	20.9	0	20.9						
4/13/90	9:30	173.61	0.0	20.9	0	20.9						
4/24/90	9:30	184.61	0.0	20.9	0	20.9						
4/24/90	13:00	184.76	Blowers off for Shutdown Test 5									
5/2/90	9:30	184.76	Blowers on									

TABLE B-5. CALCULATED OPERATIONAL DATA FOR OFF-GAS TREATMENT PLOT V3

Date m/d/y h:mm	Calc. Cf/Co = a	Calc. Q (L/min)	Int Vol Air (L)	Cumul Vol Air (L)	Hexane Eq. THC (g)	Cum Hex Eq THC (g)	Calc K %O2/min	% THC Biodegraded	Air Flow Void Vol/day	Cum % THC Biodegraded	Biodegradation (mg/kg day)	Biodegradation (g/m3 day)	loading rate g/(m3 day)
10/4/89 11:25									1.25	64	1.72	2.48	3.86
10/10/89 14:00	.29	0.26	2283	2283	78.3	78	.00014	64	0.83	66	1.89	2.73	3.72
10/12/89 12:00	.83	0.50	1383	3665	23.7	102	.00105	73	0.69	67	0.39	0.56	0.81
10/16/89 12:00	.19	0.10	555	4220	10.8	113	.00058	69	0.69	69	0.73	1.06	1.23
10/20/89 12:00	.22	0.11	646	4311	16.3	129	.00061	86	0.69	72	0.69	1.00	1.01
10/24/89 7:28	.44	0.22	1215	5526	12.8	142	.00003	99	0.69	72	0.69	1.00	1.01
10/24/89 10:13	.44	0.22	36	5563	0.0	142		84	0.69	72			
10/26/89 12:00									1.52	72	0.92	1.32	1.45
10/27/89 10:15	.19	0.21	275	5838	4.5	146	.00082	92	1.38	76	1.43	2.06	2.19
10/31/89 12:00	.35	0.35	2066	7904	29.7	176	.00110	94	1.38	77	1.07	1.55	1.71
11/3/89 12:00	.46	0.46	1974	9878	17.1	193	.00048	90	1.38	77	0.44	0.63	0.84
11/6/89 12:00	.68	0.68	2929	12807	8.3	201	.00002	75	1.38	77	-0.40	-0.58	0.35
11/9/89 12:00	.27	0.27	1179	13986	3.5	205	-.00065	-167	1.38	64	-0.62	-0.90	0.33
11/14/89 15:00	.09	0.09	637	14624	5.6	210	-.00022	-272	1.38	64	0.83	1.20	1.69
11/16/89 15:00	.46	0.46	1335	15959	11.2	222	.00044	71	1.38	62	0.20	0.28	0.47
11/24/89 14:00	.24	0.24	2755	18714	12.5	234	-.00007	60	1.38	62	0.26	0.37	0.69
11/28/89 14:39	.30	0.30	1719	20433	9.2	243	.00046	54	1.38	62			
11/28/89 15:11	.30	0.30	10	20443	0.1	243		62	1.38	62			
12/1/89 14:00									5.46	62	1.99	2.87	4.53
12/2/89 16:46	.29	1.14	1835	22278	16.8	260	.00182	63	5.46	50	0.79	1.14	6.39
12/7/89 12:00	.43	1.68	11633	33911	101.8	362	-.00177	18	5.30	43	2.25	3.25	11.52
12/11/89 12:00	.80	3.04	17534	51445	153.0	515	.00258	28	5.30	41	0.90	1.30	7.01
12/13/89 14:30	.50	1.91	5795	57239	49.0	564	.00182	19	4.66	41	2.62	3.78	8.32
12/15/89 11:30	.81	2.74	7391	64630	51.8	616	.00089	45	3.89	37	0.58	0.83	5.82
12/22/89 12:00	.77	2.15	21786	86416	135.7	752	.00052	14	3.89	36	0.90	1.30	4.60
12/27/89 12:00	.67	1.89	13599	100014	76.4	828	.00155	28	3.89	37	2.76	3.98	5.60
12/29/89 12:00	1.33	3.74	10771	110785	37.2	865	.00091	71	3.89	37	0.70	1.01	3.15
1/2/90 12:00	.73	2.05	11828	122613	41.9	907	.00122	32	3.89	37	1.55	2.23	5.60
1/3/90 14:20	.71	1.98	3135	125748	20.4	927	.00164	40	3.89	37			
1/3/90 15:33	.71	2.00	146	125894	1.1	929		34	3.89	37			
1/8/90 13:30									9.10	34	0.55	0.79	13.35
1/10/90 12:03	.60	3.93	10983	136877	86.0	1015	.00050	6	9.10	34	2.72	3.92	15.06
1/12/90 10:05	.80	5.27	14556	151433	95.9	1110	.00158	26	4.66	33	1.41	2.03	6.87
1/16/90 10:00	.76	2.56	14732	166165	91.1	1202	.00191	30	4.66	33	2.00	2.88	8.07
1/19/90 8:00	.90	3.02	12667	178832	78.1	1280	.00082	36	4.66	33	1.67	2.41	7.84
1/22/90 10:30	.92	3.09	13800	192632	80.8	1360	.00208	31	4.66	33	1.06	1.53	7.20
1/24/90 14:00	.68	2.27	7022	199655	51.3	1412	.00124	21	4.66	33	1.41	2.04	8.15
1/25/90 6:00	.68	2.29	2196	201851	18.0	1430		25	4.66	33			
1/26/90 15:00													

TABLE B-5. CALCULATED OPERATIONAL DATA FOR OFF-GAS TREATMENT PLOT V3  
(CONCLUDED)

Date m/d/y h:mm	Calc. O <sub>2</sub> /O <sub>2</sub> = a	Calc. O <sub>2</sub> (l/min)	Int Vol Air (L)	Cumul Vol Air (L)	Hexane Eq. THC (g)	Cum Hex Eq. THC (g)	Calc K %O <sub>2</sub> /min	% THC Biodegraded	Air Flow Void Vol/day	Cum % THC Biodegraded	Biodegradation (mg/kg day)	Biodegradation (g/m <sup>3</sup> day)	Biodegradation loading rate g/(m <sup>3</sup> day)
2/1/90 16:30	.71	0.96	8337	210188	51.0	1481	.00059	37	1.85	33	0.66	0.95	2.53
2/4/90 16:30	.79	1.06	4570	214758	28.2	1509	.00054	37	1.85	33	0.72	1.04	2.83
2/12/90 15:00	.84	1.13	12884	227642	91.4	1600	.00206	63	1.85	35	1.51	2.18	3.47
2/21/90 8:00	.97	0.68	8483	236125	61.5	1662	.00118	92	0.97	37	1.36	1.96	2.13
2/24/90 10:30	.66	0.50	2214	238338	15.0	1677	.00092	98	1.04	37	0.99	1.43	1.46
2/28/90 10:00	.68	0.51	2937	241275	22.8	1700	.00113	97	1.05	38	1.16	1.68	1.72
3/3/90 11:00	.96	2.92	12773	254048	80.1	1780	.00205	87	4.19	40	4.77	6.88	7.93
3/3/90 11:06	.96	2.91	17	254066	0.1	1780			4.19	40			
3/6/90 12:30													
3/7/90 11:05	.31	0.22	294	254359	11.2	1791	.00077	34	0.97	40	0.85	1.22	3.59
3/7/90 13:54	.30	0.21	36	254395	1.4	1792	.00070	31	0.97	40	0.75	1.08	3.52
3/8/90 11:45	.42	0.30	389	254784	12.5	1805	.00128	55	0.97	41	1.58	2.28	4.14
3/8/90 15:26	.39	0.28	61	254845	1.7	1807	.00146	66	0.97	41	1.52	2.19	3.33
3/8/90 18:02	.40	0.28	43	254889	1.2	1808	.00137	63	0.97	41	1.48	2.14	3.43
3/8/90 21:57	.41	0.29	68	254956	1.8	1810	.00151	70	0.97	41	1.65	2.37	3.40
3/8/90 23:20	.42	0.29	24	254981	0.6	1810	.00143	74	0.97	41	1.73	2.49	3.37
3/9/90 8:50	.43	0.30	170	255151	4.6	1815	.00168	72	0.97	41	1.73	2.49	3.49
3/9/90 9:20	.43	0.30	9	255160	0.3	1815			0.97	41	1.73	2.49	3.49

TABLE B-6. OPERATIONAL DATA FOR BACKGROUND PLOT V4

Date m/d/y h:mm	Venting Time (days)	CO2 (%)	O2 (%)	THC (µL/L)	O2+CO2 (%)
10/4/89 12:04	0.08	2.6	17.5	44.0	20.1
10/10/89 14:00	6.16	2.0	18.5	380.0	20.5
10/12/89 12:00	8.08	2.2	18.4	410.0	20.6
10/16/89 12:00	12.08	2.3	18.0	180.0	20.3
10/20/89 12:00	16.08	1.0	20.0	9.0	21.0
10/24/89 8:31	19.93	1.5	19.0	8.5	20.5
10/24/89 10:13	20.01	Blowers off for Shutdown Test 1			
10/26/89 12:00	20.01	Blowers on			
10/27/89 9:53	20.92	1.6	18.8	0.0	20.4
10/31/89 12:00	25.01	1.3	19.3	0.0	20.6
11/3/89 12:00	28.01	1.2	19.4	ND	20.6
11/6/89 12:00	31.01	1.5	19.2	ND	20.7
11/9/89 12:00	34.01	1.5	19.5	ND	21.0
11/14/89 15:00	39.13	1.4	19.4	ND	20.8
11/16/89 15:00	41.13	0.9	20.0	ND	20.9
11/21/89 15:00	46.13	1.0	19.5	ND	20.5
11/24/89 14:00	49.09	0.7	20.4	ND	21.1
11/28/89 14:20	53.10	0.9	19.6	2.0	20.5
11/28/89 15:11	53.14	Blowers off for Shutdown Test 2			
12/1/89 14:00	53.14	Blowers on			
12/2/89 16:02	54.22	0.7	20.2	2.0	20.9
12/5/89 12:00	57.05	0.6	20.2	4.0	
12/7/89 12:00	59.05	0.7	20.2	ND	20.9
12/11/89 12:00	63.05	0.5	20.0	ND	20.5
12/13/89 14:30	65.16	0.5	20.5	2.0	21.0
12/15/89 11:30	67.03	0.4	20.2	ND	20.6
12/22/89 12:00	74.05	0.2	21.0	ND	21.2
12/27/89 12:00	79.05	0.4	20.8	ND	21.2
12/29/89 12:00	81.05	0.5	20.0	ND	20.5
1/2/90 12:00	85.05	0.5	20.2	ND	20.7
1/3/90 13:55	86.13	0.3	20.5	ND	20.8
1/3/90 15:33	86.20	Blowers off for Shutdown Test 3			
1/8/90 13:30	86.20	Blowers on			
1/16/90 10:00	94.06	0.6	20.2	ND	20.8
1/19/90 8:00	96.97	0.7	20.2	2.0	20.9
1/22/90 10:30	100.08	0.7	20.2	ND	20.9
1/24/90 14:00	102.22	0.7	20.2	3.8	20.9
1/25/90 6:00	102.89	Blowers off for Shutdown Test 3A			
1/26/90 15:00	102.89	Blowers on			
2/1/90 16:30	108.95	0.7	20.3	1.0	21.0
2/4/90 16:30	111.95	0.6	20.5	3.8	21.1
2/9/90 8:00	116.60	0.9	20.0	2.0	20.9
2/12/90 15:00	119.89	0.8	20.1	ND	20.9
2/21/90 8:00	128.60	0.6	20.2	2.0	20.8
2/24/90 10:30	131.70	0.3	20.5	2.0	20.8
2/28/90 10:00	135.68	0.7	20.2	4.3	20.9
3/3/90 11:00	138.72	0.6	20.3	1.0	20.9
3/3/90 11:06	138.73	Blowers off (V3&V4) for Shutdown Test 4			
3/6/90 12:30	138.73	Blowers on (V3 & V4) Direct JP-4 injection			
3/9/90 9:20	141.60	Blowers off (V3) for Shutdown Test 4a			
3/12/90 9:15	141.60	Blowers on (V3)			
3/13/90 7:53	142.54	1.1	19.8	ND	20.9
3/25/90 8:30	154.57	1.0	20.0	0.8	21.0
3/30/90 8:30	159.57	1.0	20.0	0.9	21.0
4/9/90 10:00	169.63	0.8	20.1	1.7	20.9
4/13/90 9:30	173.61	0.8	20.0	2.5	20.8
4/24/90 9:30	184.61	1.2	19.5	1.0	20.7
4/24/90 13:00	184.76	Blowers off for Shutdown Test 5			
5/2/90 9:30	184.76	Blowers on			

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APPENDIX C  
LABORATORY ANALYSES FOR SOIL,  
WATER, AND GAS SAMPLES

TABLE C-1. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V1 (MG/KG)

SAMPLE ID	DATE	n-octane	ethyl- benzene	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	naphthalene	n-do- decane
V1-1,1'	9/89	46.00	-	150.40	28.10	235.20	149.90	-	108.60
V1-1,1'	4/28/90	8.50	50.90	-	93.90	76.90	88.00	70.60	236.40
V1-1,2'	9/89	1.60	-	4.70	0.10	3.30	1.10	-	0.60
V1-1,2'	4/28/90	6.10	-	33.20	44.90	59.20	67.10	-	128.80
V1-1,3'	9/89	0.72	-	5.30	1.40	4.70	2.70	-	13.00
V1-1,3'	4/28/90	4.80	-	20.60	42.10	59.20	61.30	23.90	105.40
V1-1,4'	9/89	-	-	-	-	-	0.40	-	-
V1-1,4'	4/28/90	-	-	11.00	35.90	44.20	57.60	25.00	109.50
V1-1,5'	9/89	-	-	0.43	0.08	1.20	1.00	-	1.40
V1-1,5'	4/28/90	-	-	-	-	-	3.70	-	-
V1-1,6'	9/89	-	-	1.00	-	0.28	0.72	-	1.00
V1-1,6'	4/28/90	-	-	-	-	-	-	-	-
V1-1,7'	9/89	-	-	7.50	-	2.40	1.50	-	1.40
V1-1,7'	4/28/90	479.10	145.60	479.90	218.10	684.50	179.00	254.70	949.40

TABLE C-1. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V1 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V1-1,1'	9/89	53.40	-	122.40	123.40	1121.90
V1-1,1'	4/28/90	193.30	-	278.40	174.50	1179.90
V1-1,2'	9/89	-	-	-	-	33.10
V1-1,2'	4/28/90	99.40	22.50	132.90	89.70	674.30
V1-1,3'	9/89	16.60	-	9.40	11.00	71.42
V1-1,3'	4/28/90	75.20	21.30	107.20	76.10	562.80
V1-1,4'	9/89	1.00	-	-	-	2.30
V1-1,4'	4/28/90	86.40	21.90	122.60	70.50	537.70
V1-1,5'	9/89	1.00	-	0.14	0.19	29.79
V1-1,5'	4/28/90	-	-	4.50	2.50	10.70
V1-1,6'	9/89	-	-	-	-	25.22
V1-1,6'	4/28/90	-	-	2.40	1.40	7.40
V1-1,7'	9/89	1.00	-	-	-	64.30
V1-1,7'	4/28/90	779.50	243.80	1067.00	702.20	6944.50

TABLE C-1. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V1 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
V1-1,1'	9/89	-	-	-	-	-	-	101.60	2.90
V1-1,1'	4/28/90	-	-	-	-	-	-	-	30.00
V1-1,2'	9/89	-	-	-	-	-	16.90	-	4.80
V1-1,2'	4/28/90	-	-	-	-	-	-	-	13.00
V1-1,3'	9/89	-	-	-	3.40	-	-	-	3.20
V1-1,3'	4/28/90	-	-	4.40	-	-	4.00	-	2.50
V1-1,4'	9/89	-	-	-	0.90	-	-	-	-
V1-1,4'	4/28/90	-	-	-	-	-	-	-	-
V1-1,5'	9/89	-	-	-	0.17	0.20	23.90	-	0.08
V1-1,5'	4/28/90	-	-	-	-	-	-	-	-
V1-1,6'	9/89	-	-	-	0.38	-	21.50	-	0.34
V1-1,6'	4/28/90	-	-	-	-	-	3.60	-	-
V1-1,7'	9/89	-	-	-	1.40	-	45.30	-	3.80
V1-1,7'	4/28/90	-	-	-	-	53.90	25.70	241.20	1085.00

TABLE C-2. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
V1-2,1'A	7/89	-	-	-	-	-	29.50	-	264.10
V1-2,1'C	7/89	-	-	-	-	-	68.50	3.70	105.60
V1-2,1'	9/89	-	-	-	-	2.00	31.70	0.36	179.50
V1-2,1'	4/28/90	-	-	-	-	-	-	-	-
V1-2,2'A	7/89	-	-	-	-	-	8.10	2.10	164.00
V1-2,2'B	7/89	-	-	-	-	-	173.00	-	26.40
V1-2,2'B	7/89	-	-	-	-	3.80	170.00	-	120.80
V1-2,2'C	7/89	-	-	-	-	4.30	29.20	1.00	195.00
V1-2,2'	9/89	-	-	-	0.93	3.30	35.10	1.60	214.30

TABLE C-2. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-octane	ethyl- benzene	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	naphthalene	n-do- decane
V1-2,1'A	7/89	100.00	-	293.60	121.10	292.00	216.80	-	430.90
V1-2,1'C	7/89	200.00	-	514.20	210.80	464.90	785.70	-	520.70
V1-2,1'	9/89	45.90	-	131.00	107.20	206.20	245.40	-	506.10
V1-2,1'	4/28/90	-	-	-	-	-	2.30	8.10	12.30
V1-2,2'A	7/89	18.40	-	37.70	12.90	37.60	123.60	-	42.10
V1-2,2'B	7/89	51.50	-	141.40	213.00	155.70	136.30	-	188.90
V1-2,2'B,d	7/89	37.60	-	131.50	49.90	123.70	132.10	-	249.30
V1-2,2'C	7/89	74.20	-	200.50	73.00	167.30	148.60	-	325.10
V1-2,2'	9/89	95.60	-	240.70	79.40	243.40	202.00	-	254.00

TABLE C-2. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V1-2,1'A	7/89	283.50	-	119.90	168.10	2319.50
V1-2,1'C	7/89	473.30	-	492.30	462.90	4302.60
V1-2,1'	9/89	334.40	-	364.70	391.40	2545.86
V1-2,1'	4/28/90	9.10	-	18.00	4.80	46.50
V1-2,2'A	7/89	68.50	-	35.70	31.10	581.80
V1-2,2'B	7/89	173.90	-	175.60	160.40	1596.10
V1-2,2'B,d	7/89	333.90	-	137.40	109.80	1599.80
V1-2,2'C	7/89	402.40	-	89.70	198.60	1910.40
V1-2,2'	9/89	232.70	-	237.10	316.90	2157.03



TABLE C-2. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
V1-2,2'	4/28/90	-	-	-	-	-	-	-	-
V1-2,3'A	7/89	-	-	-	-	-	27.60	-	187.10
V1-2,3'B	7/89	-	-	-	-	-	30.70	3.30	26.50
V1-2,3'B,d	7/89	-	-	-	-	-	42.10	0.30	35.60
V1-2,3'	9/89	-	-	-	1.10	4.50	49.80	10.50	174.10
V1-2,3'	4/28/90	-	-	-	-	-	-	-	-
V1-2,4'	9/89	-	-	-	0.83	6.10	-	4.00	243.20
V1-2,4'	4/28/90	-	-	-	-	-	-	-	-
V1-2,5'	9/89	-	-	-	0.70	-	-	-	1.10
V1-2,5'	4/28/90	-	-	-	-	-	-	-	-
V1-2,6'	9/89	-	-	-	0.90	-	-	0.30	21.50
V1-2,6'	4/28/90	-	-	-	-	-	-	-	-
V1-2,7'	9/89	-	-	-	0.86	-	-	-	0.74
V1-2,7'	4/28/90	-	-	-	-	-	-	-	-
V1-2,7',d	4/28/90	-	-	-	-	-	-	-	-

TABLE C-2. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-octane	ethyl- benzene	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	naphthalene	n-do- decane
V1-2,2'	4/28/90	-	-	3.80	42.50	59.50	92.50	47.30	186.90
V1-2,3'A	7/89	-	-	173.50	54.00	163.00	129.50	-	243.30
V1-2,3'B	7/89	63.00	-	131.60	3.10	137.50	111.20	-	198.10
V1-2,3'B,d	7/89	13.40	-	32.30	10.90	32.40	106.70	-	49.80
V1-2,3'	9/89	91.20	-	208.90	61.50	204.30	155.50	-	297.30
V1-2,3'	4/28/90	4.60	-	21.00	34.10	60.10	62.40	32.00	136.20
V1-2,4'	9/89	122.50	-	272.50	86.30	257.50	157.40	-	94.20
V1-2,4'	4/28/90	-	-	2.90	20.30	31.20	40.90	24.60	97.30
V1-2,5'	9/89	-	-	-	-	-	1.20	-	-
V1-2,5'	4/28/90	-	-	-	-	-	-	-	-
V1-2,6'	9/89	7.20	-	25.70	16.00	22.60	23.10	-	58.00
V1-2,6'	4/28/90	-	-	-	4.10	4.70	4.10	-	6.90
V1-2,7'	9/89	-	-	2.21	-	0.86	1.96	-	0.55
V1-2,7'	4/28/90	-	-	-	-	-	-	-	-
V1-2,7,d	4/28/90	-	-	-	-	-	-	-	3.30

TABLE C-2. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V1-2,2'	4/28/90	151.60	45.30	210.30	132.60	879.70
V1-2,3'A	7/89	341.10	-	181.50	183.00	1683.60
V1-2,3'B	7/89	241.00	-	124.80	100.00	1170.80
V1-2,3'B,d	7/89	264.40	-	15.70	136.30	739.90
V1-2,3'	9/89	356.00	-	220.30	45.80	1880.80
V1-2,3'	4/28/90	108.00	31.80	149.30	91.80	667.50
V1-2,4'	9/89	239.70	-	246.00	277.00	2007.23
V1-2,4'	4/28/90	85.60	24.50	127.00	89.70	494.90
V1-2,5'	9/89	-	-	8.50	40.50	52.00
V1-2,5'	4/28/90	-	-	3.40	-	3.40
V1-2,6'	9/89	34.10	-	26.40	-	235.80
V1-2,6'	4/28/90	6.50	-	17.50	4.00	47.80
V1-2,7'	9/89	2.38	-	2.18	-	11.74
V1-2,7'	4/28/90	-	-	3.60	1.50	5.10
V1-2,7',d	4/28/90	-	-	5.90	3.10	12.30

TABLE C-3. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 3 OF PLOT V1 (MG/KG)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
V1-3,1'	9/89	-	-	-	1.90	-	81.00	43.90	154.00
V1-3,1'	4/28/90	-	-	-	-	-	-	-	-
V1-3,2'	9/89	-	-	-	3.00	-	86.00	-	118.40
V1-3,2'	4/28/90	-	-	-	-	-	-	-	0.10
V1-3,3'	9/89	-	-	-	2.80	-	132.70	-	106.70
V1-3,3'	4/28/90	-	-	-	-	-	3.80	-	-
V1-3,4'	9/89	-	-	-	2.60	-	123.60	-	-
V1-3,4'	4/28/90	-	-	-	-	-	-	-	-
V1-3,5'	9/89	-	-	-	2.00	-	-	3.20	-
V1-3,5'	4/28/90	-	-	-	-	-	-	-	-
V1-3,6'	9/89	-	-	-	11.20	-	88.10	-	-
V1-3,6'	4/28/90	-	-	-	-	-	-	-	-
V1-3,6', d	4/28/90	-	-	-	-	-	-	-	-
V1-3,7'	9/89	-	-	-	3.00	-	106.10	-	-
V1-3,7'	4/28/90	-	-	-	-	-	-	-	-

TABLE C-3. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 3 OF PLOT V1 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	ethyl-				n-propyl-			n-butyl-		n-do- decane
		n-octane	benzene	p-xylene	benzene	n-decane	benzene	naphthalene			
V1-3,1'	9/89	45.80	-	65.80	121.50	228.30	272.90	-	543.70		
V1-3,1'	4/28/90	-	-	-	25.50	29.80	56.40	112.80	290.60		
V1-3,2'	9/89	36.30	-	58.90	70.30	177.50	177.00	-	338.60		
V1-3,2'	4/28/90	5.7	-	40.4	101.1	110.7	170.40	83.00	346.90		
V1-3,3'	9/89	46.50	-	133.50	60.80	175.60	155.80	-	295.80		
V1-3,3'	4/28/90	4.10	-	19.40	42.10	37.60	69.10	35.30	140.60		
V1-3,4'	9/89	-	-	0.70	1.10	-	3.50	-	3.70		
V1-3,4'	4/28/90	-	-	-	5.50	5.40	7.10	9.60	24.70		
V1-3,5'	9/89	-	-	-	-	-	-	-	-		
V1-3,5'	4/28/90	-	-	-	-	-	-	-	-		
V1-3,6'	9/89	-	-	0.90	0.84	1.10	1.50	-	5.20		
V1-3,6', d	4/28/90	-	-	-	-	-	-	-	-		
V1-3,6'	4/28/90	-	-	-	-	-	-	-	-		
V1-3,7'	9/89	-	-	1.60	-	2.20	1.70	-	0.90		
V1-3,7'	4/28/90	-	-	-	-	-	-	-	-		

TABLE C-3. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 3 OF PLOT V1 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V1-3,1'	9/89	35.00	-	-	-	174.42
V1-3,2'	9/89	-	-	-	-	158.78
V1-3,3'	9/89	-	-	0.08	0.02	19.50
V1-3,4'	9/89	0.03	-	-	-	0.59
V1-3,5'	9/89	0.02	-	-	-	0.09
V1-3,6'	9/89	0.04	-	0.01	-	2.06
V1-3,7'	9/89	0.03	-	-	-	0.26
V1-3,1'	9/89	351.60	-	399.40	425.20	2735.00
V1-3,1'	4/28/90	257.90	-	425.00	251.50	1336.70
V1-3,2'	9/89	463.50	-	329.40	200.70	2059.60
V1-3,2'	4/28/90	266.70	81.90	358.40	208.60	1609.00
V1-3,3'	9/89	390.10	-	205.10	190.30	1895.70
V1-3,3'	4/28/90	111.40	35.40	151.20	90.90	670.20
V1-3,4'	9/89	-	-	12.90	7.70	155.80
V1-3,4'	4/28/90	27.40	-	50.10	36.10	156.30
V1-3,5'	9/89	-	-	-	-	5.20
V1-3,5'	4/28/90	-	-	-	1.10	1.10
V1-3,6'	9/89	9.80	-	5.70	1.80	126.14
V1-3,6'	4/28/90	7.10	-	14.70	23.60	45.40
V1-3,6'	4/28/90	-	-	4.20	2.40	6.60
V1-3,7',d	9/89	2.00	-	-	-	117.50
V1-3,7'	4/28/90	-	-	-	1.10	1.10

TABLE C-4. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V2 (MG/KG)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
V2-1,1'	9/89	-	-	0.52	1.60	0.09	0.09	0.31	0.68
V2-1,1'D	9/89	-	-	-	-	0.89	1.30	0.67	0.23
V2-1,2'	9/89	-	-	-	3.40	7.20	1.90	0.81	50.20
V2-1,2'D	9/89	-	-	0.15	0.50	0.38	0.68	4.30	5.80
V2-1,3'	9/89	-	-	-	0.20	0.12	0.36	0.23	1.70
V2-1,3'D	9/89	-	-	0.18	0.39	1.90	0.31	3.90	11.30
V2-1,4'	9/89	-	-	0.69	0.40	1.50	0.44	0.89	1.40
V2-1,4'D	9/89	-	-	0.07	0.25	0.79	0.63	2.60	0.83
V2-1,5'	9/89	-	-	-	-	-	-	0.75	0.02
V2-1,5'D	9/89	-	-	0.04	-	-	0.99	4.90	6.40
V2-1,6'	9/89	-	-	0.02	-	-	0.03	0.41	0.37
V2-1,7'	9/89	-	-	-	1.20	0.11	0.05	0.48	0.47
V2-1,1'	9/89	-	-	-	6.60	-	-	10.20	-
V2-1,1'	4/28/90	-	-	-	-	-	-	-	-
V2-1,2'	9/89	-	-	-	2.80	2.80	-	84.70	242.00
V2-1,2'	4/28/90	-	-	-	3.40	-	13.10	-	-
V2-1,3'	9/89	-	-	-	-	-	-	-	10.60
V2-1,3'	4/28/90	-	-	-	-	-	-	-	-
V2-1,4'	9/89	-	-	-	1.40	19.50	-	283.60	4.20
V2-1,4'	4/28/90	-	-	-	-	-	-	-	3.80
V2-1,5'	9/89	-	-	-	3.30	1.30	-	1.50	5.10
V2-1,5'	4/28/90	-	-	-	-	-	-	-	-
V2-1,6'	9/89	-	-	-	-	1.80	-	-	-
V2-1,6'	4/28/90	-	-	-	-	-	-	-	-
V2-1,7'	9/89	-	-	-	3.40	1.30	-	-	-
V2-1,7'	4/28/90	-	-	-	-	-	4.80	-	-

TABLE C-4. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-octane	ethyl- benzene	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	naphthalene	n-do- decane
V2-1,1'	9/89	-	-	-	-	-	-	-	-
V2-1,1'	4/28/90	-	-	-	-	-	-	-	-
V2-1,2'	9/89	47.60	-	168.70	222.50	159.50	183.90	-	385.60
V2-1,2'	4/28/90	-	-	4.80	96.10	162.50	308.30	178.20	751.80
V2-1,3'	9/89	29.30	-	-	46.50	102.40	73.40	-	53.10
V2-1,3'	4/28/90	-	-	-	7.20	13.40	24.60	17.60	67.20
V2-1,4'	9/89	322.10	-	698.40	301.60	387.00	336.40	-	343.50
V2-1,4'	4/28/90	14.70	-	33.00	69.30	220.90	147.80	61.30	288.00
V2-1,5'	9/89	6.70	-	12.20	3.90	10.60	10.30	-	36.30
V2-1,5'	4/28/90	-	-	-	-	2.60	-	-	3.30
V2-1,6'	9/89	0.35	-	0.18	1.10	0.55	0.70	-	2.40
V2-1,6'	4/28/90	-	-	-	-	2.80	-	-	-
V2-1,7'	9/89	-	-	0.89	-	0.94	3.10	-	1.30
V2-1,7'	4/28/90	-	-	1.90	-	3.70	-	-	-



TABLE C-4. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V2-1,1'	9/89	-	-	-	-	16.8
V2-1,1'	4/28/90	-	-	2.50	0.96	3.46
V2-1,2'	9/89	420.50	-	257.00	138.50	2316.1
V2-1,2'	4/28/90	574.10	-	692.80	393.00	3178.1
V2-1,3'	9/89	107.10	-	7.70	33.50	463.6
V2-1,3'	4/28/90	53.50	-	71.10	39.10	293.7
V2-1,4'	9/89	378.70	-	198.00	366.40	3640.8
V2-1,4'	4/28/90	207.30	53.90	262.10	83.70	1445.8
V2-1,5'	9/89	23.30	-	41.10	29.40	185
V2-1,5'	4/28/90	3.10	-	11.90	6.20	27.1
V2-1,6'	9/89	4.90	-	1.80	-	13.78
V2-1,6'	4/28/90	-	-	5.30	1.80	9.9
V2-1,7'	9/89	4.30	-	2.30	1.10	18.63
V2-1,7'	4/28/90	-	-	2.70	1.90	15

TABLE C-5. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
V2-2,1'B	7/89	-	-	-	-	-	45.20	-	7.10
V2-2,1'C	7/89	-	-	-	-	-	-	-	-
V2-2,1'	9/89	-	-	-	-	-	-	-	-
V2-2,1'	4/28/90	-	-	-	-	-	-	-	-
V2-2,2'A	7/89	-	-	-	-	-	22.90	-	2.00
V2-2,2'A,d	7/89	-	-	-	-	-	27.60	-	2.20
V2-2,2'B	7/89	-	-	-	-	-	276.90	-	598.00
V2-2,2'B,d	7/89	-	-	-	-	-	166.50	-	94.90

TABLE C-5. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	methyl-		2-methyl-		2,4-dimethyl-		benzene	n-heptane	toluene
		butane	pentane	pentane	n-hexane	pentane	hexane			
V2-2,2'	9/89	-	-	-	2.80	1.80	-	-	50.10	6.50
V2-2,2'	4/28/90	-	-	-	-	-	-	6.40	-	-
V2-2,3'A	7/89	-	-	-	1.60	1.00	-	5.80	2.70	215.60
V2-2,3'C	7/89	-	-	-	0.40	1.00	-	2.90	2.70	141.20
V2-2,3'	9/89	-	-	-	2.40	9.40	-	69.00	10.30	401.80
V2-2,3'	4/28/90	-	-	-	-	-	-	-	-	-
V2-2,4'	9/89	-	-	-	3.20	16.10	-	86.70	81.40	275.70
V2-2,4'	4/28/90	-	-	-	-	-	-	-	2.50	129.40
V2-2,5'	9/89	-	-	-	1.50	2.00	-	1.40	12.30	27.50
V2-2,5'	4/28/90	-	-	-	-	5.20	-	-	32.40	43.10
V2-2,6'D	9/89	-	-	-	2.30	0.80	-	-	1.00	1.60
V2-2,6'	4/28/90	-	-	-	-	-	-	-	-	-
V2-2,7'	9/89	-	-	-	-	-	-	3.90	-	-
V2-2,7'	4/28/90	-	-	-	-	-	-	5.50	-	-

TABLE C-5. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-octane	ethyl- benzene	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	naphthalene	n-do- decane
V2-2,1'B	7/89	-	-	3.40	3.30	4.60	-	-	22.40
V2-2,1'C	7/89	-	-	-	-	-	-	-	1.00
V2-2,1'	9/89	-	-	-	-	-	-	-	-
V2-2,1'	4/28/90	-	-	-	-	-	-	-	-
V2-2,2'A	7/89	35.30	-	83.00	45.70	95.00	123.30	-	214.40
V2-2,2'A,d	7/89	9.70	-	36.80	48.70	89.20	202.40	-	220.40
V2-2,2'B	7/89	29.70	-	105.20	56.40	144.80	639.80	-	312.70
V2-2,2'B,d	7/89	25.30	-	85.50	50.80	101.10	114.10	-	292.40

TABLE C-5. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-octane	ethyl- benzene	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	naphthalene	n-do- decane
V2-2,2'	9/89	51.80	-	135.80	112.20	67.00	153.10	-	167.60
V2-2,2'	4/28/90	-	-	-	17.40	27.40	53.70	65.90	225.80
V2-2,3'A	7/89	110.60	-	333.90	116.90	277.30	323.70	-	480.00
V2-2,3'C	7/89	85.10	-	216.80	123.80	334.60	100.80	-	262.30
V2-2,3'	9/89	221.60	-	505.80	155.90	422.00	423.80	-	606.10
V2-2,3'	4/28/90	-	-	5.20	57.10	150.00	173.30	99.90	501.70
V2-2,4'	9/89	376.40	-	-	187.90	415.70	331.60	-	416.30
V2-2,4'	4/28/90	132.00	-	346.00	314.70	717.60	217.50	254.10	1170.00
V2-2,5'	9/89	47.90	-	-	58.90	52.30	45.60	-	98.30
V2-2,5'	4/28/90	155.70	41.80	163.30	75.40	227.10	54.50	69.30	255.40
V2-2,6'D	9/89	3.70	-	8.80	4.60	7.30	8.40	-	23.60
V2-2,6'	4/28/90	-	-	-	-	2.10	-	-	1.60
V2-2,7'	9/89	-	-	3.90	4.90	3.20	1.10	-	-
V2-2,7'	4/28/90	-	-	1.70	-	2.90	-	-	-

TABLE C-5. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V2-2,1'B	7/89	19.20	-	35.90	17.00	158.10
V2-2,1'C	7/89	1.90	-	5.80	4.20	12.90
V2-2,1'	9/89	15.00	-	10.20	7.40	32.60
V2-2,1'	4/28/90	-	3.50	-	9.30	12.80
V2-2,2'A	7/89	249.50	-	124.00	93.60	1088.70
V2-2,2'A	7/89	285.50	-	150.60	139.90	1213.00
V2-2,2'B	7/89	401.70	-	269.60	124.10	2958.90
V2-2,2'B	7/89	372.10	-	186.80	131.20	1620.70

TABLE C-5. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V2-2,2'	9/89	186.30	-	95.70	194.60	1225.30
V2-2,2'	4/28/90	182.70	-	248.10	138.30	965.70
V2-2,3'A	7/89	313.00	-	135.00	253.90	2571.00
V2-2,3'C	7/89	72.70	-	111.70	200.20	1656.20
V2-2,3'	9/89	397.80	-	12.30	373.50	3611.70
V2-2,3'	4/28/90	376.00	104.30	479.00	286.30	2232.80
V2-2,4'	9/89	405.40	-	14.00	457.00	3067.40
V2-2,4'	4/28/90	882.40	257.40	1029.00	697.60	6150.20
V2-2,5'	9/89	60.60	-	31.70	55.30	495.30
V2-2,5'	4/28/90	199.50	64.00	257.70	155.40	1799.80
V2-2,6'D	9/89	40.70	-	16.70	19.80	139.30
V2-2,6'	4/28/90	1.90	-	2.00	1.00	8.60
V2-2,7'	9/89	1.50	-	1.60	-	20.10
V2-2,7'	4/28/90	-	-	-	0.92	11.02

TABLE C-6. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 3 OF PLOT V2 (MG/KG)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
V2-3,1'D	9/89	-	-	-	2.80	-	-	-	-
V2-3,1'	4/28/90	-	-	-	-	-	-	-	-
V2-3,2'	9/89	-	-	-	1.80	1.40	43.00	130.30	2.90
V2-3,2'	4/28/90	-	-	-	-	-	-	-	34.30
V2-3,3'	9/89	-	-	-	2.90	1.10	11.90	-	-
V2-3,3'	4/28/90	-	-	-	-	-	4.60	-	-
V2-3,4'	9/89	-	-	-	3.30	7.20	-	32.70	212.10
V2-3,4'	4/28/90	-	-	-	-	-	3.90	-	1.20
V2-3,5'	9/89	-	-	-	1.90	-	-	-	-
V2-3,5'	4/28/90	-	-	-	-	2.70	3.80	-	21.20
V2-3,6'	9/89	-	-	-	2.80	-	-	4.00	19.40
V2-3,6'	4/28/90	-	-	-	-	-	3.00	-	-
V2-3,7'	9/89	-	-	-	-	-	0.40	-	0.40
V2-3,7'	4/28/90	-	-	-	-	-	4.20	-	-



TABLE C-6. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 3 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	ethyl-		n-propyl-		n-butyl-		n-do-	
		n-octane	benzene	p-xylene	benzene	n-decane	benzene	naphthalene	decane
V2-3,1'D	9/89	-	-	-	-	-	-	-	-
V2-3,1'	4/28/90	-	-	-	-	-	-	-	2.00
V2-3,2'	9/89	19.80	-	59.10	102.80	61.20	128.20	-	270.10
V2-3,2'	4/28/90	5.10	-	18.50	75.20	73.60	116.70	93.60	324.10
V2-3,3'	9/89	28.50	-	50.80	42.90	50.60	60.60	-	148.40
V2-3,3'	4/28/90	-	-	4.10	25.40	25.00	33.60	28.60	93.20
V2-3,4'	9/89	195.20	-	367.70	108.20	254.00	221.10	-	131.30
V2-3,4'	4/28/90	6.80	-	48.00	133.10	120.10	132.20	57.70	264.90
V2-3,5'	9/89	1.20	-	-	-	0.60	1.50	-	1.50
V2-3,5'	4/28/90	-	-	107.70	94.00	145.20	33.60	47.00	166.30
V2-3,6'	9/89	26.40	-	52.80	16.60	59.60	47.70	-	86.50
V2-3,6'	4/28/90	-	-	-	-	1.70	-	-	1.20
V2-3,7'	9/89	-	-	1.70	-	0.70	-	-	0.30
V2-3,7'	4/28/90	-	-	1.60	-	3.00	2.00	-	-

TABLE C-6. SPECIFIC HYDROCARBON DISTRIBUTION IN AREA 3 OF PLOT V2 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V2-3,1',d	9/89	0.60	-	0.90	-	4.30
V2-3,1'	4/28/90	2.00	-	2.60	0.77	7.37
V2-3,2'	9/89	142.50	-	75.20	165.80	1201.20
V2-3,2'	4/28/90	273.60	71.20	383.90	238.80	1512.40
V2-3,3'	9/89	82.50	-	41.90	83.60	640.00
V2-3,3'	4/28/90	84.60	-	115.40	70.80	456.70
V2-3,4'	9/89	331.60	-	321.90	1.30	2187.60
V2-3,4'	4/28/90	-	187.40	261.60	166.50	1138.30
V2-3,5'	9/89	3.50	-	2.50	5.40	18.10
V2-3,5'	4/28/90	-	127.50	174.40	114.90	863.80
V2-3,6'	9/89	114.80	-	78.60	58.70	567.90
V2-3,6'	4/28/90	-	-	2.40	-	8.30
V2-3,7'	9/89	4.90	-	6.30	-	14.70
V2-3,7'	4/28/90	-	-	2.60	0.87	14.27

TABLE C-7. SPECIFIC HYDROCARBON DISTRIBUTION IN PLOT V3 (MG/KG)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene	n-octane
V3,1'	7/89	-	-	-	-	-	33.1	-	-	-
V3,1'	4/28/90	-	-	-	-	-	-	-	-	-
V3,2'	7/89	-	-	-	-	-	33.3	-	-	-
V3,2'	4/28/90	-	-	-	-	-	-	-	-	-
V3,3'	7/89	-	-	-	-	-	-	-	-	-
V3,3'	4/28/90	-	-	-	-	-	-	-	-	-
V3,3',d	4/28/90	-	-	-	-	-	-	-	-	-
V3,4'	7/89	-	-	-	-	-	28.0	-	-	-
V3,4'	4/28/90	-	-	-	3.6	-	-	-	-	-
V3,5'	4/28/90	-	-	-	-	-	-	-	-	-

TABLE C-7. SPECIFIC HYDROCARBON DISTRIBUTION IN PLOT V3 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	n-do- decane	n-tri- decane	n-tetra- decane	n-penta- decane	total hydrocarbon
V3,1'	7/89	-	-	-	-	-	4.9	NC	-	38.0
V3,1'	4/28/90	-	-	-	-	-	-	-	1.0	1.0
V3,2'	7/89	-	-	4.6	6.6	8.7	5.6	8.3	9.8	76.9
V3,2'	4/28/90	-	-	-	-	-	-	1.9	1.3	3.2
V3,3'	7/89	-	-	0.1	-	-	0.8	-	-	0.9
V3,3'	4/28/90	-	-	-	-	-	-	-	1.6	1.6
V3,3', d	4/28/90	-	-	-	-	-	-	-	2.5	2.5
V3,4'	7/89	-	-	-	-	-	-	-	1.0	29.0
V3,4'	4/28/90	-	-	-	-	-	-	-	1.3	4.9
V3,5'	4/28/90	-	-	-	-	-	-	-	1.1	1.1

TABLE C-8. SPECIFIC HYDROCARBON DISTRIBUTION IN PLOT V4 (MG/KG)

SAMPLE ID	DATE	methyl-		2-methyl-		2,4-dimethyl-		benzene	n-heptane	toluene	n-octane
		butane	pentane	pentane	pentane	pentane	pentane				
V4,1'	7/89	-	-	-	-	-	-	-	-	-	-
V4,1'	4/28/90	-	-	-	-	-	-	-	-	-	-
V4,2'	7/89	-	-	-	-	-	55.5	-	-	1.1	-
V4,2'	4/28/90	-	-	-	-	-	-	-	-	-	-
V4,3'	7/89	-	-	-	-	-	18.5	-	-	-	-
V4,3'	4/28/90	-	-	-	-	-	-	-	-	-	-
V4,4'	7/89	-	-	-	-	-	6.4	-	-	-	-
V4,4'	4/28/90	-	-	-	-	-	-	-	-	-	-
V4,5'	7/89	-	-	-	-	-	31.2	-	-	-	-
V4,5'	4/28/90	-	-	-	-	-	-	-	-	-	-

TABLE C-8. SPECIFIC HYDROCARBON DISTRIBUTION IN PLOT V4 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	n-do- decane	n-tri- decane	n-tetra- decane	n-penta- decane	total hydrocarbon
V4,1'	7/89	-	-	-	0.3	5.6	5.4	9.0	4.7	25.0
V4,1'	4/28/90	-	-	-	-	-	-	-	1.6	1.6
V4,2'	7/89	0.6	3.5	3.1	4.6	6.7	5.4	5.8	1.2	87.5
V4,2'	4/28/90	-	-	-	-	-	-	-	13.8	13.8
V4,3'	7/89	-	-	-	-	-	5.0	-	-	23.5
V4,3'	4/28/90	-	-	-	-	-	-	-	1.0	1.0
V4,4'	7/89	-	-	-	-	-	-	-	2.5	8.9
V4,4'	4/28/90	-	-	-	-	-	-	3.9	2.1	6.0
V4,5'	7/89	-	-	-	-	-	0.9	-	-	32.1
V4,5'	4/28/90	-	-	-	-	-	-	-	4.0	4.0

TABLE C-9. SPECIFIC HYDROCARBON DISTRIBUTION OUTSIDE THE PLOTS (MG/KG)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
OUTSIDE 1'	4/28/90	-	-	-	-	-	-	-	0.10
OUTSIDE 2'	4/28/90	-	-	-	-	-	-	-	-
OUTSIDE 2', d	4/28/90	-	-	-	-	-	-	-	-
OUTSIDE 3'	4/28/90	-	-	-	-	-	-	-	-
OUTSIDE 4'	4/28/90	-	-	-	-	-	-	-	15.40
OUTSIDE 5'	4/28/90	-	-	-	-	3.20	-	2.80	139.80

TABLE C-9. SPECIFIC HYDROCARBON DISTRIBUTION OUTSIDE THE PLOTS (MG/KG) (CONTINUED)

SAMPLE ID	DATE	ethyl-		p-xylene	n-propyl-		n-butyl-		n-do- decane
		n-octane	benzene		benzene	n-decane	benzene	naphthalene	
OUTSIDE 1'	4/28/90	-	-	3.50	22.30	26.90	44.20	86.5	242.60
OUTSIDE 2'	4/28/90	-	-	-	30.70	43.60	83.00	114.7	279.50
OUTSIDE 2',d	4/28/90	-	-	-	31.00	45.00	62.40	98.6	74.60
OUTSIDE 3'	4/28/90	-	-	-	12.90	13.80	22.80	20.5	67.60
OUTSIDE 4'	4/28/90	5.70	-	23.00	66.70	116.50	125.90	54.4	249.10
OUTSIDE 5'	4/28/90	21.20	-	26.10	16.10	46.80	50.90	15.5	45.50



TABLE C-9. SPECIFIC HYDROCARBON DISTRIBUTION OUTSIDE THE PLOTS (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
OUTSIDE 1'	4/28/90	239.50	-	381.10	358.30	1405.00
OUTSIDE 2'	4/28/90	249.00	-	336.90	219.40	1356.80
OUTSIDE 2', d	4/28/90	-	168.5	124.70	182.10	786.90
OUTSIDE 3'	4/28/90	55.40	-	73.50	37.60	304.10
OUTSIDE 4'	4/28/90	174.80	49.9	218.70	133.40	1233.50
OUTSIDE 5'	4/28/90	27.90	8.8	14.30	7.70	426.60

TABLE C-10. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V1 (MG/KG)

SAMPLE ID	DATE	<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12
V1-1,1'	9/89	65.70	----->	----->	552.30	803.50	440.80	1389.00
V1-1,1'	4/28/90	0.00	0.00	11.30	63.30	451.00	420.90	1418.00
V1-1,2'	9/89	43.00	----->	----->	----->	18.90	9.60	8.10
V1-1,2'	4/28/90	0.00	0.00	5.50	36.80	349.60	244.00	775.70
V1-1,3'	9/89	1.30	----->	97.90	----->	18.10	17.80	90.20
V1-1,3'	4/28/90	16.80	----->	5.50	18.50	283.50	238.20	685.40
V1-1,4'	9/89	1.06	----->	53.10	----->	----->	----->	----->
V1-1,4'	4/28/90	0.00	0.00	12.70	2.20	201.20	200.90	640.20
V1-1,5'	9/89	1.10	----->	29.40	2.10	4.10	2.90	5.00
V1-1,5'	4/28/90	0.00	0.00	9.20	0.00	0.00	0.00	6.60
V1-1,6'	9/89	1.73	----->	24.60	0.60	1.50	0.88	1.70
V1-1,6'	4/28/90	0.00	0.00	5.40	0.00	2.70	0.00	0.00
V1-1,7'	9/89	2.20	----->	54.00	4.80	11.70	5.70	6.40
V1-1,7'	4/28/90	606.20	----->	896.40	3079.00	3533.00	1728.00	5871.00

TABLE C-10. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V1 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO C-14 TO				TOTAL		
		C-13	C-13 TO C-14	C-14 TO C-15	C-15	>C-15	HYDROCARBON	HEXANE
V1-1,1'	9/89	508.00	516.30	379.40	140.80	4795.80	6430.00	
V1-1,1'	4/28/90	833.20	671.30	455.60	231.10	4555.70	4540.00	
V1-1,2'	9/89	5.10	----->	----->	----->	84.70	94.90	
V1-1,2'	4/28/90	397.10	312.40	220.90	141.70	2483.70	2467.00	
V1-1,3'	9/89	54.40	43.10	34.50	1.60	358.90	474.60	
V1-1,3'	4/28/90	311.50	242.80	180.20	117.40	2099.80	2069.00	
V1-1,4'	9/89	----->	8.90	----->	----->	63.06	79.60	
V1-1,4'	4/28/90	338.50	274.30	207.30	160.90	2038.20	2032.00	
V1-1,5'	9/89	2.00	1.40	0.61	2.00	50.61	60.00	
V1-1,5'	4/28/90	0.00	5.80	5.10	4.80	31.50	28.10	
V1-1,6'	9/89	-	-	-	-	31.01	34.50	
V1-1,6'	4/28/90	0.00	2.90	1.90	1.40	14.30	10.50	
V1-1,7'	9/89	1.40	0.84	----->	----->	87.04	100.40	
V1-1,7'	4/28/90	3090.00	2636.00	1826.00	769.80	24035.40	23716.00	

TABLE C-11. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG)

SAMPLE ID	DATE	C-5 TO C-12											
		<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12					
V1-2,1'A	7/89	1375.00	>	>	>	>	>	>	>	>	>	>	>
V1-2,1'B	7/89	ND	ND	131.30	1520.00	1750.00	2390.00	1000.00	1407.00	2681.00	4630.00		
V1-2,1'C	7/89	967.70	967.70	967.70	2029.00	2894.00	1656.00	1656.00	4441.00				
V1-2,1'	9/89	2.50	>	114.10	401.80	944.50	767.80	2832.00					
V1-2,1'	4/28/90	0.00	0.00	0.00	0.00	0.00	1.90	40.40					
V1-2,2'A	7/89	317.80	>	>	597.70	835.60	466.80	1247.60					
V1-2,2'B	7/89	1049.00	>	>	>	1031.00	281.90	1416.00					
V1-2,2'B,d	7/89	902.30	>	>	>	748.30	335.40	1544.00					
V1-2,2'C	7/89	ND	ND	168.60	608.10	1100.20	477.90	2099.50					
V1-2,2'	9/89	1.00	>	174.10	706.40	1272.00	862.80	2088.00					
V1-2,2'	4/28/90	0.00	0.00	13.20	3.50	121.40	249.80	1154.00					

TABLE C-11. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	C-5 TO C-12											
		<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12					
V1-2,3'A	7/89	1005.00	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,3'B	7/89	212.40	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,3'B,d	7/89	245.70	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,3'C	7/89	10.20	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,3'	9/89	2.50	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,3'	4/28/90	0.00	0.00	71.10	12.70	259.70	224.20	785.10	1775.00	512.10	2.50	0.00	0.00
V1-2,4'	9/89	1.60	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,4'	4/28/90	0.00	0.00	3.70	1.80	85.70	116.40	512.10	2.50	0.00	0.00	0.00	0.00
V1-2,5'	9/89	ND	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,5'	4/28/90	0.00	0.00	6.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V1-2,6'	9/89	87.10	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,6'	4/28/90	0.00	0.00	6.50	0.00	4.10	9.60	31.70	6.10	0.00	0.00	0.00	0.00
V1-2,7'	9/89	1.00	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->	----->
V1-2,7',d	4/28/90	0.00	0.00	13.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V1-2,7',d	4/28/90	0.00	0.00	20.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE C-11. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	C-12 TO C-14 TO			TOTAL		
		C-13	C-13 TO C-14	C-14 TO C-15	>C-15	HYDROCARBON	HEXANE
V1-2,1'A	7/89	1160.00	651.90	773.80	18.50	9410.20	11908.00
V1-2,1'B	7/89	2684.00	1200.00	1664.00	345.60	15971.90	21695.00
V1-2,1'C	7/89	1956.00	1705.00	1129.00	130.10	18843.20	21987.00
V1-2,1'	9/89	1481.00	1278.00	900.10	104.00	8825.80	11803.00
V1-2,1'	4/28/90	49.80	44.90	35.30	13.60	185.90	183.80
V1-2,2'A	7/89	687.90	345.70	308.10	35.80	4843.00	6226.00
V1-2,2'B	7/89	704.00	605.00	404.10	36.50	5527.50	6883.00
V1-2,2'B,d	7/89	819.80	407.30	311.40	100.90	5169.40	6485.00
V1-2,2'C	7/89	1015.30	286.40	668.00	38.30	6462.30	8676.00
V1-2,2'	9/89	940.60	799.60	676.70	67.90	7589.10	9933.00
V1-2,2'	4/28/90	638.30	512.00	353.50	182.80	3228.50	3230.00

TABLE C-11. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V1 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO C-13 TO C-14 TO			TOTAL		
		C-13	C-14	C-15	>C-15	HYDROCARBON	HEXANE
V1-2,3'A	7/89	863.90	435.70	440.50	46.60	5588.00	7181.00
V1-2,3'B	7/89	563.50	540.00	265.10	28.70	4047.00	5323.00
V1-2,3'B,d	7/89	660.50	199.80	469.80	29.70	4242.50	5558.00
V1-2,3'C	7/89	576.30	464.70	299.50	94.50	4859.60	6429.00
V1-2,3'	9/89	1003.00	615.10	350.10	500.20	6732.10	8871.00
V1-2,3'	4/28/90	445.60	356.70	246.80	127.00	2528.90	2519.00
V1-2,4'	9/89	1205.10	829.70	623.50	64.20	7842.00	10272.00
V1-2,4'	4/28/90	337.90	291.80	213.60	125.60	1688.60	1687.00
V1-2,5'	9/89	19.60	11.90	40.20	68.90	206.20	273.90
V1-2,5'	4/28/90	0.00	0.00	4.10	1.40	12.40	11.20
V1-2,6'	9/89	119.60	140.10	171.20	----->	1123.20	1491.00
V1-2,6'	4/28/90	15.10	23.70	25.90	11.50	128.10	116.60
V1-2,7'	9/89	2.40	2.90	1.60	----->	60.60	74.90
V1-2,7',d	4/28/90	0.00	0.00	2.80	1.50	17.60	16.10
V1-2,7',d	4/28/90	4.90	6.80	4.70	3.10	40.40	32.60

TABLE C-12. BOILING POINT DISTRIBUTION IN AREA 3 OF PLOT V1 (MG/KG)

SAMPLE ID	DATE	<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12
V1-3,1'	9/89	2.60	----->	138.60	376.50	1103.00	794.40	3045.00
V1-3,1'	4/28/90	0.00	0.00	93.70	1.60	72.00	126.00	1165.00
V1-3,2'	9/89	6.10	----->	136.30	304.60	800.60	552.80	1883.10
V1-3,2'	4/28/90	0.00	0.00	0.00	16.50	488.20	561.10	2072.00
V1-3,3'	9/89	2.20	----->	195.20	350.40	802.00	543.50	1644.00
V1-3,3'	4/28/90	0.00	0.00	9.00	2.40	194.50	212.90	805.00
V1-3,4'	9/89	6.60	----->	144.00	ND	4.80	1.90	15.70
V1-3,4'	4/28/90	0.00	0.00	19.60	0.00	7.30	18.70	108.20
V1-3,5'	9/89	2.60	----->	96.50	-	-	-	-
V1-3,5'	4/28/90	0.00	0.00	4.60	0.00	0.00	0.00	0.00
V1-3,6'	9/89	3.00	----->	113.50	ND	2.80	3.40	22.40
V1-3,6',d	4/28/90	0.00	0.00	14.30	0.00	0.00	0.00	3.20
V1-3,6',d	4/28/90	0.00	0.00	37.70	0.00	0.00	0.00	0.00
V1-3,7'	9/89	2.60	----->	126.00	ND	1.60	2.20	2.70
V1-3,7'	4/28/90	0.00	0.00	15.60	0.00	0.00	0.00	0.00



TABLE C-12. BOILING POINT DISTRIBUTION IN AREA 3 OF PLOT V1 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO C-13 TO C-14 TO				TOTAL		
		C-13	C-14	C-15	C-15	>C-15	HYDROCARBON	HEXANE
V1-3,1'	9/89	1579.00	1408.00	993.00	98.00	9538.10	13046.00	
V1-3,1'	4/28/90	1308.00	1209.00	858.90	340.20	5174.40	5202.00	
V1-3,2'	9/89	1177.30	685.10	445.70	132.70	6124.30	8323.00	
V1-3,2'	4/28/90	1119.00	877.00	597.30	290.70	6021.80	6015.00	
V1-3,3'	9/89	977.20	493.90	457.00	41.80	5507.20	7432.00	
V1-3,3'	4/28/90	455.20	363.90	251.20	129.50	2423.60	2417.00	
V1-3,4'	9/89	20.10	47.00	21.30	2.50	263.90	324.40	
V1-3,4'	4/28/90	98.80	103.30	84.10	53.40	493.40	489.70	
V1-3,5'	9/89	-	-	-	-	99.10	108.80	
V1-3,5'	4/28/90	0.00	0.00	0.00	1.10	5.70	5.50	
V1-3,6'	9/89	19.50	11.70	4.60	ND	180.90	217.80	
V1-3,6',d	4/28/90	0.00	25.80	23.60	31.30	98.20	93.70	
V1-3,6',d	4/28/90	0.00	5.70	3.30	11.30	58.00	53.70	
V1-3,7'	9/89	3.40	1.40	----->	----->	139.90	156.90	
V1-3,7'	4/28/90	0.00	2.10	0.00	1.10	18.80	17.20	

TABLE C-13. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V2 (MG/KG)

SAMPLE ID	DATE	<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12
V2-1,1'C	9/89	120.70	----->	----->	----->	----->	----->	----->
V2-1,1'	4/28/90	0.00	0.00	8.70	0.00	0.00	0.00	0.00
V2-1,2'C	9/89	ND	----->	234.70	540.70	1061.00	530.00	2605.00
V2-1,2'	4/28/90	0.00	0.00	23.30	0.01	196.60	591.20	4094.00
V2-1,3'C	9/89	404.90	----->	----->	----->	401.00	232.30	1129.00
V2-1,3'	4/28/90	0.00	0.00	7.20	0.00	10.20	38.00	333.70
V2-1,4'C	9/89	2.00	----->	582.50	1771.00	3237.00	1314.00	4002.00
V2-1,4'	4/28/90	0.00	0.00	7.60	33.90	512.80	488.60	1884.00
V2-1,5'C	9/89	1.80	----->	125.60	29.90	53.40	29.00	187.50
V2-1,5'	4/28/90	0.00	0.00	8.10	0.00	0.00	0.00	9.10
V2-1,6'C	9/89	3.40	----->	14.20	2.80	5.00	2.10	10.10
V2-1,6'	4/28/90	0.00	0.00	5.40	0.00	0.00	0.00	2.40
V2-1,7'C	9/89	ND	----->	19.50	3.80	8.50	0.93	10.90
V2-1,7'	4/28/90	0.00	0.00	7.40	1.50	6.80	0.00	7.40

TABLE C-13. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 1 OF PLOT V2 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO C-13 TO C-14 TO C-15				TOTAL		
		C-13	C-14	C-15	>C-15	HYDROCARBON	HEXANE	HEXANE
V2-1,1'C	9/89	0.01	1.70	----->	----->	122.41	150.80	
V2-1,1'	4/28/90	0.00	1.70	2.10	2.20	14.70	12.50	
V2-1,2'C	9/89	1103.00	536.60	148.00	116.30	6875.30	9220.00	
V2-1,2'	4/28/90	2456.00	1791.00	1128.00	540.57	10820.68	10846.00	
V2-1,3'C	9/89	645.50	398.00	307.50	123.20	3641.40	4835.00	
V2-1,3'	4/28/90	216.10	168.60	112.80	48.50	935.10	929.30	
V2-1,4'C	9/89	2052.00	1514.00	982.90	298.80	15756.20	21050.00	
V2-1,4'	4/28/90	894.10	666.30	440.50	317.70	5245.50	5231.00	
V2-1,5'C	9/89	107.10	137.20	54.50	5.00	731.00	972.90	
V2-1,5'	4/28/90	8.10	14.20	17.20	10.50	67.20	62.90	
V2-1,6'C	9/89	9.20	12.10	19.10	----->	78.00	102.40	
V2-1,6'	4/28/90	0.00	6.70	8.70	4.80	28.00	24.00	
V2-1,7'C	9/89	4.40	9.70	6.70	1.00	65.43	84.20	
V2-1,7'	4/28/90	0.00	0.00	2.00	2.20	27.30	39.40	

TABLE C-14. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG)

SAMPLE ID	DATE	C-5 TO C-12											
		<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-11	C-11 TO C-12				
V2-2,1'A	7/89	48.60	→	→	→	→	→	→	→	→	→	→	1.10
V2-2,1'B	7/89	108.70	→	→	→	→	→	→	→	→	→	23.10	104.90
V2-2,1'C	7/89	2.80	→	→	→	→	→	→	→	→	→	→	→
V2-2,1'D	9/89	22.30	→	→	→	→	→	→	→	→	→	→	→
V2-2,1'	4/28/90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10
V2-2,2'A	7/89	471.90	→	→	→	→	→	→	→	→	→	343.00	1228.20
V2-2,2'A,d	7/89	530.50	→	→	→	→	→	→	→	→	→	303.90	1220.60
V2-2,2'B	7/89	4391.00	→	→	→	→	→	→	→	→	→	1903.00	6700.00
V2-2,2'B,d	7/89	688.50	→	→	→	→	→	→	→	→	→	299.00	1702.00

TABLE C-14. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	C-5 TO C-12											
		<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12					
V2-2,2'D	9/89	ND	----->	64.10	318.10	829.80	435.60	1980.00					
V2-2,2'	4/28/90	0.00	0.00	5.10	10.80	20.50	86.60	914.90					
V2-2,3'A	7/89	ND	ND	99.40	733.50	1756.50	803.30	3365.90					
V2-2,3'C	7/89	0.60	----->	72.20	510.20	1061.00	705.20	1849.00					
V2-2,3'D	9/89	ND	----->	320.90	1474.20	2546.60	1487.90	3906.70					
V2-2,3'	4/28/90	14.10	----->	21.50	0.00	216.40	141.40	2533.00					
V2-2,4'D	9/89	ND	----->	434.60	1824.00	3051.00	1154.00	4329.00					
V2-2,4'	4/28/90	0.00	0.00	7.40	721.30	3879.00	2275.00	7263.00					
V2-2,5'D	9/89	ND	----->	47.30	207.20	369.40	151.00	647.90					
V2-2,5'	4/28/90	0.00	0.00	91.90	541.40	1324.00	556.30	1693.00					
V2-2,6'D	9/89	0.00	----->	6.20	14.80	33.50	23.10	122.90					
V2-2,6'	4/28/90	0.00	0.00	4.40	0.00	0.00	3.60	6.10					
V2-2,7'D	9/89	5.90	----->	4.50	0.00	5.20	4.90	8.40					
V2-2,7'	4/28/90	15.00	----->	8.80	0.94	6.10	3.00	3.30					

TABLE C-14. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG) (CONTINUED)

SAMPLE ID	DATE	C-12 TO C-15				TOTAL	
		C-13	C-13 TO C-14	C-14 TO C-15	>C-15	HYDROCARBON	HEXANE
V2-2,1'A	7/89	2.10	3.60	1.00	-	56.40	59.90
V2-2,1'B	7/89	85.20	99.20	42.10	1.00	464.20	605.00
V2-2,1'C	7/89	8.40	15.20	8.60	0.20	35.20	48.40
V2-2,1'D	9/89	----->	56.30	27.30	2.30	108.20	154.70
V2-2,1'	4/28/90	0.00	7.60	0.00	11.10	20.80	20.40
V2-2,2'A	7/89	650.00	298.50	242.40	27.10	3826.50	5020.00
V2-2,2'A,d	7/89	729.30	372.50	361.90	30.60	4089.50	5411.00
V2-2,2'B	7/89	4073.00	2265.00	1235.00	33.80	23326.80	4988.00
V2-2,2'B,d	7/89	939.80	443.80	348.50	45.90	5044.70	6479.00

TABLE C-14. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 2 OF PLOT V2 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO C-13 TO C-14 TO				TOTAL		
		C-13	C-14	C-15	C-15	>C-15	HYDROCARBON	HEXANE
V2-2,2'D	9/89	1052.00	756.80	511.80	235.10	6183.30	8435.00	
V2-2,2'	4/28/90	803.70	620.60	392.70	194.90	3049.80	3057.00	
V2-2,3'A	7/89	1293.30	718.90	933.30	39.10	9743.20	13132.00	
V2-2,3'C	7/89	659.80	708.80	714.10	101.50	6382.40	8626.00	
V2-2,3'D	9/89	1690.80	1408.80	891.70	69.80	13797.40	18469.00	
V2-2,3'	4/28/90	1544.00	1195.00	797.10	370.80	6833.30	7106.00	
V2-2,4'D	9/89	1750.00	1553.00	1062.00	92.70	15250.30	20350.00	
V2-2,4'	4/28/90	3582.00	2797.00	1857.00	1049.00	23430.70	23216.00	
V2-2,5'D	9/89	202.40	236.00	223.00	35.30	2119.50	2852.00	
V2-2,5'	4/28/90	791.50	640.80	434.40	217.30	6290.60	6192.00	
V2-2,6'D	9/89	89.20	32.40	81.00	5.10	408.20	562.10	
V2-2,6'	4/28/90	5.60	2.80	2.20	5.00	29.70	24.70	
V2-2,7'D	9/89	5.30	3.20	24.60	----->	62.00	81.30	
V2-2,7'	4/28/90	0.00	3.50	0.00	0.92	41.56	21.70	

TABLE C-15. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 3 OF PLOT V2 (MG/KG)

SAMPLE ID	DATE	C-5 TO C-12											
		<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12					
V2-3,1'D	9/89	0.00	----->	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
V2-3,1'	4/28/90	0.00	0.00	12.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
V2-3,2'	9/89	0.00	----->	54.70	308.60	688.80	405.70	1728.00					
V2-3,2'	4/28/90	0.00	0.00	9.00	23.00	243.70	362.70	1830					
V2-3,3'	9/89	0.00	----->	18.00	106.80	305.50	180.10	912.70					
V2-3,3'	4/28/90	0.00	0.00	15.40	0.00	78.20	111.20	518.10					
V2-3,4'	9/89	0.00	----->	217.00	1026.00	1777.00	725.30	2848.00					
V2-3,4'	4/28/90	0.00	0.00	3.80	21.40	402.90	582.90	1586.00					
V2-3,5'	9/89	0.00	----->	1.70	0.00	2.10	2.00	15.40					
V2-3,5'	4/28/90	0.00	0.00	11.80	300.30	671.20	450.50	1101.00					
V2-3,6'	9/89	0.00	----->	23.10	128.40	259.70	174.20	483.40					
V2-3,6'	4/28/90	0.00	0.00	2.30	0.00	1.50	2.80	3.90					
V2-3,7'	9/89	0.00	----->	1.80	0.05	2.60	1.40	4.50					
V2-3,7'	4/28/90	0.00	0.00	20.10	0.00	4.80	3.10	4.10					



TABLE C-15. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA 3 OF PLOT V2 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO C-14 TO					TOTAL	
		C-13	C-13 TO C-14	C-14	C-14 TO C-15	C-15	>C-15	HYDROCARBON
V2-3,1'D	9/89	0.60	1.80	20.10	25.00	35.20		
V2-3,1'	4/28/90	2.60	3.40	2.80	1.80	23.50		20.80
V2-3,2'	9/89	528.70	564.20	551.70	30.60	4861.00		6601.00
V2-3,2'	4/28/90	1180.00	945.70	641.70	318.30	5554.10		5559.00
V2-3,3'	9/89	295.10	330.70	221.60	97.40	2467.90		3372.00
V2-3,3'	4/28/90	340.80	281.80	190.80	95.00	1631.30		1626.00
V2-3,4'	9/89	1647.00	1077.00	424.80	375.80	10117.90		13601.00
V2-3,4'	4/28/90	835.50	643.80	440.60	247.70	4764.60		4757.00
V2-3,5'	9/89	20.00	21.40	19.40	4.00	86.00		120.70
V2-3,5'	4/28/90	519.90	426.20	294.90	159.30	3935.10		3885.00
V2-3,6'	9/89	283.20	160.40	116.80	10.80	1640.00		2215.00
V2-3,6'	4/28/90	2.40	3.30	2.00	1.30	19.50		13.00
V2-3,7'	9/89	8.60	6.40	0.80	----->	26.15		36.30
V2-3,7'	4/28/90	0.00	2.60	2.80	0.87	38.37		30.70

TABLE C-16. BOILING POINT HYDROCARBON DISTRIBUTION IN PLOT V3 (MG/KG)

SAMPLE ID	DATE	C-12 TO C-14 TO					TOTAL	
		C-13	C-13 TO C-14	C-14	C-14 TO C-15	C-15	>C-15	HYDROCARBON
V3,1'	7/89	----->	7.3	7.3	7.3	7.3	67.2	58.3
V3,1'	4/28/90	0.00	0.00	0.00	0.00	1.00	15.7	15.50
V3,2'	7/89	68.7	65.6	28.0	28.0	2.1	284.1	380.6
V3,2'	4/28/90	0.00	2.50	1.60	1.60	1.30	66.7	64.40
V3,3'	7/89	1.0	1.4	1.4	1.4	1.4	14.1	9.1
V3,3', d	4/28/90	0.00	0.00	0.00	0.00	2.50	23.5	23.00
V3,3', d	4/28/90	0.00	0.00	0.00	0.00	1.60	12.8	12.60
V3,4'	7/89	-	-	-	-	-	44.9	38.6
V3,4'	4/28/90	0.00	0.00	0.00	0.00	1.30	15.0	14.77
V3,5'	4/28/90	0.00	0.00	0.00	0.00	1.10	624.8	621.70

TABLE C-16. BOILING POINT HYDROCARBON DISTRIBUTION IN PLOT V3 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	C-5 TO C-12											
		<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12					
V3,1'	7/89	45.3	>	>	>	>	>	>	>	>	>	>	>
V3,1'	4/28/90	0.00	0.00	14.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V3,2'	7/89	47.5	>	>	>	>	>	>	>	>	>	>	72.2
V3,2'	4/28/90	0.00	0.00	61.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V3,3'	7/89	7.9	>	>	>	>	>	>	>	>	>	>	1.0
V3,3',d	4/28/90	0.00	0.00	21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V3,3',d	4/28/90	0.00	0.00	11.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V3,4'	7/89	44.9	>	>	>	>	>	>	>	>	>	>	>
V3,4'	4/28/90	0.00	0.00	13.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V3,5'	4/28/90	0.00	0.00	623.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE C-17. BOILING POINT HYDROCARBON DISTRIBUTION IN PLOT V4 (MG/KG)

SAMPLE ID	DATE	<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12
V4,1'	7/89	25.8	→	→	→	→	→	18.0
V4,1'	4/28/90	0.00	0.00	25.40	0.00	0.00	0.00	0.00
V4,2'	7/89	84.0	→	→	7.1	12.0	8.1	32.4
V4,2'	4/28/90	0.00	0.00	14.20	0.00	0.00	0.00	3.30
V4,3'	7/89	23.7	→	→	→	→	→	→
V4,3'	4/28/90	0.00	0.00	25.70	0.00	0.00	0.00	0.00
V4,4'	7/89	100.2	→	→	4.1	→	→	→
V4,4'	4/28/90	0.00	0.00	81.10	0.00	0.00	0.00	0.00
V4,5'	7/89	38.7	→	→	→	→	→	→
V4,5'	4/28/90	0.00	0.00	20.10	0.00	0.00	0.00	0.00

TABLE C-17. BOILING POINT HYDROCARBON DISTRIBUTION IN PLOT V4 (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO		C-13 TO		C-14 TO		C-15		TOTAL	
		C-13	C-14	C-13 TO	C-14	C-14 TO	C-15	>C-15	HYDROCARBON	HEXANE	
V4,1'	7/89	12.6	24.3	24.3	13.9	ND	94.6	119.7			
V4,1'	4/28/90	0.00	0.00	0.00	0.00	1.60	27.0	26.70			
V4,2'	7/89	25.1	23.2	23.2	10.8	2.5	205.2	235.5			
V4,2'	4/28/90	0.00	12.50	12.50	0.00	17.70	47.7	43.50			
V4,3'	7/89	----->	5.0	5.0	-	-	28.7	32.2			
V4,3'	4/28/90	0.00	0.00	0.00	0.00	1.00	26.7	26.50			
V4,4'	7/89	2.5	----->	----->	----->	ND	106.8	94.8			
V4,4'	4/28/90	0.00	0.00	0.00	3.20	2.10	86.4	84.73			
V4,5'	7/89	----->	0.9	0.9	-	-	39.6	42.1			
V4,5'	4/28/90	0.00	2.20	2.20	0.00	4.00	26.3	24.80			

TABLE C-18. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA OUTSIDE THE PLOTS (MG/KG)

SAMPLE ID	DATE	BOILING POINT HYDROCARBON DISTRIBUTION IN AREA OUTSIDE THE PLOTS (MG/KG)											
		<C-5	C-5 TO C-6	C-6 TO C-7	C-7 TO C-8	C-8 TO C-9	C-9 TO C-10	C-10 TO C-12					
OUTSIDE 1'	4/28/90	0.00	0.00	19.20	12.70	59.60	105.30	960.50					
OUTSIDE 2'	4/28/90	0.00	0.00	71.10	3.50	51.90	138.30	1452.00					
OUTSIDE 2', d	4/28/90	0.00	0.00	36.60	1.30	18.30	59.00	919.00					
OUTSIDE 3'	4/28/90	0.00	0.00	17.00	1.80	32.20	57.40	365.00					
OUTSIDE 4'	4/28/90	0.00	0.00	21.50	35.00	369.30	387.80	1547.00					
OUTSIDE 5'	4/28/90	0.00	0.00	51.00	224.20	288.80	159.60	384.10					

TABLE C-18. BOILING POINT HYDROCARBON DISTRIBUTION IN AREA OUTSIDE THE PLOTS (MG/KG) (CONCLUDED)

SAMPLE ID	DATE	TOTAL				
		C-12 TO C-13	C-13 TO C-14	C-14 TO C-15	>C-15	HEXANE
OUTSIDE 1'	4/28/90	1106.00	1079.00	762.20	391.00	4495.50
OUTSIDE 2'	4/28/90	1204.00	976.20	627.70	309.20	4833.90
OUTSIDE 2',d	4/28/90	610.10	802.00	538.60	203.90	3188.80
OUTSIDE 3'	4/28/90	244.60	186.30	117.20	46.80	1068.30
OUTSIDE 4'	4/28/90	761.20	559.00	364.20	186.90	4231.90
OUTSIDE 5'	4/28/90	112.90	69.10	46.90	18.70	1355.30

TABLE C-19. BOILING POINT HYDROCARBON DISTRIBUTION OF METHYLENE CHLORIDE EXTRACTED WATER SAMPLES (MICROGRAMS/LITER)

SAMPLE ID	DATE	C-5 TO		C-6 TO		C-7 TO		C-8 TO		C-9 TO		C-10 TO	
		<C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12				
V1-1	9/26/89	0.00	0.00	502.50	572.80	751.90	380.10	725.60					
V1-1	4/28/90	0.00	----->	172.40	368.70	341.20	236.30	636.50					
V1-1 d	4/28/90	0.00	----->	111.90	312.30	327.50	321.60	849.70					
V1-2	9/26/89	0.00	0.00	762.30	565.00	1164.00	514.20	1233.00					
V1-2	4/28/90	0.00	----->	77.80	386.60	1357.00	1293.00	5592.00					
V1-2 d	4/28/90	262.80	----->	930.00	1491.00	1486.00	640.20	1726.00					
V1-3	9/26/89	69.40	----->	225.40	741.90	2290.00	2040.00	9416.00					
V1-3	4/28/90	134.40	----->	51.10	197.00	2442.00	2347.00	7702.00					
V1-3 d	4/28/90	0.00	----->	85.10	35.60	64.90	162.20	283.10					
V2-1	9/26/89	218.5	----->	4755.00	13464.00	43559.00	21797.00	78582.00					
V2-1	4/28/90	340.50	----->	1288.00	2803.00	5382.00	2305.00	5806.00					
V2-1 d	4/28/90	408.80	----->	2018.00	10213.00	16490.00	8362.00	23551.00					
V2-2	9/26/89	317.60	----->	5118.00	1812.00	1857.00	3907.00	4302.00					
V2-2	4/28/90	1065.00	----->	3181.00	11895.00	21734.00	9468.00	22995.00					
V2-2 d	4/28/90	1963.00	----->	3491.20	9348.60	26971.00	11872.00	29386.00					
V2-3	9/26/89	0.00	----->	723.80	2910.00	2906.00	4383.00	6221.00					
V2-3	4/28/90	384.40	----->	732.40	2396.00	4321.00	2090.00	5581.00					
V2-3 d	4/28/90	289.20	----->	1075.00	5035.00	10044.00	5023.00	15739.00					
V3	9/26/89	127.00	----->	2047.00	724.90	742.80	1563.00	1721.00					
V3	4/28/90	273.60	----->	465.40	663.20	322.40	97.90	79.00					
V3	4/28/90	246.50	----->	169.70	166.10	123.30	92.80	184.20					
V4	9/26/89	8.10	----->	18.10	4.80	3.00	7.10	21.00					
V4,d	9/26/89	0.00	----->	17.80	3.10	5.30	12.00	0.00					
V4	4/28/90	137.10	----->	222.00	265.00	181.90	48.40	24.90					
V4 d	4/28/90	0.00	----->	192.20	274.40	187.60	41.40	18.30					
DEWATER	4/28/90	132.30	----->	187.50	280.10	150.10	44.50	57.40					
DEWATER d	4/28/90	272.90	----->	322.60	515.60	297.40	147.40	637.90					



TABLE C-19. BOILING POINT HYDROCARBON DISTRIBUTION OF METHYLENE CHLORIDE EXTRACTED WATER SAMPLES (MICROGRAMS/LITER) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO C-13 TO C-14 TO			C-15	>C-15	TOTAL	
		C-13	C-14	C-14 TO C-15			HYDROCARBON	HEXANE
V1-1	9/26/89	210.70	244.50	102.60	44.5	3535.20	4557.00	
V1-1	4/28/90	235.30	417.60	473.20	102.30	2983.50	2601.00	
V1-1 d	4/28/90	137.70	169.30	328.70	67.70	2626.40	2417.00	
V1-2	9/26/89	235.10	136.90	0.00	0.00	4610.50	5896.00	
V1-2	4/28/90	3279.00	2750.00	1858.00	759.70	17353.10	17128.00	
V1-2 d	4/28/90	474.50	347.70	260.10	75.40	7693.70	7090.00	
V1-3	9/26/89	6415.00	3356.00	1786.00	206.20	26545.90	36424.00	
V1-3	4/28/90	4594.00	4407.00	3606.00	1941.00	27421.50	27213.00	
V1-3 d	4/28/90	46.00	0.00	0.00	1241.00	1917.90	1818.00	
V2-1	9/26/89	27456.00	18146.00	331.30	85.40	208394.20	278610.00	
V2-1	4/28/90	2432.00	1902.00	1191.00	523.30	23972.80	23096.00	
V2-1 d	4/28/90	10488.00	8121.00	6645.00	2225.00	88521.80	86613.00	
V2-2	9/26/89	1448.00	1194.00	1184.00	775.30	21914.90	28121.00	
V2-2	4/28/90	9131.00	6770.00	3483.00	890.30	90612.30	88439.00	
V2-2 d	4/28/90	10960.00	8586.00	4940.00	1412.00	108929.80	106569.00	
V2-3	9/26/89	1988.00	1635.00	1747.00	1204.00	23717.80	31744.00	
V2-3	4/28/90	2469.00	2190.00	2364.00	917.50	23445.30	22705.00	
V2-3 d	4/28/90	7983.00	6244.00	3461.00	960.80	55854.00	54589.00	
V3	9/26/89	579.20	477.40	473.50	310.10	8765.90	730.70	
V3	4/28/90	0.00	0.00	0.00	63.00	1964.50	1543.00	
V3	4/28/90	47.80	94.90	125.20	69.60	1320.10	897.80	
V4	9/26/89	16.80	24.20	0.00	0.00	103.10	132.30	
V4, d	9/26/89	12.10	2.60	1.20	2.90	57.00	73.20	
V4	4/28/90	0.00	0.00	1036.00	1008.00	2923.30	2767.00	
V4 d	4/28/90	0.00	0.00	0.00	0.00	713.90	624.70	
DEWATER	4/28/90	0.00	18.10	115.70	737.70	1723.40	1526.00	
DEWATER d	4/28/90	76.30	0.00	52.60	78.60	2401.30	1962.00	

TABLE C-20. SPECIFIC HYDROCARBON DISTRIBUTION OF METHYLENE CHLORIDE EXTRACTED WATER SAMPLES (MICROGRAMS/LITER)

SAMPLE ID	DATE	methyl- butane	pentane	2-methyl- pentane	n-hexane	2,4-dimethyl- pentane	benzene	n-heptane	toluene
V1-1	9/26/89	-	-	-	136.90	35.60	10.70	3.30	167.70
V1-1	4/28/90	-	-	-	-	-	-	-	-
V1-1	4/28/90	-	-	-	-	-	-	-	-
V1-1 d	4/28/90	-	-	-	-	-	-	-	19.10
V1-2	9/26/89	-	-	-	500.20	29.00	64.30	70.00	136.80
V1-2	4/28/90	-	-	-	-	-	-	-	72.70
V1-2 d	4/28/90	-	-	-	-	-	-	393.10	525.50
V1-3	9/26/89	-	-	26.10	11.60	23.60	24.70	-	53.00
V1-3	4/28/90	-	-	40.00	-	-	-	-	-
V1-3 d	4/28/90	-	-	-	-	-	-	-	-
V2-1	9/26/89	-	25.90	-	119.70	-	485.00	807.10	1052.00
V2-1	4/28/90	-	-	138.90	127.20	-	181.00	299.50	780.20
V2-1 d	4/28/90	-	-	-	-	-	-	-	-
V2-2	9/26/89	-	-	5.60	5473.00	-	-	46.40	-
V2-2	4/28/90	-	153.60	-	-	-	-	-	-
V2-2 d	4/28/90	-	-	253.10	382.30	600.70	83.40	1388.00	1162.00
V2-3	9/26/89	-	-	-	-	47.50	33.50	297.30	62.00
V2-3	4/28/90	-	-	77.80	-	-	-	-	567.70
V2-3 d	4/28/90	-	-	-	-	-	-	-	1078.00

TABLE C-20. SPECIFIC HYDROCARBON DISTRIBUTION OF METHYLENE CHLORIDE EXTRACTED WATER SAMPLES (MICROGRAMS/LITER) (CONTINUED)

SAMPLE ID	DATE	methyl-		2-methyl-		2,4-dimethyl-			benzene	n-heptane	toluene
		butane	pentane	pentane	pentane	n-hexane	pentane	hexane			
V3	9/26/89	-	-	2.20	29.40	-	-	3.20	-	-	28.20
V3	9/26/89	-	-	4.20	-	-	-	-	-	-	-
V3	4/28/90	-	-	-	-	-	-	171.60	187.30	152.60	-
V3	4/28/90	-	-	73.00	62.00	-	54.70	79.20	62.20	11.00	-
V4	9/26/89	-	-	6.70	3.20	-	-	-	-	-	4.50
V4	9/26/89	-	-	-	12.10	-	3.30	3.30	-	-	2.90
V4	4/28/90	-	-	50.70	53.70	-	49.10	77.80	79.40	110.60	-
V4 d	4/28/90	-	-	-	-	-	-	77.90	-	-	96.50
DEWATER	4/28/90	-	-	-	-	-	-	-	48.40	132.80	-
DEWATER d	4/28/90	-	-	100.20	-	-	79.00	-	104.80	204.60	-

TABLE C-20. SPECIFIC HYDROCARBON DISTRIBUTION OF METHYLENE CHLORIDE EXTRACTED WATER SAMPLES (MICROGRAMS/LITER) (CONTINUED)

SAMPLE ID	DATE	ethyl-		n-propyl-		n-butyl-		n-do-	
		n-octane	benzene	p-xylene	benzene	n-decane	benzene	naphthalene	decane
V1-1	9/26/89	29.40	-	348.20	16.30	49.50	7.80	-	59.60
V1-1	4/28/90	130.70	-	89.10	85.80	83.30	49.00	-	109.80
V1-1	4/28/90	-	-	-	-	-	-	-	-
V1-1 d	4/28/90	73.50	50.20	90.60	46.80	71.30	30.50	-	80.70
V1-2	9/26/89	75.50	-	365.50	69.40	103.70	139.60	-	65.10
V1-2	4/28/90	88.90	-	206.50	215.30	259.00	350.90	336.50	884.50
V1-2 d	4/28/90	294.10	-	513.80	130.40	150.70	154.10	-	170.20
V1-3	9/26/89	130.40	-	418.20	196.30	571.60	587.60	-	1822.00
V1-3	4/28/90	54.50	-	292.70	402.70	390.80	278.90	383.50	1204.00
V1-3 d	4/28/90	-	-	-	119.60	39.40	32.90	-	34.70
V2-1	9/26/89	2252.00	-	4727.00	2293.00	11903.00	8795.00	-	4826.00
V2-1	4/28/90	506.70	401.70	2090.00	245.30	613.80	244.20	356.10	798.10
V2-1 d	4/28/90	108.10	722.00	223.30	864.10	2483.00	844.40	1018.00	3372.00
V2-2	9/26/89	116.80	-	15.20	116.90	965.30	330.70	-	320.40
V2-2	4/28/90	2084.00	1285.00	7330.00	944.80	2515.00	1037.00	1179.00	2970.00
V2-2 d	4/28/90	2356.00	1617.00	8658.00	1260.00	3355.00	1212.00	1637.00	3542.00
V2-3	9/26/89	431.30	-	177.20	567.50	705.80	378.90	-	425.20
V2-3	4/28/90	387.30	138.50	1626.60	245.80	606.00	202.60	262.90	796.50
V2-3 d	4/28/90	690.40	-	116.40	653.70	1683.00	484.70	657.70	2482.00

TABLE C-20. SPECIFIC HYDROCARBON DISTRIBUTION OF METHYLENE CHLORIDE EXTRACTED WATER SAMPLES (MICROGRAMS/LITER) (CONTINUED)

SAMPLE ID	DATE	n-octane	ethyl- benzene	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	naphthalene	n-do- decane
V3	9/26/89	3.90	-	7.80	8.60	16.80	32.20	-	2.40
V3	9/26/89	-	-	-	-	-	-	-	-
V3	4/28/90	132.60	112.60	45.60	53.80	52.90	31.90	-	-
V3	4/28/90	85.60	56.30	5.80	49.90	47.10	59.10	-	28.20
V4	9/26/89	-	-	1.90	1.00	2.30	5.20	-	1.70
V4	9/26/89	-	-	5.50	-	4.00	-	-	-
V4	4/28/90	69.50	60.90	65.40	29.50	27.50	-	-	-
V4 d	4/28/90	60.70	62.10	58.90	26.70	20.70	-	-	-
DEWATER	4/28/90	55.10	50.70	29.40	25.80	20.40	-	-	-
DEWATER d	4/28/90	115.70	97.60	65.90	51.10	64.80	51.20	59.60	50.00

TABLE C-20. SPECIFIC HYDROCARBON DISTRIBUTION OF METHYLENE CHLORIDE EXTRACTED WATER SAMPLES (MICROGRAMS/LITER) (CONTINUED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V1-1	9/26/89	72.50	-	71.10	19.50	1028.10
V1-1	4/28/90	140.70	82.40	321.20	102.30	1022.80
V1-1	4/28/90	-	-	2646.00	1120.00	3766.00
V1-1 d	4/28/90	76.90	-	174.60	34.50	698.50
V1-2	9/26/89	26.50	-	32.30	-	1677.90
V1-2	4/28/90	737.70	530.40	1138.00	749.90	4703.40
V1-2 d	4/28/90	114.80	-	147.30	29.20	2623.20
V1-3	9/26/89	2324.00	-	1463.00	830.50	8482.60
V1-3	4/28/90	1060.00	839.20	1785.00	1824.00	7332.60
V1-3 d	4/28/90	-	-	-	-	226.60
V2-1	9/26/89	1813.00	-	167.00	67.40	39333.10
V2-1	4/28/90	639.10	222.50	735.70	499.10	7898.80
V2-1 d	4/28/90	2564.00	767.80	3145.00	2178.00	15781.90
V2-2	9/26/89	602.80	-	254.90	256.20	8504.20
V2-2	4/28/90	2319.00	793.60	1545.00	853.30	21751.70
V2-2 d	4/28/90	2963.00	1006.00	2256.00	1378.00	30849.50
V2-3	9/26/89	819.20	-	360.10	402.10	4707.60
V2-3	4/28/90	629.30	180.90	1342.00	735.00	7216.60
V2-3 d	4/28/90	1921.00	515.50	2842.00	916.40	12867.60

TABLE C-20. SPECIFIC HYDROCARBON DISTRIBUTION OF METHYLENE CHLORIDE EXTRACTED WATER SAMPLES (MICROGRAMS/LITER) (CONCLUDED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V3	9/26/89	29.80	-	41.10	6.30	211.90
V3	9/26/89	-	-	-	-	4.20
V3	4/28/90	-	-	-	-	828.30
V3	4/28/90	52.80	-	77.10	28.20	775.90
V4	9/26/89	16.60	-	12.30	-	55.40
V4	9/26/89	12.00	-	-	-	43.10
V4	4/28/90	-	-	-	1008.00	1621.20
V4 d	4/28/90	-	-	-	-	341.40
DEWATER	4/28/90	19.30	-	121.00	-	452.20
DEWATER d	4/28/90	-	-	-	-	887.30

TABLE C-21. BOILING POINT HYDROCARBON DISTRIBUTION FROM GAS (CANISTER)  
VOLATILE ANALYSIS (MICROGRAMS/LITER)

SAMPLE ID	DATE	C-5 TO		C-6 TO		C-7 TO		C-8 TO		C-9 TO		C-10 TO	
		<C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12				
V1-1A	7/89	1984.20	3431.00	20591.00	18530.00	4769.60	781.90	591.10					
V1-1B	7/89	2105.70	3334.00	19965.00	18338.80	5192.70	489.60	371.60					
V1-1 (MEAN)	7/89	2044.95	3382.50	20278.00	18434.00	4981.20	635.80	481.35					
V1-2A	7/89	4729.60	3304.40	18929.10	18569.90	6335.10	1237.80	952.00					
V1-3A	7/89	692.40	767.30	8677.90	8807.60	4746.00	1070.70	741.60					
V2-1A	7/89	2381.30	756.10	7457.50	5527.80	3381.90	900.80	27.50					
V2-2A	7/89	694.00	3793.30	-	6579.30	3858.70	1029.60	820.40					
V2-3A	7/89	62.50	3071.40	-	3633.10	2957.30	803.10	835.10					
V2-3B	7/89	58.80	3049.10	-	3627.90	2980.00	656.20	1059.80					
V2-3 (MEAN)	7/89	60.65	3060.25	-	3630.50	2968.70	729.70	947.45					
V1-A	10/5/89	54247.00	----->	----->	----->	5121.00	612.20	488.00					
V1-B	10/5/89	2081.00	----->	16600.00	18560.00	5658.00	955.40	559.90					
V2-A	10/5/89	4516.00	----->	12880.00	10636.00	3149.00	556.50	383.10					
V2-B	10/5/89	4427.00	----->	12863.00	10561.00	3074.00	529.60	339.70					
V1	10/27/89	7124.00	----->	----->	8032.00	4360.00	1055.00	1018.00					
V2	10/27/89	13359.00	----->	----->	10170.00	4408.00	1071.00	891.40					
V1	12/2/89	3349.00	----->	----->	----->	1428.00	410.00	----->					
V2	12/2/89	5542.00	----->	----->	----->	1538.00	----->	----->					
V1	1/12/90	6.20	----->	175.80	1220.00	1768.00	522.70	285.70					
V2	1/12/90	4.10	13.50	575.50	1403.00	1230.00	300.20	147.80					



TABLE C-21. BOILING POINT HYDROCARBON DISTRIBUTION FROM GAS (CANISTER)  
VOLATILE ANALYSIS (MICROGRAMS/LITER) (CONCLUDED)

SAMPLE ID	DATE	C-12 TO C-13 TO C-14 TO			C-14 TO C-15			TOTAL		
		C-13	C-14	C-15	C-14	C-15	>C-15	HYDROCARBON	HEXANE	HEXANE
V1-1A	7/89	13.30	628.90	-	-	6.50	-	51327.50	-	-
V1-1B	7/89	65.90	5.40	-	-	-	-	49868.70	-	-
V1-1 (MEAN)	7/89	39.60	317.15	-	-	6.50	-	50601.05	-	-
V1-2A	7/89	44.30	7.80	-	-	0.00	-	54110.00	-	-
V1-3A	7/89	140.30	12.60	24.80	-	-	-	25681.20	-	-
V2-1A	7/89	20.10	7.10	-	-	-	-	20460.10	-	-
V2-2A	7/89	18.20	7.70	-	-	-	-	16801.20	-	-
V2-3A	7/89	26.10	9.30	-	-	-	-	11397.90	-	-
V2-3B	7/89	33.00	7.60	-	-	3.30	-	11475.70	-	-
V2-3 (MEAN)	7/89	29.55	8.45	-	-	3.30	-	11438.55	-	-
V1-A	10/5/89	13.70	222.50	----->	----->	----->	----->	60704.40	47280.00	
V1-B	10/5/89	16.60	----->	----->	----->	----->	----->	44430.90	49655.00	
V2-A	10/5/89	63.80	----->	----->	----->	10.40	----->	32194.80	34322.00	
V2-B	10/5/89	32.50	----->	----->	----->	----->	----->	31826.80	33908.00	
V1	10/27/89	24.10	8.90	----->	----->	----->	----->	21622.00	22662.00	
V2	10/27/89	21.40	4.00	----->	----->	----->	----->	29924.80	29411.00	
V1	12/2/89	17.40	10.60	40.00	6.00	6.00		5261.00	4869.00	
V2	12/2/89	----->	111.50					7191.50	6660.00	
V1	1/12/90	140.60	----->	----->	----->	----->	----->	4119.00	5103.00	
V2	1/12/90	71.10	----->	----->	----->	----->	----->	3745.20	4552.00	

TABLE C-22. SPECIFIC HYDROCARBON DISTRIBUTION FROM GAS (CANISTER)  
VOLATILE ANALYSIS (MICROGRAMS/LITER)

SAMPLE ID	DATE	methyl-		2-methyl-		2,4-dimethyl-		benzene	n-heptane	toluene
		butane	pentane	pentane	pentane	pentane	pentane			
V1-1A	7/89	400.90	80.10	1978.30	111.80	4211.60	277.20	506.30	6647.30	
V1-1B	7/89	411.60	153.80	1921.80	111.10	4166.80	256.20	516.20	943.70	
V1-1 (MEAN)	7/89	406.25	116.95	1950.05	111.45	4189.20	266.70	511.25	3795.50	
V1-2A	7/89	381.17	163.28	1855.80	75.51	4086.28	269.16	222.06	6249.78	
V1-3A	7/89	68.30	15.70	403.70	3.40	1264.00	98.70	8.40	3926.00	
V2-1A	7/89	118.19	14.52	459.21	7.46	910.30	49.67	5.21	2286.86	
V2-2A	7/89	24.99	20.99	53.59	-	-	40.25	2170.23	2309.71	
V2-3A	7/89	-	18.80	113.50	-	326.60	27.00	1592.80	1607.70	
V2-3B	7/89	-	17.30	109.60	-	323.80	26.60	1590.00	1610.00	
V2-3 (MEAN)	7/89	-	18.05	111.55	-	325.20	26.80	1591.40	1608.85	
V1-A	10/5/89	-	-	737.30	-	2652.00	183.50	-	5674.00	
V1-B	10/5/89	-	-	778.10	37.40	2756.00	185.90	212.70	5919.00	
V2-A	10/5/89	-	-	1480.00	361.70	2162.00	-	445.80	3473.00	
V2-B	10/5/89	-	-	1461.00	350.70	2151.00	134.80	444.30	3457.00	
V1	10/27/89	-	-	45.10	-	305.00	-	30.60	3330.00	
V2	10/27/89	-	-	-	-	902.80	-	402.80	3208.00	
V1	12/2/89	12.10	-	3.60	-	16.60	4.50	-	795.00	
V2	12/2/89	-	-	13.10	-	73.30	-	-	864.70	
V1	1/12/90	-	-	-	-	4.20	16.80	-	529.10	
V2	1/12/90	-	3.00	6.70	-	33.60	15.00	16.20	500.10	

TABLE C-22. SPECIFIC HYDROCARBON DISTRIBUTION FROM GAS (CANISTER)  
VOLATILE ANALYSIS (MICROGRAMS/LITER) (CONTINUED)

SAMPLE ID	DATE	n-octane	ethyl- benzene	p-xylene	n-propyl- benzene	n-decane	n-butyl- benzene	naphthalene	n-do- decane
V1-1A	7/89	1148.40	-	1234.40	119.40	167.30	41.40	-	7.90
V1-1B	7/89	1144.10	-	311.40	280.80	131.60	51.20	-	17.70
V1-1 (MEAN)	7/89	1146.25	-	772.90	200.10	149.45	46.30	-	12.80
V1-2A	7/89	1308.48	-	1539.27	195.24	277.11	41.66	-	51.64
V1-3A	7/89	624.90	-	865.10	202.80	239.60	47.00	-	60.90
V2-1A	7/89	172.81	-	191.62	127.62	158.56	121.42	-	67.73
V2-2A	7/89	397.74	-	332.42	174.49	211.24	107.36	-	35.03
V2-3A	7/89	166.50	-	303.20	154.70	166.60	125.70	-	55.60
V2-3B	7/89	166.40	-	309.90	158.50	126.60	132.30	-	65.00
V2-3 (MEAN)	7/89	166.45	-	306.55	156.60	146.60	129.00	-	60.30
V1-A	10/5/89	1168.00	-	1179.00	133.40	109.40	-	-	6.00
V1-B	10/5/89	1241.00	-	1284.00	155.10	201.50	26.10	-	5.40
V2-A	10/5/89	707.40	-	735.60	94.00	118.60	16.00	-	10.70
V2-B	10/5/89	696.70	-	-	89.80	111.10	-	-	19.40
V1	10/27/89	566.10	-	418.50	196.90	228.00	-	-	49.40
V2	10/27/89	834.40	-	-	154.30	254.20	-	-	53.70
V1	12/2/89	176.30	-	183.90	161.40	-	69.60	-	6.70
V2	12/2/89	237.30	-	202.70	150.00	-	-	-	-
V1	1/12/90	80.50	-	300.20	116.00	75.50	29.80	-	2.30
V2	1/12/90	126.60	-	139.10	68.30	45.00	15.70	-	-

TABLE C-22. SPECIFIC HYDROCARBON DISTRIBUTION FROM GAS (CANISTER)  
VOLATILE ANALYSIS (MICROGRAMS/LITER) (CONCLUDED)

SAMPLE ID	DATE	n-tri decane	1-methyl- naphthalene	n-tetra- decane	n-penta- decane	total hydrocarbon
V1-1A	7/89	2.30	-	-	210.90	17145.50
V1-1B	7/89	11.20	-	-	-	10429.20
V1-1 (MEAN)	7/89	6.75	-	-	210.90	13892.80
V1-2A	7/89	7.36	-	-	2.16	16725.96
V1-3A	7/89	13.00	-	1.50	23.90	7866.90
V2-1A	7/89	7.81	-	-	12.82	4711.81
V2-2A	7/89	3.77	-	-	3.05	5884.86
V2-3A	7/89	5.50	-	-	3.30	4667.50
V2-3B	7/89	7.20	-	-	3.40	4646.60
V2-3 (MEAN)	7/89	6.35	-	-	3.35	4657.05
V1-A	10/5/89	10.60	-	-	-	11853.20
V1-B	10/5/89	-	-	-	-	12802.20
V2-A	10/5/89	-	-	-	6.60	9611.40
V2-B	10/5/89	-	-	-	-	8915.80
V1	10/27/89	6.80	-	-	-	5176.40
V2	10/27/89	4.80	-	-	-	5815.00
V1	12/2/89	4.90	-	3.50	6.70	1444.80
V2	12/2/89	7.60	-	-	-	1548.70
V1	1/12/90	-	-	-	-	1154.40
V2	1/12/90	-	-	-	-	969.30



TABLE C-24. SUMMARY OF NUTRIENT ANALYSES AND ACETYLENE REDUCTION TESTS FOR SOIL AND WATER SAMPLES FROM TYNDALL AFB

Location of Soil Samples	PO4-P mg P/kg		PO4-P mg P/L		Tot-P mg P/kg		Tot-P mg P/L		NO3+NO2-N mg N/kg		NO3+NO2-N mg N/L		NH4-N mg N/kg		NH4-N mg N/L	
	Jul/Sep/89	Dec-89	Apr-90	Jul/Sep/89	Dec-89	Apr-90	Jul/Sep/89	Dec-89	Apr-90	Jul/Sep/89	Dec-89	Apr-90	Jul/Sep/89	Dec-89	Apr-90	Jul/Sep/89
V1-1, 1'	<0.7	<0.7	<0.7	24	40	1.45	0.7	2.3	61.91							
V1-1, 2'	<0.7	1.91	1.23	25	25	1.25	2	3.45								
V1-1, 3'	<0.7	<0.7	1.05	<20	<20	<0.5	2.8	4.82								
V1-1, 4'	<0.7	<0.7	<0.5	22	<20	<0.5	2.3	1.95								
V1-1, 5'	<0.7	<0.7	<0.5	22	21	<0.5	3.2	7.42								
V1-3, 1'	<0.7	<0.7	0.96	30	<20	0.96	<0.5	2.3	5.37							
V1-3, 2'	<0.7	<0.7	1.38	<15	14.5	1.38	1.3	3.45								
V1-3, 3'	4.45	<0.7	0.83	<15	10.3	0.83	1.4	1.14								
V1-3, 4'	<0.7	<0.7	<0.5	41.7	<7.5	<0.5	1	13.03								
V1-3, 5'	<0.7	<0.7	<0.5	<15	19	<0.5	1.6	2.36								
V2-1, 1'	<0.7	<0.7	1.42	25	29	1.42	2.8	2.36								
V2-1, 2'	<0.7	<0.7	4.58	<15	<20	4.58	0.7	4.82								
V2-1, 3'	<0.7	<0.7	13.98	15	<20	13.98	1.3	4.14								
V2-1, 4'	<0.7	<0.7	<0.5	21.3	<20	<0.5	1.45	2.09								
V2-1, 5'	<0.7	<0.7	<0.5	25	25	<0.5	1.7	45.88								
V2-3, 1'	<0.7	<0.7	0.97	21	29.9	0.97	4.9	4.96								
V2-3, 2'	<0.7	<0.7	<0.5	<15	14.1	<0.5	<0.5	63.28								
V2-3, 3'	<0.7	<0.7	0.85	<15	11.6	0.85	<0.5	78.33								
V2-3, 4'	<0.7	<0.7	<0.5	20.3	41.3	<0.5	<0.5	8.93								
V2-3, 5'	<0.7	<0.7	1.2	<15	13.2	1.2	<0.5	4.82								
V3, 1'	<0.7	<0.7	0.98	30	36	0.98	1.76	8.24								
V3, 2'	<0.7	<0.7	0.34	27	36	0.34	1.3	6.88								
V3, 3'	<0.7	1.83	0.93	22	70	0.93	0.6	3.45								
V4, 1'	<0.7	14.57	2.25	27	61	2.25	1.2	495.9								
V4, 2'	<0.7	9.83	3.32	36	106	3.32	1.4	2.77								
V4, 3'	<0.7	<0.7	3.53	42	29	3.53	0.6	6.19								
Water Samples	mg P/L	mg P/L	mg P/L	mg P/L	mg P/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L
V1-1	<0.07	14	0.17	14	14	<1.0	0.19	961								
V1-2	<0.07	<4.2	0.13	<4.2	<4.2	<3.0	0.23	1372								
V1-3	<0.07	68.3	<0.05	68.3	68.3	18.3	0.25	10623								
V2-1	<0.07	<0.07	0.27	87.5	87.5	<3.9*	0.66	4177								
V2-2	<0.07	<0.07	<3.9*	<0.07	<0.07	33.2	6.17	19861								
V2-3	<0.07	<21	0.11	<21	<21	<15	0.33	1645								
V3	<0.07	66.18	0.17	66.18	66.18	1.54	0.17	59								
V4	<0.07	<2.1	8.01	<2.1	<2.1	4.37	8.61	17								

TABLE C-24. SUMMARY OF NUTRIENT ANALYSES AND ACETYLENE REDUCTION TESTS FOR SOIL AND WATER SAMPLES FROM TYNDALL AFB (CONCLUDED)

Location of Soil Samples	TKN		Organic-N		Organic-N		Organic-N		Acet- Reduc.		Acet- Reduc.	
	mg N/kg Jul/Sep/89	mg N/kg Dec-89	mg N/kg Apr-90	mg N/kg Jul/Sep/89	mg N/kg Dec-89	mg N/kg Apr-90	mmole/kg-h Jul/Sep/89	mmole/kg-h Dec-89	mmole/kg-h Jul/Sep/89	mmole/kg-h Dec-89	mmole/kg-h Apr-90	mmole/kg-h Apr-90
V1-1, 1'	39.1			36.8			743				13	
V1-1, 2'	51.3			49.3			1007				8	
V1-1, 3'	73			70.2			1				11	
V1-1, 4'	60.8			58.5							12	
V1-1, 5'	86.5			83.3							12	
V1-3, 1'	181.3	205.7		180	203.4		371	581			11	
V1-3, 2'	71.6	45.9		70.3	44.9		118	16			10	
V1-3, 3'	60.8	79.7		59.4	48.9		1	21			67	
V1-3, 4'	43.2	32.3		42.2	29.1			2			12	
V1-3, 5'	45.9	55.3		44.3	54			3			8	
V2-1, 1'	194.8			192			2				11	
V2-1, 2'	52.6			51.9			2				12	
V2-1, 3'	31			28.7			7				11	
V2-1, 4'	45.9			44.6							5	
V2-1, 5'	45.9			44.2							12	
V2-3, 1'	128.5	167.7		127.3	166.59		2				13	
V2-3, 2'	70.2	132.5		67.9	86		66				106	
V2-3, 3'	56.7	109.5		55.6	104.3		85				15	
V2-3, 4'	63.5	540.8		62.3	528.7						15	
V2-3, 5'	114.9	85.1		112.3	52.8						9	
V3, 1'	104.1			102.8			15				10	
V3, 2'	142			140.7			24				9	
V3, 3'	59.4			58.8			29				7	
V4, 1'	93.3			92.1			28				13	
V4, 2'	161			159.6			24				10	
V4, 3'	142			141.4			36				10	
Water Samples	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L
V1-1	3.2											
V1-2	3.1											
V1-3	-											
V2-1	4.8	1062										
V2-2	2.7											
V2-3	-											
V3	-											
V4	9.3											

TABLE C-25. SUMMARY OF SOIL MOISTURE CONTENT BY WEIGHT

Location	Initial		Final		Location	Initial		Final		Location	Initial		Final						
	Samples Sept., 89 %	Dec., 1989 Samples %	Samples Sept., 89 %	Dec., 1989 Samples %		Samples Sept., 89 %	Dec., 1989 Samples %	Samples July, 89 %	Apr., 90 Samples %		Samples July, 89 %	Apr., 90 Samples %	Samples July, 89 %	Apr., 90 Samples %					
V1-1, 1'	12.1		11.9		V2-1, 1'	14.43		19.2		V3B, 1'	7.77		6.3		V4B, 1'	5.41		3.9	
V1-1, 2'	10.55		6.5		V2-1, 2'	6.88		5.6		V3B, 2'	19.08		4.2		V4B, 2'	7.88		3.6	
V1-1, 3'	4.84		7.2		V2-1, 3'	5.92		4.3		V3B, 3'	17		13.1		V4B, 3'	20.02		9.8	
V1-1, 4'	8.37		5.2		V2-1, 4'	6.42		6.7		V3B, 4'			19.3		V4B, 4'			16.7	
V1-1, 5'	19.8		18.4		V2-1, 5'	20.03		18.3		V3B, 5'			18.8					19.5	
V1-1, 6'	22		18.8		V2-1, 6'	18.85		18.6											
V1-1, 7'	22.09		24.6		V2-1, 7'	18.38		23.8											
V1-2, 1'	9.67		7.4		V2-2, 1'	15.45		7.1											
V1-2, 2'	8.63		5.5		V2-2, 2'	9.55		9.2											
V1-2, 3'	5.7		4.2		V2-2, 3'	5.79		4.5											
V1-2, 4'	5.26		5.8		V2-2, 4'	12.94		10											
V1-2, 5'	16.85		18.9		V2-2, 5'	18.73		20.1											
V1-2, 6'	22.84		16.1		V2-2, 6'	16.98		18.6											
V1-2, 7'	21.97		18		V2-2, 7'	20.11		19.8											
V1-3, 1'	5.89	9.69	6		V2-3, 1'	14.07		11.5	10.62										
V1-3, 2'	9.28	5.25	6.9		V2-3, 2'	10.77		11.3	10.92										
V1-3, 3'	4.11	5.6	7.3		V2-3, 3'	5.94		4.4	3.96										
V1-3, 4'	4.66	5.39	4.2		V2-3, 4'	9		7.9	13.62										
V1-3, 5'	16.45	17.94	18.6		V2-3, 5'	18.97		21.2	24.86										
V1-3, 6'	17.85		20		V2-3, 6'	18.15		17.7											
V1-3, 7'	18.62		17.9		V2-3, 7'	19.85		18.9											



TABLE C-26. SUMMARY OF PHYSICAL ANALYSES OF SOIL SAMPLES FROM TYNDALL AFB

Location	% Hydrometer			Clay		Silt		Texture		pH		O.C.		O.C.		CEC	
	Jul/Sep/89	Jul/Sep/89	Jul/Sep/89	Jul/Sep/89	Jul/Sep/89	Jul/Sep/89	Jul/Sep/89	Jul/Sep/89	Jul/Sep/89	Apr-90	Dec-89	Apr-90	Dec-89	Apr-90	Dec-89	Apr-90	Dec-89
V1-1, 1'	95	2	3	3	3	6.3	Sand	6.3	6.5	0.82	0.88	0.88	0.88	2.8	7.7	<DL	<DL
V1-1, 2'	92	5	3	3	3	5.3	Sand	5.3	5.5	0.27	0.4	0.4	0.4	<DL	<DL	<DL	<DL
V1-1, 3'	96	2	2	2	2	5.6	Sand	5.6	5.6	0.15	0.21	0.21	0.21	0.5	2.28	0.4	0.4
V1-1, 4'	95	2	2	2	2	5.3	Sand	5.3	5.9	0.09	0.1	0.1	0.1	0.4	<DL	0.6	<DL
V1-1, 5'	97	1	2	2	2	5.4	Sand	5.4	6	0.18	0.03	0.03	0.03	0.6	2.2	0.3	0.3
V1-3, 1'	92	4	4	4	4	6.1	Sand	6.1	6.4	0.91	0.81	0.81	0.81	3.4	1.69	0.4	0.4
V1-3, 2'	96	2	2	2	2	6.4	Sand	6.4	6.5	0.22	0.36	0.36	0.36	0.4	<DL	0.4	<DL
V1-3, 3'	97	1	2	2	2	6.4	Sand	6.4	6.5	0.16	0.2	0.2	0.2	0.4	0.47	0.3	0.3
V1-3, 4'	96	2	2	2	2	5.8	Sand	5.8	6.7	0.16	0.1	0.1	0.1	0.1	9.98	0.1	0.1
V1-3, 5'	98	1	1	1	1	6	Sand	6	6.5	0.04	0.08	0.08	0.08	0.1	4.05	0.6	0.6
V2-1, 1'	94	3	3	3	3	6.2	Sand	6.2	6.1	0.86	0.57	0.57	0.57	3.3	4.02	0.8	0.8
V2-1, 2'	96	2	2	2	2	5.7	Sand	5.7	5.6	0.26	0.21	0.21	0.21	0.6	0.53	0.1	0.1
V2-1, 3'	96	2	2	2	2	5.7	Sand	5.7	5.4	0.33	0.17	0.17	0.17	0.8	<DL	0.1	<DL
V2-1, 4'	98	1	1	1	1	5.9	Sand	5.9	5.2	0.11	0.07	0.07	0.07	0.1	3.83	2.3	2.3
V2-1, 5'	-	-	-	-	-	-	Sand	-	5.9	-	0.15	0.15	0.15	-	3.56	0.7	0.7
V2-3, 1'	95	3	2	2	2	6.2	Sand	6.2	6.6	0.68	0.72	0.72	0.72	0.3	1.93	0.2	0.2
V2-3, 2'	96	2	2	2	2	6	Sand	6	6.1	0.26	0.41	0.41	0.41	0.3	1.28	1.6	1.6
V2-3, 3'	97	1	2	2	2	6.1	Sand	6.1	6	0.2	0.13	0.13	0.13	0.2	<DL	1.7	1.7
V2-3, 4'	97	1	2	2	2	6	Sand	6	5.8	0.12	0.93	0.93	0.93	0.2	0.14	1.9	1.9
V2-3, 5'	97	1	2	2	2	5.4	Sand	5.4	5.1	0.44	0.45	0.45	0.45	1.1	2.59	2.4	2.4
V3, 1'	96	2	2	2	2	5.4	Sand	5.4	7.1	0.53	0.53	0.53	0.53	1.7	4.16	1.7	1.7
V3, 2'	96	2	2	2	2	5.2	Sand	5.2	5.7	0.73	0.45	0.45	0.45	1	2.4	1.7	1.7
V3, 3'	95	3	2	2	2	4.6	Sand	4.6	6.6	0.43	0.41	0.41	0.41	1.1	4.16	1.1	1.1
V4, 1'	97	1	2	2	2	6	Sand	6	5.5	0.49	0.45	0.45	0.45	2.4	4.16	2.4	2.4
V4, 2'	96	2	2	2	2	5	Sand	5	5.3	0.85	0.5	0.5	0.5	1.7	4.16	1.7	1.7
V4, 3'	97	1	2	2	2	4.1	Sand	4.1	5.7	0.78	0.46	0.46	0.46	1.7	2.1	1.7	1.7

TABLE C-27. SUMMARY OF NUTRIENTS ANALYSES AND ACETYLENE REDUCTION TESTS FOR SOIL AND WATER SAMPLES FROM TYNDALL AFB

Location of Soil Samples	PO4-P mg P/Kg		Tot-P mg P/Kg		Tot-P mg P/L		NO3+NO2-N mg N/Kg		NO3+NO2-N mg N/L		NO3+NO2-N mg N/L		NH4-N mg N/Kg		NH4-N mg N/L	
	Jul/89	Apr-90	Jul/89	Apr-90	Jul/89	Apr-90	Jul/89	Apr-90	Jul/89	Apr-90	Jul/89	Apr-90	Jul/89	Apr-90	Jul/89	Apr-90
V1-1, 1'	<0.7	<0.7	24	40	1.45	0.7	2.3	61.91								
V1-1, 2'	<0.7	1.91	17	25	1.23	1.25	2	3.45								
V1-1, 3'	<0.7	<0.7	17	<20	1.05	<0.5	2.8	4.82								
V1-1, 4'	<0.7	<0.7	22	<20	<0.5	<0.5	2.3	1.95								
V1-1, 5'	<0.7	<0.7	22	21	<0.5	<0.5	3.2	7.42								
V1-3, 1'	<0.7	<0.7	30	<20	0.96	1.48	1.3	5.37								
V1-3, 2'	<0.7	<0.7	<15	<20	0.97	1.38	1.3	3.45								
V1-3, 3'	4.45	<0.7	<15	10.3	0.83	0.51	1.4	1.14								
V1-3, 4'	<0.7	<0.7	41.7	<7.5	<0.5	<0.5	1	13.03								
V1-3, 5'	<0.7	<0.7	<15	19	<0.5	<0.5	1.6	2.36								
V2-1, 1'	<0.7	<0.7	25	29	1.42	1.54	2.8	2.36								
V2-1, 2'	<0.7	<0.7	<15	<20	4.58	0.72	0.7	4.82								
V2-1, 3'	<0.7	<0.7	15	<20	13.98	0.84	1.3	4.14								
V2-1, 4'	<0.7	<0.7	21.3	<20	<0.5	1.45	1.3	2.09								
V2-1, 5'	<0.7	<0.7	-	25	<0.5	<0.5	1.7	45.88								
V2-3, 1'	<0.7	<0.7	21	29.9	0.97	5.54	1.2	4.96								
V2-3, 2'	<0.7	<0.7	<15	14.1	<0.5	<0.5	2.3	63.28								
V2-3, 3'	<0.7	<0.7	<15	11.6	0.85	<0.5	1.1	78.33								
V2-3, 4'	<0.7	<0.7	20.3	41.3	<0.5	<0.5	1.2	8.93								
V2-3, 5'	<0.7	<0.7	<15	13.2	1.2	<0.5	2.6	4.82								
V3, 1'	<0.7	<0.7	30	36	0.98	1.76	1.3	8.24								
V3, 2'	<0.7	<0.7	27	36	0.34	0.63	1.3	6.88								
V3, 3'	<0.7	1.83	22	70	1.93	0.93	0.6	3.45								
V4, 1'	<0.7	14.57	27	61	2.39	2.25	1.2	495.9								
V4, 2'	<0.7	9.83	36	106	3.32	1.24	1.4	2.77								
V4, 3'	<0.7	<0.7	42	29	3.53	3.71	0.6	6.19								
Water Samples	mg P/L	mg P/L	mg P/L	mg P/L	mg P/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L
V1-1	<0.07	14	0.17	0.17	<1.0	0.19	0.19	961								
V1-2	<0.07	<4.2	0.13	0.13	<3.0	0.23	0.23	1372								
V1-3	<0.07	68.3	<0.05	<0.05	18.3	0.25	0.25	10623								
V2-1	<0.07	87.5	0.27	0.27	33.2	0.66	0.66	4177								
V2-2	<0.07	<0.07	<3.9*	<3.9*	<3.9*	6.17	6.17	19861								
V2-3	<0.07	<21	0.11	0.11	<15	0.33	0.33	1645								
V3	<0.07	66.18	0.17	0.17	1.54	0.17	0.17	59								
V4	<0.07	<2.1	8.01	8.01	4.37	8.61	8.61	17								

TABLE C-27. SUMMARY OF NUTRIENTS ANALYSES AND ACETYLENE REDUCTION TESTS FOR SOIL AND WATER SAMPLES FROM TYNDALL AFB (CONCLUDED)

Location of Soil Samples	TKN mg N/kg		TKN mg N/kg		Organic-N mg N/kg		Organic-N mg N/kg		Acet- Reduc. mmole/kg·h		Acet- Reduc. mmole/kg·h	
	Jul/Sep/89	Dec-89	mg N/kg	Apr-90	mg N/kg	Jul/Sep/89	mg N/kg	Apr-90	mmole/kg·h	Jul/Sep/89	mmole/kg·h	Apr-90
V1-1, 1'	39.1				36.8				743			13
V1-1, 2'	51.3				49.3				1007			8
V1-1, 3'	73				70.2				1			11
V1-1, 4'	60.8				58.5							12
V1-1, 5'	86.5				83.3							12
V1-3, 1'	181.3	205.7			180		203.4		371		581	11
V1-3, 2'	71.6	45.9			70.3		44.9		118		16	10
V1-3, 3'	60.8	79.7			59.4		48.9		1		21	67
V1-3, 4'	43.2	32.3			42.2		29.1				2	12
V1-3, 5'	45.9	55.3			44.3		54				3	8
V2-1, 1'	194.8				192				2			11
V2-1, 2'	52.6				51.9				2			12
V2-1, 3'	31				29.7				7			11
V2-1, 4'	45.9				44.6							5
V2-1, 5'	45.9				44.2							12
V2-3, 1'	128.5	167.7			127.3		166.59		2			13
V2-3, 2'	70.2	132.5			67.9		86		66			106
V2-3, 3'	56.7	109.5			55.6		104.3		85			15
V2-3, 4'	63.5	540.8			62.3		528.7					15
V2-3, 5'	114.9	85.1			112.3		52.8					9
V3, 1'	104.1				102.8				15			10
V3, 2'	142				140.7				24			9
V3, 3'	59.4				58.8				29			7
V4, 1'	93.3				92.1				28			13
V4, 2'	161				159.6				24			10
V4, 3'	142				141.4				36			10
Water Samples	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L	mg N/L
V1-1	3.2											
V1-2	3.1											
V1-3	-											
V2-1	4.8	1062										
V2-2	2.7											
V2-3	-											
V3	-											
V4	9.3											

APPENDIX D  
IN SITU RESPIRATION DATA

TABLE D-1. IN SITU RESPIRATION DATA

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
10/24/89 10:13		Blowers Off						
10/24/89 9:42	0	V1-1A	5.4	13.9	2.632	19.3	1	1
10/24/89 10:47	34	V1-1A	5.3	13.2	2.580	18.5	0.98	0.95
10/24/89 13:07	174	V1-1A	5.9	12	2.485	17.9	1.09	0.863
10/24/89 15:25	312	V1-1A	5.9	11	2.398	16.9	1.09	0.791
10/24/89 18:03	470	V1-1A	7.1	8.5	2.140	15.6	1.31	0.612
10/24/89 22:26	733	V1-1A	8.3	5.9	1.775	14.2	1.55	0.424
10/25/89 3:28	1035	V1-1A	10.7	4	1.386	14.7	2	0.288
10/25/89 8:49	1356	V1-1A	11.5	2.5	0.916	14.0	2.14	0.18
10/25/89 14:52	1719	V1-1A	12.2	0.8	-0.223	13.0		
10/25/89 20:50	2077	V1-1A	13.9	0.5	-0.693	14.4		
10/26/89 9:02	2809	V1-1A	13.9	0.3	-1.204	14.2		
10/24/89 9:52	0	V1-1B	4.4	15	2.708	19.4	1	1
10/24/89 10:50	37	V1-1B	4.4	14.5	2.674	18.9	1	0.967
10/24/89 13:09	176	V1-1B	4.8	13.8	2.625	18.6	1.09	0.92
10/24/89 15:27	314	V1-1B	5.3	13.5	2.603	18.8	1.21	0.9
10/24/89 18:07	474	V1-1B	5.5	12	2.485	17.5	1.25	0.8
10/24/89 22:32	739	V1-1B	6.6	10.5	2.351	17.1	1.5	0.7
10/25/89 3:34	1041	V1-1B	7.3	9.2	2.219	16.5	1.66	0.613
10/25/89 8:52	1359	V1-1B	9.0	7	1.946	16.0	2.04	0.467
10/25/89 14:57	1724	V1-1B	10.0	4.9	1.589	14.9	2.28	0.327
10/25/89 21:01	2088	V1-1B	11.0	3.3	1.194	14.3	2.51	0.22
10/26/89 9:06	2813	V1-1B	13.6	0.8	-0.223	14.4		
10/24/89 9:55	0	V1-1C	4.5	14.5	2.674	19.0	1	1
10/24/89 10:53	40	V1-1C	4.8	14	2.639	18.8	1.06	0.966
10/24/89 13:14	181	V1-1C	4.9	13.6	2.610	18.5	1.09	0.938
10/24/89 15:30	317	V1-1C	4.9	13.7	2.617	18.6	1.09	0.945
10/24/89 18:09	476	V1-1C	5.7	12.2	2.501	17.9	1.27	0.841
10/24/89 22:35	742	V1-1C	6.6	11.2	2.416	17.8	1.47	0.772
10/25/89 3:37	1044	V1-1C	7.1	10.2	2.322	17.3	1.58	0.703
10/25/89 8:56	1363	V1-1C	8.3	8	2.079	16.3	1.85	0.552
10/25/89 15:00	1727	V1-1C	8.6	6.1	1.808	14.7	1.92	0.421
10/25/89 21:05	2092	V1-1C	12.5	4.3	1.459	16.8	2.78	0.297
10/26/89 9:10	2817	V1-1C	13.0	1.2	0.182	14.2	2.91	0.083
10/24/89 10:00	0	V1-2A	2.0	18.5	2.918	20.5	1	1
10/24/89 10:56	43	V1-2A	2.7	16.5	2.803	19.2	1.35	0.892
10/24/89 13:19	186	V1-2A	3.8	13.4	2.595	17.2	1.9	0.724
10/24/89 15:33	320	V1-2A	4.5	12	2.485	16.5	2.25	0.649
10/24/89 18:13	480	V1-2A	5.5	8.8	2.175	14.3	2.75	0.476
10/24/89 22:40	747	V1-2A	7.3	6	1.792	13.3	3.63	0.324
10/25/89 3:42	1049	V1-2A	9.0	4.3	1.459	13.3	4.51	0.232
10/25/89 9:01	1368	V1-2A	11.7	2.2	0.788	13.9	5.83	0.119
10/25/89 15:03	1730	V1-2A	11.2	0.8	-0.223	12.0		
10/25/89 21:08	2095	V1-2A	14.7	0.5	-0.693	15.2		
10/26/89 9:14	2821	V1-2A	13.9	0.4	-0.916	14.3		

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
10/24/89 10:02	0	V1-2B	4.4	15	2.708	19.4	1	1
10/24/89 10:58	45	V1-2B	4.6	14.5	2.674	19.1	1.05	0.967
10/24/89 13:24	191	V1-2B	4.9	13.8	2.625	18.7	1.1	0.92
10/24/89 15:36	323	V1-2B	5.0	13.2	2.580	18.2	1.14	0.88
10/24/89 18:16	483	V1-2B	5.8	11.5	2.442	17.3	1.32	0.767
10/24/89 22:44	751	V1-2B	6.7	10.3	2.332	17.0	1.52	0.687
10/25/89 3:45	1052	V1-2B	7.5	8.9	2.186	16.4	1.7	0.593
10/25/89 9:05	1372	V1-2B	9.5	6.5	1.872	16.0	2.16	0.433
10/25/89 15:06	1733	V1-2B	9.9	3.8	1.335	13.7	2.25	0.253
10/25/89 21:12	2099	V1-2B	14.2	2.1	0.742	16.3	3.22	0.14
10/26/89 9:17	2824	V1-2B	14.4	0.2	-1.609	14.6		
10/24/89 10:04	0	V1-2C	7.0	12	2.485	19.0	1	1
10/24/89 11:00	47	V1-2C	6.4	12	2.485	18.4	0.91	1
10/24/89 13:26	193	V1-2C	6.9	11.5	2.442	18.4	0.98	0.958
10/24/89 15:38	325	V1-2C	6.9	12	2.485	18.9	0.98	1
10/24/89 18:19	486	V1-2C	7.3	10.4	2.342	17.7	1.04	0.867
10/24/89 22:47	754	V1-2C	7.9	10	2.303	17.9	1.13	0.833
10/25/89 3:50	1057	V1-2C	8.0	9.2	2.219	17.2	1.15	0.767
10/25/89 9:10	1377	V1-2C	10.5	7.4	2.001	17.9	1.51	0.617
10/25/89 15:09	1736	V1-2C	10.2	5	1.609	15.2	1.47	0.417
10/25/89 21:16	2103	V1-2C	13.9	3.4	1.224	17.3	1.99	0.283
10/26/89 9:20	2827	V1-2C	14.4	0.3	-1.204	14.7		
10/24/89 10:06	0	V1-3A	1.5	19	2.944	20.5	1	1
10/24/89 11:04	51	V1-3A	2.1	17.2	2.845	19.3	1.45	0.905
10/24/89 13:29	196	V1-3A	3.0	15.8	2.760	18.8	2.03	0.832
10/24/89 15:43	330	V1-3A	3.4	15	2.708	18.4	2.34	0.789
10/24/89 18:22	489	V1-3A	4.3	13	2.565	17.3	2.98	0.684
10/24/89 22:50	757	V1-3A	5.6	11	2.398	16.6	3.86	0.579
10/25/89 3:54	1061	V1-3A	6.7	8.8	2.175	15.5	4.6	0.463
10/25/89 9:14	1381	V1-3A	9.7	6	1.792	15.7	6.7	0.316
10/25/89 15:14	1741	V1-3A	9.1	4	1.386	13.1	6.28	0.211
10/25/89 21:20	2107	V1-3A	13.9	1.2	0.182	15.1	9.57	0.063
10/26/89 9:23	2830	V1-3A	13.9	0.1	-2.303	14.0		
10/24/89 10:09	0	V1-3B	4.4	14.5	2.674	18.9	1	1
10/24/89 11:08	55	V1-3B	3.2	16.1	2.779	19.3	0.73	1.11
10/24/89 13:31	198	V1-3B	3.6	15.5	2.741	19.1	0.82	1.069
10/24/89 15:46	333	V1-3B	3.9	14.8	2.695	18.7	0.89	1.021
10/24/89 18:25	492	V1-3B	5.1	12.5	2.526	17.6	1.16	0.862
10/24/89 22:55	762	V1-3B	6.3	10.8	2.380	17.1	1.43	0.745
10/25/89 3:59	1066	V1-3B	7.5	9	2.197	16.5	1.7	0.621
10/25/89 9:19	1386	V1-3B	10.1	6.3	1.841	16.4	2.29	0.434
10/25/89 15:16	1743	V1-3B	10.6	3.4	1.224	14.0	2.4	0.234
10/25/89 21:24	2111	V1-3B	14.7	1.7	0.531	16.4	3.34	0.117
10/26/89 9:27	2834	V1-3B	14.7	0.1	-2.303	14.8		

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time		Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
10/24/89	10:10	0	V1-3C	3.0	16.5	2.803	19.5	1	1
10/24/89	11:10	57	V1-3C	4.7	13.7	2.617	18.4	1.57	0.83
10/24/89	13:33	200	V1-3C	5.1	13	2.565	18.1	1.7	0.788
10/24/89	15:48	335	V1-3C	5.5	13	2.565	18.5	1.83	0.788
10/24/89	18:28	495	V1-3C	6.6	10.8	2.380	17.4	2.19	0.655
10/24/89	22:58	765	V1-3C	7.6	9.6	2.262	17.2	2.52	0.582
10/25/89	4:03	1070	V1-3C	8.4	8.4	2.128	16.8	2.81	0.509
10/25/89	9:23	1390	V1-3C	11.3	6	1.792	17.3	3.75	0.364
10/25/89	15:19	1746	V1-3C	11.5	3	1.099	14.5	3.84	0.182
10/25/89	21:29	2116	V1-3C	14.7	2	0.693	16.7	4.9	0.121
10/26/89	9:30	2837	V1-3C	15.3	0.1	-2.303	15.4		
10/24/89	9:04	0	V2-1A	0.5	19.8	2.986	20.3	1	1
10/24/89	11:14	61	V2-1A	0.6	19.5	2.970	20.1	1.33	0.985
10/24/89	13:37	204	V2-1A	1.3	18.5	2.918	19.8	2.89	0.934
10/24/89	15:50	337	V2-1A	1.2	18.5	2.918	19.7	2.67	0.934
10/24/89	18:38	505	V2-1A	1.7	18	2.890	19.7	3.78	0.909
10/24/89	23:05	772	V2-1A	1.9	18	2.890	19.9	4.22	0.909
10/25/89	4:07	1074	V2-1A	2.7	16	2.773	18.7	6	0.808
10/25/89	9:28	1395	V2-1A	2.3	17	2.833	19.3	5.11	0.859
10/25/89	15:24	1751	V2-1A	5.9	8.6	2.152	14.5	13	0.434
10/25/89	21:35	2122	V2-1A	7.6	6.2	1.825	13.8	16.8	0.313
10/26/89	9:44	2851	V2-1A	10.5	2.6	0.956	13.1	23.4	0.131
10/24/89	9:06	0	V2-1B	4.3	14.7	2.688	19.0	1	1
10/24/89	11:17	64	V2-1B	4.5	13.3	2.588	17.8	1.05	0.905
10/24/89	13:42	209	V2-1B	5.6	12.2	2.501	17.8	1.3	0.83
10/24/89	15:53	340	V2-1B	5.9	11.6	2.451	17.5	1.37	0.789
10/24/89	18:39	506	V2-1B	7.2	9.2	2.219	16.4	1.67	0.626
10/24/89	23:07	774	V2-1B	8.4	8	2.079	16.4	1.96	0.544
10/25/89	4:11	1078	V2-1B	9.0	7	1.946	16.0	2.1	0.476
10/25/89	9:33	1400	V2-1B	12.4	5	1.609	17.4	2.9	0.34
10/25/89	15:29	1756	V2-1B	11.7	3.5	1.253	15.2	2.71	0.238
10/25/89	21:43	2130	V2-1B	13.6	3	1.099	16.6	3.16	0.204
10/26/89	9:50	2857	V2-1B	14.4	0.2	-1.609	14.6		
10/24/89	9:08	0	V2-1C	5.6	12.5	2.526	18.1	1	1
10/24/89	11:20	67	V2-1C	5.6	12.2	2.501	17.8	1	0.976
10/24/89	13:44	211	V2-1C	6.3	12	2.485	18.3	1.13	0.96
10/24/89	15:58	345	V2-1C	6.5	11	2.398	17.5	1.16	0.88
10/24/89	18:44	511	V2-1C	7.4	10	2.303	17.4	1.32	0.8
10/24/89	23:11	778	V2-1C	8.2	8.5	2.140	16.7	1.48	0.68
10/25/89	4:14	1081	V2-1C	8.6	8.1	2.092	16.7	1.55	0.648
10/25/89	9:37	1404	V2-1C	11.7	6	1.792	17.7	2.09	0.48
10/25/89	15:30	1757	V2-1C	11.0	4.8	1.569	15.8	1.98	0.384
10/25/89	21:50	2137	V2-1C	11.5	4.1	1.411	15.6	2.06	0.328
10/26/89	9:55	2862	V2-1C	14.2	0.2	-1.609	14.4		

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
10/24/89 9:10	0	V2-2A	0.2	20.2	3.006	20.4	1	1
10/24/89 11:25	72	V2-2A	0.2	20.2	3.006	20.4	1	1
10/24/89 13:46	213	V2-2A	0.3	20	2.996	20.3	1.67	0.99
10/24/89 16:08	355	V2-2A	0.4	20	2.996	20.4	2.33	0.99
10/24/89 18:47	514	V2-2A	0.5	19	2.944	19.5	3	0.941
10/24/89 23:15	782	V2-2A	0.5	20	2.996	20.5	3.33	0.99
10/25/89 4:19	1086	V2-2A	0.9	18.2	2.901	19.1	6	0.901
10/25/89 9:40	1407	V2-2A	0.7	19.5	2.970	20.2	4.33	0.965
10/25/89 15:37	1764	V2-2A	2.2	13.9	2.632	16.1	14.7	0.688
10/25/89 21:58	2145	V2-2A	3.9	10.8	2.380	14.7	25.7	0.535
10/26/89 9:59	2866	V2-2A	6.1	5	1.609	11.1	40.4	0.248
10/24/89 9:17	0	V2-2B	3.3	16.3	2.791	19.6	1	1
10/24/89 11:27	74	V2-2B	3.1	16	2.773	19.1	0.94	0.982
10/24/89 13:48	215	V2-2B	3.8	14.6	2.681	18.4	1.14	0.896
10/24/89 16:10	357	V2-2B	4.7	13	2.565	17.7	1.41	0.798
10/24/89 18:51	518	V2-2B	5.4	12	2.485	17.4	1.64	0.736
10/24/89 23:18	785	V2-2B	6.7	10.5	2.351	17.2	2.02	0.644
10/25/89 4:26	1093	V2-2B	7.3	8	2.079	15.3	2.2	0.491
10/25/89 9:52	1419	V2-2B	9.3	6.7	1.902	16.0	2.81	0.411
10/25/89 15:40	1767	V2-2B	10.2	4.5	1.504	14.7	3.1	0.276
10/25/89 22:00	2147	V2-2B	12.8	2.8	1.030	15.6	3.87	0.172
10/26/89 10:02	2869	V2-2B	13.9	0.2	-1.609	14.1		
10/24/89 9:26	0	V2-2C	5.0	14	2.639	19.0	1	1
10/24/89 11:28	75	V2-2C	5.0	13.2	2.580	18.2	1.01	0.943
10/24/89 13:50	217	V2-2C	5.8	12.5	2.526	18.3	1.17	0.893
10/24/89 16:03	350	V2-2C	6.3	11	2.398	17.3	1.27	0.786
10/24/89 18:54	521	V2-2C	7.4	9.8	2.282	17.2	1.49	0.7
10/24/89 23:23	790	V2-2C	8.4	8.1	2.092	16.5	1.71	0.579
10/25/89 4:31	1098	V2-2C	8.5	6.5	1.872	15.0	1.72	0.464
10/25/89 9:54	1421	V2-2C	11.8	3.6	1.281	15.4	2.39	0.257
10/25/89 15:43	1770	V2-2C	11.0	3.5	1.253	14.5	2.21	0.25
10/25/89 22:05	2152	V2-2C	13.3	1.7	0.531	15.0	2.69	0.121
10/26/89 10:07	2874	V2-2C	13.6	0.1	-2.303	13.7		
10/24/89 9:29	0	V2-3A	0.8	19.5	2.970	20.3	1	1
10/24/89 11:30	77	V2-3A	1.1	18.5	2.918	19.6	1.47	0.949
10/24/89 13:52	219	V2-3A	1.6	17.7	2.874	19.3	2.13	0.908
10/24/89 16:16	363	V2-3A	2.2	16.5	2.803	18.7	2.93	0.846
10/24/89 18:58	525	V2-3A	2.3	16.6	2.809	18.9	3.07	0.851
10/24/89 23:27	794	V2-3A	2.8	15.5	2.741	18.3	3.73	0.795
10/25/89 4:34	1101	V2-3A	4.1	12.5	2.526	16.6	5.47	0.641
10/25/89 9:58	1425	V2-3A	4.0	13.1	2.573	17.1	5.33	0.672
10/25/89 15:46	1773	V2-3A	7.0	6.5	1.872	13.5	9.38	0.333
10/25/89 22:09	2156	V2-3A	8.6	4.9	1.589	13.5	11.5	0.251
10/26/89 10:12	2879	V2-3A	12.2	1.1	0.095	13.3	16.3	0.056



TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
10/24/89 9:30	0	V2-3B	4.4	14.8	2.695	19.2	1	1
10/24/89 11:32	79	V2-3B	4.4	14.2	2.653	18.6	1	0.959
10/24/89 13:54	221	V2-3B	4.0	14.8	2.695	18.8	0.91	1
10/24/89 16:18	365	V2-3B	5.5	12	2.485	17.5	1.25	0.811
10/24/89 19:00	527	V2-3B	6.3	11	2.398	17.3	1.43	0.743
10/24/89 23:29	796	V2-3B	7.5	9.5	2.251	17.0	1.7	0.642
10/25/89 4:37	1104	V2-3B	7.9	7.2	1.974	15.1	1.78	0.486
10/25/89 10:00	1427	V2-3B	10.6	5.3	1.668	15.9	2.4	0.358
10/25/89 15:50	1777	V2-3B	11.0	3.8	1.335	14.8	2.49	0.257
10/25/89 22:15	2162	V2-3B	13.9	2.3	0.833	16.2	3.15	0.155
10/26/89 10:17	2884	V2-3B	14.4	0.4	-0.916	14.8		
10/24/89 9:32	0	V2-3C	7.2	10	2.303	17.2	1	1
10/24/89 11:34	81	V2-3C	7.6	10	2.303	17.6	1.06	1
10/24/89 13:57	224	V2-3C	7.9	8.6	2.152	16.5	1.09	0.86
10/24/89 16:25	372	V2-3C	5.5	13.2	2.580	18.7		
10/24/89 19:04	531	V2-3C	8.2	8.5	2.140	16.7		
10/24/89 23:34	801	V2-3C	10.0	5.5	1.705	15.5		
10/25/89 4:42	1109	V2-3C	11.8	3.4	1.224	15.2		
10/25/89 10:05	1432	V2-3C	14.4	1.5	0.405	15.9		
10/25/89 15:55	1782	V2-3C	14.2	0.5	-0.693	14.7		
10/25/89 22:18	2165	V2-3C	15.3	0.4	-0.916	15.7		
10/26/89 10:20	2887	V2-3C	15.3	0.1	-2.303	15.4		
10/24/89 7:59	0	V3A	2.0	18.5	2.918	20.5	1	1
10/24/89 11:40	87	V3A	1.9	18	2.890	19.9	0.95	0.973
10/24/89 14:02	229	V3A	2.0	18.2	2.901	20.2	0.98	0.984
10/24/89 19:14	541	V3A	2.3	18.2	2.901	20.5	1.15	0.984
10/25/89 11:11	1498	V3A	2.4	17.8	2.879	20.2	1.2	0.962
10/26/89 10:43	2910	V3A	2.6	17.5	2.862	20.1	1.28	0.946
10/24/89 8:01	0	V3B	2.3	18.2	2.901	20.5	1	1
10/24/89 11:42	89	V3B	2.2	17.8	2.879	20.0	0.96	0.978
10/24/89 14:06	233	V3B	2.1	18.2	2.901	20.3	0.91	1
10/24/89 19:16	543	V3B	2.4	18.1	2.896	20.5	1.04	0.995
10/25/89 11:14	1501	V3B	2.6	17.5	2.862	20.1	1.13	0.962
10/26/89 10:45	2912	V3B	2.6	17.3	2.851	19.9	1.13	0.951
10/24/89 8:06	0	V3C	2.5	18	2.890	20.5	1	1
10/24/89 11:43	90	V3C	2.2	17.7	2.874	19.9	0.88	0.983
10/24/89 14:08	235	V3C	2.3	18	2.890	20.3	0.9	1
10/24/89 19:18	545	V3C	2.5	18	2.890	20.5	1	1
10/25/89 11:16	1503	V3C	2.7	17.5	2.862	20.2	1.08	0.972
10/26/89 10:47	2914	V3C	2.8	17.1	2.839	19.9	1.1	0.95
10/24/89 8:14	0	V4A	1.1	19.2	2.955	20.3	1	1
10/24/89 11:45	92	V4A	1.0	19	2.944	20.0	0.9	0.99
10/24/89 14:10	237	V4A	1.1	19.2	2.955	20.3	1.05	1
10/24/89 19:20	547	V4A	1.4	19.2	2.955	20.6	1.33	1
10/25/89 11:18	1505	V4A	1.7	18.8	2.934	20.5	1.62	0.979
10/26/89 10:50	2917	V4A	1.7	18.5	2.918	20.2	1.62	0.964

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
10/24/89 8:23	0	V4B	1.2	19.2	2.955	20.4	1	1
10/24/89 11:47	94	V4B	1.1	19	2.944	20.1	0.96	0.99
10/24/89 14:12	239	V4B	1.2	19.2	2.955	20.4	1	1
10/24/89 19:22	549	V4B	1.4	19.3	2.960	20.7	1.17	1.005
10/25/89 11:20	1507	V4B	1.6	18.9	2.939	20.5	1.39	0.984
10/26/89 10:52	2919	V4B	1.6	18.5	2.918	20.1	1.39	0.964
10/24/89 8:28	0	V4C	1.4	19.2	2.955	20.6	1	1
10/24/89 11:50	97	V4C	1.3	18.8	2.934	20.1	0.96	0.979
10/24/89 14:14	241	V4C	1.3	19.2	2.955	20.5	0.93	1
10/24/89 19:25	552	V4C	1.4	19.2	2.955	20.6	1.04	1
10/25/89 11:25	1512	V4C	1.7	18.8	2.934	20.5	1.26	0.979
10/26/89 10:54	2921	V4C	1.7	18.5	2.918	20.2	1.26	0.964

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
11/28/89 15:11	Blowers Off							
11/28/89 11:53	0	V1-1A	4.6	14.4	2.667	19.0	1	1
11/28/89 16:10	59	V1-1A	4.9	13.8	2.625	18.7	1.07	0.96
11/28/89 18:28	197	V1-1A	6.1	12.4	2.518	18.5	1.32	0.86
11/28/89 21:05	354	V1-1A	6.2	11.3	2.425	17.5	1.34	0.78
11/29/89 1:29	618	V1-1A	7.2	9.5	2.251	16.7	1.57	0.66
11/29/89 7:10	959	V1-1A	8.0	7.8	2.054	15.8	1.74	0.54
11/29/89 12:34	1283	V1-1A	8.4	7.0	1.946	15.4	1.83	0.49
11/29/89 19:26	1695	V1-1A	9.4	5.8	1.758	15.2	2.04	0.4
11/30/89 6:58	2387	V1-1A	9.8	4.2	1.435	14.0	2.12	0.29
11/30/89 16:27	2956	V1-1A	11.0	3.4	1.224	14.4	2.4	0.24
12/1/89 8:23	3912	V1-1A	12.8	1.0	0.000	13.8	2.78	0.07
11/28/89 11:57	0	V1-1B	4.8	14.5	2.674	19.3	1	1
11/28/89 16:12	61	V1-1B	4.9	14.0	2.639	18.9	1.01	0.97
11/28/89 18:32	201	V1-1B	5.8	13.4	2.595	19.2	1.2	0.92
11/28/89 21:09	358	V1-1B	5.9	13.0	2.565	18.9	1.22	0.9
11/29/89 1:32	621	V1-1B	6.6	12.0	2.485	18.6	1.38	0.83
11/29/89 7:13	962	V1-1B	7.2	10.8	2.380	18.0	1.51	0.74
11/29/89 12:37	1286	V1-1B	7.4	9.5	2.251	16.9	1.55	0.66
11/29/89 19:30	1699	V1-1B	8.6	8.0	2.079	16.6	1.79	0.55
11/30/89 7:01	2390	V1-1B	9.4	5.5	1.705	14.9	1.95	0.38
11/30/89 16:31	2960	V1-1B	10.9	4.1	1.411	15.0	2.26	0.28
12/1/89 8:27	3916	V1-1B	12.1	1.6	0.470	13.7	2.53	0.11
11/28/89 12:02	0	V1-1C	5.9	13.6	2.610	19.5	1	1
11/28/89 16:14	63	V1-1C	5.9	13.5	2.603	19.4	1	0.99
11/28/89 18:36	205	V1-1C	6.1	13.0	2.565	19.1	1.03	0.96
11/28/89 21:15	364	V1-1C	6.1	13.0	2.565	19.1	1.03	0.96
11/29/89 1:35	624	V1-1C	6.7	12.3	2.510	19.0	1.15	0.9
11/29/89 7:16	965	V1-1C	7.0	11.1	2.407	18.1	1.2	0.82
11/29/89 12:40	1289	V1-1C	7.4	10.0	2.303	17.4	1.27	0.74
11/29/89 19:33	1702	V1-1C	8.4	8.5	2.140	16.9	1.43	0.63
11/30/89 7:04	2393	V1-1C	9.2	6.0	1.792	15.2	1.57	0.44
11/30/89 16:34	2963	V1-1C	11.0	4.5	1.504	15.5	1.88	0.33
12/1/89 8:34	3923	V1-1C	12.1	2.3	0.833	14.4	2.07	0.17
11/28/89 12:08	0	V1-2A	2.3	17.8	2.879	20.1	1	1
11/28/89 16:18	67	V1-2A	3.0	16.2	2.785	19.2	1.28	0.91
11/28/89 18:40	209	V1-2A	4.0	13.6	2.610	17.6	1.74	0.76
11/28/89 21:19	368	V1-2A	4.6	12.0	2.485	16.6	2	0.67
11/29/89 1:40	629	V1-2A	5.9	10.5	2.351	16.4	2.55	0.59
11/29/89 7:20	969	V1-2A	6.8	9.0	2.197	15.8	2.97	0.51
11/29/89 12:43	1292	V1-2A	7.4	7.7	2.041	15.1	3.23	0.43
11/29/89 19:36	1705	V1-2A	8.4	6.7	1.902	15.1	3.65	0.38
11/30/89 7:08	2397	V1-2A	9.2	5.2	1.649	14.4	3.99	0.29
11/30/89 16:37	2966	V1-2A	10.9	3.5	1.253	14.4	4.73	0.2
12/1/89 8:36	3925	V1-2A	12.1	1.8	0.588	13.9	5.28	0.1

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
11/28/89 12:13	0	V1-2B	3.8	15.8	2.760	19.6	1	1
11/28/89 16:21	70	V1-2B	4.1	15.5	2.741	19.6	1.08	0.98
11/28/89 18:43	212	V1-2B	4.6	14.6	2.681	19.2	1.21	0.92
11/28/89 21:22	371	V1-2B	4.8	14.0	2.639	18.8	1.26	0.89
11/29/89 1:43	632	V1-2B	5.8	13.0	2.565	18.8	1.52	0.82
11/29/89 7:25	974	V1-2B	6.4	11.5	2.442	17.9	1.7	0.73
11/29/89 12:45	1294	V1-2B	6.9	10.0	2.303	16.9	1.83	0.63
11/29/89 19:39	1708	V1-2B	8.0	8.4	2.128	16.4	2.11	0.53
11/30/89 7:11	2400	V1-2B	9.0	6.0	1.792	15.0	2.37	0.38
11/30/89 16:42	2971	V1-2B	10.9	4.2	1.435	15.1	2.86	0.27
12/1/89 8:40	3929	V1-2B	12.5	1.8	0.588	14.3	3.28	0.11
11/28/89 12:18	0	V1-2C	7.0	12.4	2.518	19.4	1	1
11/28/89 16:24	73	V1-2C	6.6	13.0	2.565	19.6	0.94	1.05
11/28/89 18:46	215	V1-2C	6.6	12.9	2.557	19.5	0.94	1.04
11/28/89 21:26	375	V1-2C	6.6	12.9	2.557	19.5	0.94	1.04
11/29/89 1:47	636	V1-2C	7.0	12.6	2.534	19.6	1	1.02
11/29/89 7:27	976	V1-2C	7.2	11.5	2.442	18.7	1.03	0.93
11/29/89 12:48	1297	V1-2C	7.6	10.1	2.313	17.7	1.08	0.81
11/29/89 19:42	1711	V1-2C	8.4	9.0	2.197	17.4	1.19	0.73
11/30/89 7:14	2403	V1-2C	9.4	5.8	1.758	15.2	1.33	0.47
11/30/89 16:44	2973	V1-2C	11.2	4.1	1.411	15.3	1.59	0.33
12/1/89 8:42	3931	V1-2C	12.5	1.8	0.588	14.3	1.77	0.15
11/28/89 12:24	0	V1-3A	1.8	18.5	2.918	20.3	1	1
11/28/89 16:28	77	V1-3A	2.5	17.0	2.833	19.5	1.39	0.92
11/28/89 18:49	218	V1-3A	3.2	15.8	2.760	19.0	1.78	0.85
11/28/89 21:30	379	V1-3A	3.7	14.8	2.695	18.5	2.06	0.8
11/29/89 1:51	640	V1-3A	4.0	14.2	2.653	18.2	2.22	0.77
11/29/89 7:31	980	V1-3A	4.1	14.2	2.653	18.3	2.28	0.77
11/29/89 12:52	1301	V1-3A	4.1	13.5	2.603	17.6	2.28	0.73
11/29/89 19:45	1714	V1-3A	4.9	12.0	2.485	16.9	2.69	0.65
11/30/89 7:17	2406	V1-3A	5.7	10.0	2.303	15.7	3.15	0.54
11/30/89 16:47	2976	V1-3A	7.2	7.8	2.054	15.0	4.02	0.42
12/1/89 8:47	3936	V1-3A	8.9	5.0	1.609	13.9	4.94	0.27
11/28/89 12:32	0	V1-3B	3.4	16.4	2.797	16.4	1	1
11/28/89 16:30	79	V1-3B	3.6	16.2	2.785	19.8	1.06	0.99
11/28/89 18:51	220	V1-3B	4.1	15.2	2.721	19.3	1.21	0.93
11/28/89 21:32	381	V1-3B	4.4	14.8	2.695	19.2	1.29	0.9
11/29/89 1:54	643	V1-3B	4.9	13.9	2.632	18.8	1.44	0.85
11/29/89 7:35	984	V1-3B	5.7	12.5	2.526	18.2	1.67	0.76
11/29/89 12:55	1304	V1-3B	7.0	10.4	2.342	17.4	2.07	0.63
11/29/89 19:48	1717	V1-3B	7.8	9.0	2.197	16.8	2.3	0.55
11/30/89 7:22	2411	V1-3B	9.2	6.1	1.808	15.3	2.7	0.37
11/30/89 16:52	2981	V1-3B	10.0	4.6	1.526	14.6	2.93	0.28
12/1/89 8:52	3941	V1-3B	13.1	2.6	0.956	15.7	3.86	0.16

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
11/28/89 12:37	0	V1-3C	4.6	14.6	2.681	19.2	1	1
11/28/89 16:33	82	V1-3C	4.9	14.6	2.681	19.5	1.05	1
11/28/89 18:53	222	V1-3C	5.1	14.0	2.639	19.1	1.11	0.96
11/28/89 21:34	383	V1-3C	5.7	13.7	2.617	19.4	1.23	0.94
11/29/89 1:57	646	V1-3C	6.3	12.9	2.557	19.2	1.38	0.88
11/29/89 7:38	987	V1-3C	7.0	11.1	2.407	18.1	1.53	0.76
11/29/89 12:58	1307	V1-3C	7.8	9.2	2.219	17.0	1.7	0.63
11/29/89 19:52	1721	V1-3C	8.6	7.8	2.054	16.4	1.87	0.53
11/30/89 7:25	2414	V1-3C	9.8	4.9	1.589	14.7	2.12	0.34
11/30/89 16:55	2984	V1-3C	12.5	3.3	1.194	15.8	2.71	0.23
12/1/89 8:55	3944	V1-3C	14.1	1.3	0.262	15.4	3.06	0.09
11/28/89 12:50	0	V2-1A	0.5	19.9	2.991	20.4	1	1
11/28/89 16:36	85	V2-1A	1.2	18.5	2.918	19.7	2.4	0.93
11/28/89 18:55	224	V2-1A	1.8	17.0	2.833	18.8	3.6	0.85
11/28/89 21:38	387	V2-1A	2.3	16.0	2.773	18.3	4.6	0.8
11/29/89 2:00	649	V2-1A	3.1	13.5	2.603	16.6	6.2	0.68
11/29/89 7:41	990	V2-1A	4.3	10.5	2.351	14.8	8.6	0.53
11/29/89 13:03	1312	V2-1A	5.5	8.2	2.104	13.7	10.9	0.41
11/29/89 19:55	1724	V2-1A	6.5	9.5	2.251	16.0	13.1	0.48
11/30/89 7:29	2418	V2-1A	6.4	7.8	2.054	14.2	12.9	0.39
11/30/89 16:59	2988	V2-1A	8.3	6.7	1.902	15.0	16.6	0.34
12/1/89 9:00	3949	V2-1A	8.4	6.2	1.825	14.6	16.8	0.31
11/28/89 12:55	0	V2-1B	3.6	15.2	2.721	18.8	1	1
11/28/89 16:38	87	V2-1B	4.5	14.0	2.639	18.5	1.25	0.92
11/28/89 18:58	227	V2-1B	5.6	12.2	2.501	17.8	1.55	0.8
11/28/89 21:40	389	V2-1B	6.4	11.2	2.416	17.6	1.79	0.74
11/29/89 2:03	652	V2-1B	7.6	9.2	2.219	16.8	2.12	0.61
11/29/89 7:45	994	V2-1B	8.6	7.0	1.946	15.6	2.39	0.46
11/29/89 13:05	1314	V2-1B	9.6	4.2	1.435	13.8	2.66	0.28
11/29/89 19:58	1727	V2-1B	11.7	2.8	1.030	14.5	3.24	0.18
11/30/89 7:35	2424	V2-1B	12.3	1.3	0.262	13.6	3.42	0.09
11/28/89 13:00	0	V2-1C	6.1	12.2	2.501	18.3	1	1
11/28/89 16:40	89	V2-1C	6.4	11.8	2.468	18.2	1.06	0.97
11/28/89 19:03	232	V2-1C	7.0	11.2	2.416	18.2	1.16	0.92
11/28/89 21:43	392	V2-1C	7.6	10.8	2.380	18.4	1.26	0.89
11/29/89 2:06	655	V2-1C	8.2	9.2	2.219	17.4	1.35	0.75
11/29/89 7:48	997	V2-1C	8.8	7.3	1.988	16.1	1.45	0.6
11/29/89 13:10	1319	V2-1C	9.4	4.8	1.569	14.2	1.55	0.39
11/29/89 20:02	1731	V2-1C	11.8	3.2	1.163	15.0	1.95	0.26
11/30/89 7:42	2431	V2-1C	12.5	1.0	0.000	13.5	2.06	0.08

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time		Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
11/28/89	13:09	0	V2-2A	0.3	20.5	3.020	20.8	1	1
11/28/89	16:44	93	V2-2A	0.4	19.8	2.986	20.2	1.6	0.97
11/28/89	19:07	236	V2-2A	0.7	18.5	2.918	19.2	2.6	0.9
11/28/89	21:46	395	V2-2A	1.1	17.6	2.868	18.7	4.4	0.86
11/29/89	2:09	658	V2-2A	1.6	16.0	2.773	17.6	6.4	0.78
11/29/89	7:51	1000	V2-2A	2.0	14.3	2.660	16.3	8	0.7
11/29/89	13:13	1322	V2-2A	2.5	12.8	2.549	15.3	10	0.62
11/29/89	20:06	1735	V2-2A	3.1	11.5	2.442	14.6	12.4	0.56
11/30/89	7:47	2436	V2-2A	4.0	9.0	2.197	13.0	15.8	0.44
11/30/89	17:06	2995	V2-2A	5.6	6.8	1.917	12.4	22.3	0.33
12/1/89	9:16	3965	V2-2A	7.4	5.5	1.705	12.9	29.7	0.27
11/28/89	13:18	0	V2-2B	7.6	10.0	2.303	17.6	1	1
11/28/89	16:46	95	V2-2B	7.4	10.5	2.351	17.9	0.97	1.05
11/28/89	19:09	238	V2-2B	7.8	9.8	2.282	17.6	1.03	0.98
11/28/89	21:48	397	V2-2B	8.1	10.0	2.303	18.1	1.06	1
11/29/89	2:10	659	V2-2B	8.6	8.3	2.116	16.9	1.13	0.83
11/29/89	7:54	1003	V2-2B	9.0	6.2	1.825	15.2	1.18	0.62
11/29/89	13:16	1325	V2-2B	9.8	4.8	1.569	14.6	1.28	0.48
11/29/89	20:09	1738	V2-2B	11.8	3.9	1.361	15.7	1.55	0.39
11/30/89	7:50	2439	V2-2B	12.5	1.3	0.262	13.8	1.64	0.13
11/28/89	13:23	0	V2-2C	12.8	3.2	1.163	16.0	1	1
11/28/89	16:52	101	V2-2C	13.7	3.3	1.194	17.0	1.07	1.03
11/28/89	19:13	242	V2-2C	13.4	3.9	1.361	17.3	1.05	1.22
11/28/89	21:52	401	V2-2C	13.7	5.0	1.609	18.7	1.07	1.56
11/29/89	2:15	664	V2-2C	14.6	4.5	1.504	19.1	1.13	1.41
11/29/89	7:57	1006	V2-2C	13.4	3.1	1.131	16.5	1.05	0.97
11/29/89	13:19	1328	V2-2C	13.9	1.5	0.405	15.4	1.08	0.47
11/29/89	20:12	1741	V2-2C	14.1	1.0	0.000	15.1	1.09	0.31
11/30/89	7:53	2442	V2-2C	13.4	0.5	-0.693	13.9		
11/28/89	13:33	0	V2-3A	0.7	19.8	2.986	20.5	1	1
11/28/89	16:55	104	V2-3A	1.4	18.2	2.901	19.6	2	0.92
11/28/89	19:19	248	V2-3A	2.0	16.5	2.803	18.5	2.86	0.83
11/28/89	21:56	405	V2-3A	2.6	15.4	2.734	18.0	3.71	0.78
11/29/89	2:20	669	V2-3A	3.4	13.2	2.580	16.6	4.86	0.67
11/29/89	7:59	1008	V2-3A	4.0	11.5	2.442	15.5	5.71	0.58
11/29/89	13:21	1330	V2-3A	4.6	11.0	2.398	15.6	6.57	0.56
11/29/89	20:15	1744	V2-3A	5.7	9.4	2.241	15.1	8.09	0.47
11/30/89	7:57	2446	V2-3A	7.0	6.0	1.792	13.0	10	0.3
11/30/89	17:08	2997	V2-3A	9.0	5.0	1.609	14.0	12.8	0.25
12/1/89	9:19	3968	V2-3A	9.8	4.5	1.504	14.3	14	0.23

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
11/28/89 13:37	0	V2-3B	5.7	13.0	2.565	18.7	1	1
11/28/89 16:58	107	V2-3B	6.4	12.5	2.526	18.9	1.14	0.96
11/28/89 19:21	250	V2-3B	7.0	11.1	2.407	18.1	1.24	0.85
11/28/89 21:58	407	V2-3B	7.6	10.6	2.361	18.2	1.34	0.82
11/29/89 2:25	674	V2-3B	8.7	8.2	2.104	16.9	1.53	0.63
11/29/89 8:03	1012	V2-3B	9.3	6.0	1.792	15.3	1.64	0.46
11/29/89 13:24	1333	V2-3B	11.5	3.5	1.253	15.0	2.03	0.27
11/29/89 20:23	1752	V2-3B	12.8	2.3	0.833	15.1	2.26	0.18
11/30/89 8:01	2450	V2-3B	13.1	1.0	0.000	14.1	2.31	0.08
11/28/89 13:42	0	V2-3C	8.6	9.1	2.208	17.7	1	1
11/28/89 17:01	110	V2-3C	9.2	9.2	2.219	18.4	1.07	1.01
11/28/89 19:25	254	V2-3C	9.5	8.4	2.128	17.9	1.1	0.92
11/28/89 22:03	412	V2-3C	9.6	8.2	2.104	17.8	1.11	0.9
11/29/89 2:28	677	V2-3C	10.6	6.2	1.825	16.8	1.24	0.68
11/29/89 8:07	1016	V2-3C	12.1	3.8	1.335	15.9	1.41	0.42
11/29/89 13:26	1335	V2-3C	13.4	1.2	0.182	14.6	1.56	0.13
11/29/89 20:29	1758	V2-3C	14.4	0.5	-0.693	14.9		
11/30/89 8:08	2457	V2-3C	14.1	0.3	-1.204	14.4		
11/28/89 14:07	0	V4A	0.7	19.8	2.986	20.5	1	1
11/29/89 13:41	1350	V4A	0.8	19.8	2.986	20.6	1.14	1
11/30/89 17:14	3003	V4A	0.9	19.8	2.986	20.7	1.29	1
12/1/89 9:25	3974	V4A	0.9	19.8	2.986	20.7	1.29	1
11/28/89 14:10	0	V4B	0.8	19.8	2.986	20.6	1	1
11/29/89 13:43	1352	V4B	0.9	19.7	2.981	20.6	1.06	0.99
11/30/89 17:16	3005	V4B	0.9	19.8	2.986	20.7	1.13	1
12/1/89 9:27	3976	V4B	0.9	19.8	2.986	20.7	1.13	1
11/28/89 14:15	0	V4C	0.9	19.7	2.981	20.6	1	1
11/29/89 13:44	1353	V4C	0.9	19.7	2.981	20.6	1	1
11/30/89 17:17	3006	V4C	1.0	19.7	2.981	20.7	1.11	1
12/1/89 9:29	3978	V4C	1.0	19.7	2.981	20.7	1.11	1

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
1/3/90 15:33	Blowers Off							
1/3/90 11:45	0.0	V1-1A	3.8	16.5	2.803	20.3	1	1
1/3/90 16:20	47.0	V1-1A	3.9	16.5	2.803	20.4	1.03	1
1/3/90 19:16	223.0	V1-1A	4	16.2	2.785	20.2	1.05	0.98
1/3/90 23:12	459.0	V1-1A	4.2	15.8	2.760	20.0	1.11	0.96
1/4/90 5:39	846.0	V1-1A	4.3	15	2.708	19.3	1.13	0.91
1/4/90 12:09	1236.0	V1-1A	4.4	14.1	2.646	18.5	1.16	0.85
1/4/90 17:26	1553.0	V1-1A	4.8	13.3	2.588	18.1	1.26	0.81
1/5/90 6:55	2362.0	V1-1A	5.8	11.2	2.416	17.0	1.53	0.68
1/5/90 16:41	2948.0	V1-1A	6.3	9.6	2.262	15.9	1.66	0.58
1/6/90 7:55	3862.0	V1-1A	7.3	6.8	1.917	14.1	1.92	0.41
1/6/90 16:04	4351.0	V1-1A	7.8	5.4	1.686	13.2	2.05	0.33
1/7/90 8:32	5339.0	V1-1A	8.9	3.3	1.194	12.2	2.34	0.2
1/8/90 10:10	6877.0	V1-1A	10.1	0.8	-0.223	10.9		
1/3/90 11:51	0.0	V1-1B	3.4	17.1	2.839	20.5	1	1
1/3/90 16:22	49.0	V1-1B	3.5	17.1	2.839	20.6	1.03	1
1/3/90 19:18	225.0	V1-1B	3.6	17.1	2.839	20.7	1.06	1
1/3/90 23:13	460.0	V1-1B	3.7	16.8	2.821	20.5	1.09	0.98
1/4/90 5:40	847.0	V1-1B	3.8	16.2	2.785	20.0	1.12	0.95
1/4/90 12:11	1238.0	V1-1B	3.8	15.5	2.741	19.3	1.12	0.91
1/4/90 17:28	1555.0	V1-1B	4.2	15.1	2.715	19.3	1.24	0.88
1/5/90 6:57	2364.0	V1-1B	4.7	13.4	2.595	18.1	1.38	0.78
1/5/90 16:47	2954.0	V1-1B	5.1	12.1	2.493	17.2	1.5	0.71
1/6/90 7:57	3864.0	V1-1B	5.9	9.9	2.293	15.8	1.74	0.58
1/6/90 16:06	4353.0	V1-1B	6.2	8.6	2.152	14.8	1.82	0.5
1/7/90 8:34	5341.0	V1-1B	7.2	6.2	1.825	13.4	2.12	0.36
1/8/90 10:12	6879.0	V1-1B	8.5	3	1.099	11.5	2.5	0.18
1/3/90 11:56	0.0	V1-1C	3.2	17.2	2.845	20.4	1	1
1/3/90 16:24	51.0	V1-1C	3.4	17.4	2.856	20.8	1.06	1.01
1/3/90 19:20	227.0	V1-1C	3.5	17.2	2.845	20.7	1.09	1
1/3/90 23:14	461.0	V1-1C	3.6	17.1	2.839	20.7	1.13	0.99
1/4/90 5:42	849.0	V1-1C	3.8	16.4	2.797	20.2	1.19	0.95
1/4/90 12:13	1240.0	V1-1C	3.8	15.8	2.760	19.6	1.19	0.92
1/4/90 17:30	1557.0	V1-1C	4.1	15.4	2.734	19.5	1.28	0.9
1/5/90 6:59	2366.0	V1-1C	4.5	13.9	2.632	18.4	1.41	0.81
1/5/90 16:52	2959.0	V1-1C	4.9	12.4	2.518	17.3	1.53	0.72
1/6/90 7:58	3865.0	V1-1C	5.7	10.3	2.332	16.0	1.78	0.6
1/6/90 16:08	4355.0	V1-1C	6	9.1	2.208	15.1	1.88	0.53
1/7/90 8:36	5343.0	V1-1C	6.8	6.9	1.932	13.7	2.13	0.4
1/8/90 10:14	6881.0	V1-1C	8.1	3.5	1.253	11.6	2.53	0.2



TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
1/3/90 12:01	0.0	V1-2A	2	18.2	2.901	20.2	1	1
1/3/90 16:26	53.0	V1-2A	2.2	18.1	2.896	20.3	1.1	0.99
1/3/90 19:22	229.0	V1-2A	2.7	17.1	2.839	19.8	1.35	0.94
1/3/90 23:16	463.0	V1-2A	3.2	16.2	2.785	19.4	1.6	0.89
1/4/90 5:44	851.0	V1-2A	3.6	15	2.708	18.6	1.8	0.82
1/4/90 12:15	1242.0	V1-2A	3.8	13.9	2.632	17.7	1.9	0.76
1/4/90 17:32	1559.0	V1-2A	4.3	13.2	2.580	17.5	2.15	0.73
1/5/90 7:00	2367.0	V1-2A	5.2	11.1	2.407	16.3	2.6	0.61
1/5/90 16:55	2962.0	V1-2A	6	9.5	2.251	15.5	3	0.52
1/6/90 7:59	3866.0	V1-2A	7.1	7.2	1.974	14.3	3.55	0.4
1/6/90 16:10	4357.0	V1-2A	7.4	6.2	1.825	13.6	3.7	0.34
1/7/90 8:38	5345.0	V1-2A	8.4	4.2	1.435	12.6	4.2	0.23
1/8/90 10:17	6884.0	V1-2A	9.9	1.3	0.262	11.2	4.95	0.07
1/3/90 12:05	0.0	V1-2B	2.75	17.8	2.879	20.6	1	1
1/3/90 16:28	55.0	V1-2B	2.9	17.7	2.874	20.6	1.05	0.99
1/3/90 19:24	231.0	V1-2B	3.1	17.5	2.862	20.6	1.13	0.98
1/3/90 23:18	465.0	V1-2B	3.3	17.1	2.839	20.4	1.2	0.96
1/4/90 5:46	853.0	V1-2B	3.5	16.2	2.785	19.7	1.27	0.91
1/4/90 12:16	1243.0	V1-2B	3.7	15.5	2.741	19.2	1.35	0.87
1/4/90 17:34	1561.0	V1-2B	4	15.1	2.715	19.1	1.45	0.85
1/5/90 7:02	2369.0	V1-2B	4.6	13.2	2.580	17.8	1.67	0.74
1/5/90 16:59	2966.0	V1-2B	5.1	11.9	2.477	17.0	1.85	0.67
1/6/90 8:01	3868.0	V1-2B	6	9.8	2.282	15.8	2.18	0.55
1/6/90 16:12	4359.0	V1-2B	6.3	8.5	2.140	14.8	2.29	0.48
1/7/90 8:40	5347.0	V1-2B	7.3	6.2	1.825	13.5	2.65	0.35
1/8/90 10:19	6886.0	V1-2B	8.9	2.8	1.030	11.7	3.24	0.16
1/3/90 12:13	0.0	V1-2C	3.8	16.5	2.803	20.3	1	1
1/3/90 16:30	57.0	V1-2C	3.9	16.7	2.815	20.6	1.03	1.01
1/3/90 19:26	233.0	V1-2C	3.9	16.7	2.815	20.6	1.03	1.01
1/3/90 23:20	467.0	V1-2C	3.9	16.6	2.809	20.5	1.03	1.01
1/4/90 5:48	855.0	V1-2C	4	16.1	2.779	20.1	1.05	0.98
1/4/90 12:18	1245.0	V1-2C	4	15.3	2.728	19.3	1.05	0.93
1/4/90 17:36	1563.0	V1-2C	4.3	15.1	2.715	19.4	1.13	0.92
1/5/90 7:04	2371.0	V1-2C	4.7	13.5	2.603	18.2	1.24	0.82
1/5/90 17:02	2969.0	V1-2C	5.1	12.1	2.493	17.2	1.34	0.73
1/6/90 8:03	3870.0	V1-2C	6.1	10.1	2.313	16.2	1.61	0.61
1/6/90 16:14	4361.0	V1-2C	6.3	8.9	2.186	15.2	1.66	0.54
1/7/90 8:42	5349.0	V1-2C	7.2	6.4	1.856	13.6	1.89	0.39
1/8/90 10:21	6888.0	V1-2C	8.7	2.9	1.065	11.6	2.29	0.18

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
1/3/90 12:18	0.0	V1-3A	0.6	20.2	3.006	20.8	1	1
1/3/90 16:32	59.0	V1-3A	1	19.1	2.950	20.1	1.67	0.95
1/3/90 19:28	235.0	V1-3A	1.6	18.2	2.901	19.8	2.67	0.9
1/3/90 23:22	469.0	V1-3A	2.2	17.2	2.845	19.4	3.67	0.85
1/4/90 5:49	856.0	V1-3A	2.7	16.2	2.785	18.9	4.5	0.8
1/4/90 12:20	1247.0	V1-3A	3	15.2	2.721	18.2	5	0.75
1/4/90 17:38	1565.0	V1-3A	3.6	14.8	2.695	18.4	6	0.73
1/5/90 7:06	2373.0	V1-3A	4.3	12.7	2.542	17.0	7.17	0.63
1/5/90 17:04	2971.0	V1-3A	5	11.2	2.416	16.2	8.33	0.55
1/6/90 8:07	3874.0	V1-3A	6.1	9.1	2.208	15.2	10.2	0.45
1/6/90 16:16	4363.0	V1-3A	6.4	8.4	2.128	14.8	10.7	0.42
1/7/90 8:44	5351.0	V1-3A	7.2	6.5	1.872	13.7	12	0.32
1/8/90 10:23	6890.0	V1-3A	8.7	3.6	1.281	12.3	14.5	0.18
1/3/90 12:22	0.0	V1-3B	2.5	18.1	2.896	20.6	1	1
1/3/90 16:34	61.0	V1-3B	2.6	18	2.890	20.6	1.04	0.99
1/3/90 19:30	237.0	V1-3B	2.8	17.7	2.874	20.5	1.12	0.98
1/3/90 23:24	471.0	V1-3B	3	17.2	2.845	20.2	1.2	0.95
1/4/90 5:51	858.0	V1-3B	3.3	16.3	2.791	19.6	1.32	0.9
1/4/90 12:22	1249.0	V1-3B	3.5	15.5	2.741	19.0	1.4	0.86
1/4/90 17:40	1567.0	V1-3B	3.9	15.1	2.715	19.0	1.56	0.83
1/5/90 7:08	2375.0	V1-3B	4.5	13.3	2.588	17.8	1.8	0.73
1/5/90 17:05	2972.0	V1-3B	5.1	12.1	2.493	17.2	2.04	0.67
1/6/90 8:09	3876.0	V1-3B	6.1	10.4	2.342	16.5	2.44	0.57
1/6/90 16:18	4365.0	V1-3B	6.3	9.4	2.241	15.7	2.52	0.52
1/7/90 8:46	5353.0	V1-3B	7.1	7.5	2.015	14.6	2.84	0.41
1/8/90 10:25	6892.0	V1-3B	8.3	4.5	1.504	12.8	3.32	0.25
1/3/90 12:26	0.0	V1-3C	3.2	17.2	2.845	20.4	1	1
1/3/90 16:36	63.0	V1-3C	3.3	17.1	2.839	20.4	1.03	0.99
1/3/90 19:32	239.0	V1-3C	3.5	17	2.833	20.5	1.09	0.99
1/3/90 23:26	473.0	V1-3C	3.6	16.8	2.821	20.4	1.13	0.98
1/4/90 5:52	859.0	V1-3C	3.8	16	2.773	19.8	1.19	0.93
1/4/90 12:24	1251.0	V1-3C	3.9	15.2	2.721	19.1	1.22	0.88
1/4/90 17:42	1569.0	V1-3C	4.3	14.8	2.695	19.1	1.34	0.86
1/5/90 7:10	2377.0	V1-3C	4.8	13.1	2.573	17.9	1.5	0.76
1/5/90 17:07	2974.0	V1-3C	5.4	11.9	2.477	17.3	1.69	0.69
1/6/90 8:11	3878.0	V1-3C	6.2	10.1	2.313	16.3	1.94	0.59
1/6/90 16:20	4367.0	V1-3C	6.5	9.1	2.208	15.6	2.03	0.53
1/7/90 8:48	5355.0	V1-3C	7.3	7.2	1.974	14.5	2.28	0.42
1/8/90 10:27	6894.0	V1-3C	8.7	4.1	1.411	12.8	2.72	0.24

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
1/3/90 12:37	0.0	V2-1A	0.1	20.8	3.035	20.9	1	1
1/3/90 16:37	64.0	V2-1A	0.15	20.6	3.025	20.8	1.5	0.99
1/3/90 19:34	241.0	V2-1A	0.3	20.4	3.016	20.7	3	0.98
1/3/90 23:27	474.0	V2-1A	0.3	19.8	2.986	20.1	3	0.95
1/4/90 5:55	862.0	V2-1A	0.6	18.8	2.934	19.4	6	0.9
1/4/90 12:26	1253.0	V2-1A	0.6	17.9	2.885	18.5	6	0.86
1/4/90 17:44	1571.0	V2-1A	1.2	17.1	2.839	18.3	12	0.82
1/5/90 7:11	2378.0	V2-1A	2.3	14.2	2.653	16.5	23	0.68
1/5/90 17:09	2976.0	V2-1A	1.7	18.5	2.918	20.2	17	0.89
1/6/90 8:13	3880.0	V2-1A	0.2	20.7	3.030	20.9	2	1
1/6/90 16:22	4369.0	V2-1A	0.2	20.8	3.035	21.0	2	1
1/7/90 8:50	5357.0	V2-1A	0.2	20.7	3.030	20.9	2	1
1/8/90 10:29	6896.0	V2-1A	0.4	20.2	3.006	20.6	4	0.97
1/3/90 12:43	0.0	V2-1B	1.25	19.3	2.960	20.6	1	1
1/3/90 16:39	66.0	V2-1B	1.5	18.5	2.918	20.0	1.2	0.96
1/3/90 19:35	242.0	V2-1B	2.1	17.7	2.874	19.8	1.68	0.92
1/3/90 23:28	475.0	V2-1B	2.7	16.3	2.791	19.0	2.16	0.84
1/4/90 5:57	864.0	V2-1B	3.6	14	2.639	17.6	2.88	0.73
1/4/90 12:28	1255.0	V2-1B	4.2	11.9	2.477	16.1	3.36	0.62
1/4/90 17:45	1572.0	V2-1B	5	10.8	2.380	15.8	4	0.56
1/5/90 7:13	2380.0	V2-1B	6.4	7.5	2.015	13.9	5.12	0.39
1/5/90 17:16	2983.0	V2-1B	7.5	5.8	1.758	13.3	6	0.3
1/6/90 8:15	3882.0	V2-1B	8.5	6.1	1.808	14.6	6.8	0.32
1/6/90 16:24	4371.0	V2-1B	8.5	7.5	2.015	16.0	6.8	0.39
1/7/90 8:52	5359.0	V2-1B	8	9.6	2.262	17.6	6.4	0.5
1/8/90 10:31	6898.0	V2-1B	8.1	8.4	2.128	16.5	6.48	0.44
1/3/90 12:47	0.0	V2-1C	1.3	19.2	2.955	20.5	1	1
1/3/90 16:40	67.0	V2-1C	1.8	18.9	2.939	20.7	1.38	0.98
1/3/90 19:36	243.0	V2-1C	2.2	18.5	2.918	20.7	1.69	0.96
1/3/90 23:30	477.0	V2-1C	2.3	17.8	2.879	20.1	1.77	0.93
1/4/90 5:59	866.0	V2-1C	2.9	16.3	2.791	19.2	2.23	0.85
1/4/90 12:30	1257.0	V2-1C	3.2	14.8	2.695	18.0	2.46	0.77
1/4/90 17:46	1573.0	V2-1C	4	13.9	2.632	17.9	3.08	0.72
1/5/90 7:15	2382.0	V2-1C	4.8	11.2	2.416	16.0	3.69	0.58
1/5/90 17:18	2985.0	V2-1C	6	8.9	2.186	14.9	4.62	0.46
1/7/90 8:54	5361.0	V2-1C	7	14.5	2.674	21.5	5.38	0.76

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
1/3/90 12:56	0.0	V2-2A	0.05	20.9	3.040	21.0	1	1
1/3/90 16:42	69.0	V2-2A	0.1	20.8	3.035	20.9	2	1
1/3/90 19:38	245.0	V2-2A	0.15	20.5	3.020	20.7	3	0.98
1/3/90 23:32	479.0	V2-2A	0.15	20.2	3.006	20.4	3	0.97
1/4/90 6:00	867.0	V2-2A	0.2	19.1	2.950	19.3	4	0.91
1/4/90 12:32	1259.0	V2-2A	0.3	18.1	2.896	18.4	6	0.87
1/4/90 17:47	1574.0	V2-2A	0.75	17.3	2.851	18.1	15	0.83
1/5/90 7:17	2384.0	V2-2A	1.4	14.8	2.695	16.2	28	0.71
1/5/90 17:20	2987.0	V2-2A	1.8	15.5	2.741	17.3	36	0.74
1/6/90 8:19	3886.0	V2-2A	3.4	12.2	2.501	15.6	68	0.58
1/6/90 16:28	4375.0	V2-2A	3.3	13.1	2.573	16.4	66	0.63
1/7/90 8:56	5363.0	V2-2A	7.1	11.3	2.425	18.4	142	0.54
1/8/90 10:34	6901.0	V2-2A	3.4	18	2.890	21.4	68	0.86
1/3/90 13:06	0.0	V2-2B	1	19.7	2.981	20.7	1	1
1/3/90 16:43	70.0	V2-2B	1.1	19.5	2.970	20.6	1.1	0.99
1/3/90 19:40	247.0	V2-2B	1.3	19.1	2.950	20.4	1.3	0.97
1/3/90 23:34	481.0	V2-2B	1.7	18.2	2.901	19.9	1.7	0.92
1/4/90 6:02	869.0	V2-2B	2.2	16.9	2.827	19.1	2.2	0.86
1/4/90 12:34	1261.0	V2-2B	2.7	15.2	2.721	17.9	2.7	0.77
1/4/90 17:48	1575.0	V2-2B	3.3	14.4	2.667	17.7	3.3	0.73
1/5/90 7:18	2385.0	V2-2B	4.3	11.2	2.416	15.5	4.3	0.57
1/5/90 17:24	2991.0	V2-2B	5.2	9.2	2.219	14.4	5.2	0.47
1/6/90 8:21	3888.0	V2-2B	7.9	5.4	1.686	13.3	7.9	0.27
1/6/90 16:30	4377.0	V2-2B	9	5.2	1.649	14.2	9	0.26
1/7/90 8:58	5365.0	V2-2B	10.1	5.9	1.775	16.0	10.1	0.3
1/8/90 10:36	6903.0	V2-2B	10.9	5.9	1.775	16.8	10.9	0.3
1/3/90 13:09	0.0	V2-2C	1.7	19	2.944	20.7	1	1
1/3/90 16:44	71.0	V2-2C	2.1	18.6	2.923	20.7	1.24	0.98
1/3/90 19:42	249.0	V2-2C	2.5	18.4	2.912	20.9	1.47	0.97
1/3/90 23:35	482.0	V2-2C	2.6	17.8	2.879	20.4	1.53	0.94
1/4/90 6:04	871.0	V2-2C	3	16.3	2.791	19.3	1.76	0.86
1/4/90 12:36	1263.0	V2-2C	3.3	14.7	2.688	18.0	1.94	0.77
1/4/90 17:50	1577.0	V2-2C	3.9	13.9	2.632	17.8	2.29	0.73
1/5/90 7:20	2387.0	V2-2C	4.8	10.7	2.370	15.5	2.82	0.56
1/5/90 17:26	2993.0	V2-2C	5.7	8.5	2.140	14.2	3.35	0.45
1/6/90 8:24	3891.0	V2-2C	7.9	5.1	1.629	13.0	4.65	0.27
1/6/90 16:32	4379.0	V2-2C	9.1	4.8	1.569	13.9	5.35	0.25
1/7/90 9:00	5367.0	V2-2C	10.5	5.1	1.629	15.6	6.18	0.27
1/8/90 10:38	6905.0	V2-2C	11.8	4.4	1.482	16.2	6.94	0.23

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
1/3/90 13:12	0.0	V2-3A	0.1	20.7	3.030	20.8	1	1
1/3/90 16:47	74.0	V2-3A	0.15	20.5	3.020	20.7	1.5	0.99
1/3/90 19:44	251.0	V2-3A	0.3	20.2	3.006	20.5	3	0.98
1/3/90 23:37	484.0	V2-3A	0.5	19.2	2.955	19.7	5	0.93
1/4/90 6:05	872.0	V2-3A	0.8	18	2.890	18.8	8	0.87
1/4/90 12:38	1265.0	V2-3A	1.2	16.3	2.791	17.5	12	0.79
1/4/90 17:52	1579.0	V2-3A	2	15.9	2.766	17.9	20	0.77
1/5/90 7:24	2391.0	V2-3A	3.2	13.1	2.573	16.3	32	0.63
1/5/90 17:27	2994.0	V2-3A	3.2	14.4	2.667	17.6	32	0.7
1/6/90 8:26	3893.0	V2-3A	0.8	20	2.996	20.8	8	0.97
1/6/90 16:34	4381.0	V2-3A	0.7	19.9	2.991	20.6	7	0.96
1/7/90 9:02	5369.0	V2-3A	0.6	20.1	3.001	20.7	6	0.97
1/8/90 10:40	6907.0	V2-3A	0.7	19.4	2.965	20.1	7	0.94
1/3/90 13:15	0.0	V2-3B	0.9	19.5	2.970	20.4	1	1
1/3/90 16:48	75.0	V2-3B	1.1	19.4	2.965	20.5	1.22	0.99
1/3/90 19:46	253.0	V2-3B	1.4	19	2.944	20.4	1.56	0.97
1/3/90 23:39	486.0	V2-3B	1.8	18.1	2.896	19.9	2	0.93
1/4/90 6:07	874.0	V2-3B	2.6	16.7	2.815	19.3	2.89	0.86
1/4/90 12:40	1267.0	V2-3B	3.1	15.1	2.715	18.2	3.44	0.77
1/4/90 17:53	1580.0	V2-3B	3.6	14.5	2.674	18.1	4	0.74
1/5/90 7:26	2393.0	V2-3B	4.7	11.9	2.477	16.6	5.22	0.61
1/5/90 17:30	2997.0	V2-3B	5.3	10.4	2.342	15.7	5.89	0.53
1/6/90 8:28	3895.0	V2-3B	5.8	11.3	2.425	17.1	6.44	0.58
1/6/90 16:36	4383.0	V2-3B	6.1	11.8	2.468	17.9	6.78	0.61
1/7/90 9:04	5371.0	V2-3B	6.5	12	2.485	18.5	7.22	0.62
1/8/90 10:42	6909.0	V2-3B	7.2	10.7	2.370	17.9	8	0.55
1/3/90 13:18	0.0	V2-3C	2.2	18.5	2.918	20.7	1	1
1/3/90 16:49	76.0	V2-3C	2.4	18.2	2.901	20.6	1.09	0.98
1/3/90 19:48	255.0	V2-3C	2.9	17.6	2.868	20.5	1.32	0.95
1/3/90 23:40	487.0	V2-3C	3.2	16.8	2.821	20.0	1.45	0.91
1/4/90 6:09	876.0	V2-3C	3.8	15.3	2.728	19.1	1.73	0.83
1/4/90 12:42	1269.0	V2-3C	4	14	2.639	18.0	1.82	0.76
1/4/90 17:55	1582.0	V2-3C	4.7	13	2.565	17.7	2.14	0.7
1/5/90 7:28	2395.0	V2-3C	5.9	10.3	2.332	16.2	2.68	0.56
1/5/90 17:32	2999.0	V2-3C	6.7	8.5	2.140	15.2	3.05	0.46
1/6/90 8:30	3897.0	V2-3C	7.2	8.5	2.140	15.7	3.27	0.46
1/6/90 16:37	4384.0	V2-3C	7.5	8.8	2.175	16.3	3.41	0.48
1/7/90 9:06	5373.0	V2-3C	8.3	9.1	2.208	17.4	3.77	0.49
1/8/90 10:44	6911.0	V2-3C	9.8	7	1.946	16.8	4.45	0.38

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
1/3/90 14:03	0.0	V3A	3	17.7	2.874	20.7	1	1
1/3/90 16:58	85.0	V3A	3.1	17.5	2.862	20.6	1.03	0.99
1/3/90 19:51	258.0	V3A	3.2	17.6	2.868	20.8	1.07	0.99
1/3/90 23:44	491.0	V3A	3.1	17.2	2.845	20.3	1.03	0.97
1/4/90 6:13	880.0	V3A	3.2	17	2.833	20.2	1.07	0.96
1/4/90 12:48	1275.0	V3A	3.2	16.8	2.821	20.0	1.07	0.95
1/4/90 18:00	1587.0	V3A	3.5	16.6	2.809	20.1	1.17	0.94
1/5/90 7:32	2399.0	V3A	3.6	16.1	2.779	19.7	1.2	0.91
1/5/90 17:34	3001.0	V3A	3.8	15.8	2.760	19.6	1.27	0.89
1/6/90 8:34	3901.0	V3A	3.9	15.4	2.734	19.3	1.3	0.87
1/6/90 16:39	4386.0	V3A	4	15.2	2.721	19.2	1.33	0.86
1/7/90 9:09	5376.0	V3A	4	14.9	2.701	18.9	1.33	0.84
1/8/90 10:49	6916.0	V3A	4.1	14.8	2.695	18.9	1.37	0.84
1/3/90 14:05	0.0	V3B	3.2	17.3	2.851	20.5	1	1
1/3/90 16:59	86.0	V3B	3.3	17.2	2.845	20.5	1.03	0.99
1/3/90 19:53	260.0	V3B	3.3	17.3	2.851	20.6	1.03	1
1/3/90 23:45	492.0	V3B	3.2	17	2.833	20.2	1	0.98
1/4/90 6:15	882.0	V3B	3.3	16.8	2.821	20.1	1.03	0.97
1/4/90 12:49	1276.0	V3B	3.2	16.6	2.809	19.8	1	0.96
1/4/90 18:01	1588.0	V3B	3.6	16.5	2.803	20.1	1.13	0.95
1/5/90 7:33	2400.0	V3B	3.7	16.1	2.779	19.8	1.16	0.93
1/5/90 17:35	3002.0	V3B	3.9	15.8	2.760	19.7	1.22	0.91
1/6/90 8:36	3903.0	V3B	4	15.2	2.721	19.2	1.25	0.88
1/6/90 16:40	4387.0	V3B	4.1	15.1	2.715	19.2	1.28	0.87
1/7/90 9:11	5378.0	V3B	4.1	14.7	2.688	18.8	1.28	0.85
1/8/90 10:50	6917.0	V3B	4.25	14.2	2.653	18.5	1.33	0.82
1/3/90 14:07	0.0	V3C	3.2	17.2	2.845	20.4	1	1
1/3/90 17:00	87.0	V3C	3.3	17.2	2.845	20.5	1.03	1
1/3/90 19:55	262.0	V3C	3.3	17.3	2.851	20.6	1.03	1.01
1/3/90 23:47	494.0	V3C	3.2	17.1	2.839	20.3	1	0.99
1/4/90 6:16	883.0	V3C	3.3	16.8	2.821	20.1	1.03	0.98
1/4/90 12:50	1277.0	V3C	3.2	16.7	2.815	19.9	1	0.97
1/4/90 18:02	1589.0	V3C	3.5	16.5	2.803	20.0	1.09	0.96
1/5/90 7:35	2402.0	V3C	3.7	16	2.773	19.7	1.16	0.93
1/5/90 17:36	3003.0	V3C	3.9	15.7	2.754	19.6	1.22	0.91
1/6/90 8:38	3905.0	V3C	4	15.3	2.728	19.3	1.25	0.89
1/6/90 16:42	4389.0	V3C	4	15.1	2.715	19.1	1.25	0.88
1/7/90 9:13	5380.0	V3C	4.1	14.7	2.688	18.8	1.28	0.85
1/8/90 10:52	6919.0	V3C	4.2	14.3	2.660	18.5	1.31	0.83

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
1/3/90 13:49	0.0	V4A	0.2	20.6	3.025	20.8	1	1
1/3/90 17:01	88.0	V4A	0.3	20.5	3.020	20.8	1.5	1
1/4/90 12:53	1280.0	V4A	0.4	20.2	3.006	20.6	2	0.98
1/5/90 7:36	2403.0	V4A	0.6	20.1	3.001	20.7	3	0.98
1/6/90 8:39	3906.0	V4A	0.9	19.8	2.986	20.7	4.5	0.96
1/6/90 16:44	4391.0	V4A	1	19.7	2.981	20.7	5	0.96
1/7/90 9:15	5382.0	V4A	1	19.3	2.960	20.3	5	0.94
1/8/90 10:53	6920.0	V4A	1.2	19.2	2.955	20.4	6	0.93
1/3/90 13:51	0.0	V4B	0.2	20.6	3.025	20.8	1	1
1/3/90 17:02	89.0	V4B	0.3	20.5	3.020	20.8	1.5	1
1/4/90 12:54	1281.0	V4B	0.3	20.3	3.011	20.6	1.5	0.99
1/5/90 7:37	2404.0	V4B	0.6	20.1	3.001	20.7	3	0.98
1/6/90 8:40	3907.0	V4B	1	19.8	2.986	20.8	5	0.96
1/6/90 16:46	4393.0	V4B	0.9	19.7	2.981	20.6	4.5	0.96
1/7/90 9:17	5384.0	V4B	1	19.3	2.960	20.3	5	0.94
1/8/90 10:55	6922.0	V4B	1.1	19.2	2.955	20.3	5.5	0.93
1/3/90 13:53	0.0	V4C	0.3	20.5	3.020	20.8	1	1
1/3/90 17:03	90.0	V4C	0.3	20.5	3.020	20.8	1	1
1/4/90 12:56	1283.0	V4C	0.3	20.3	3.011	20.6	1	0.99
1/5/90 7:39	2406.0	V4C	0.6	20.1	3.001	20.7	2	0.98
1/6/90 8:41	3908.0	V4C	1	19.8	2.986	20.8	3.33	0.97
1/6/90 16:47	4394.0	V4C	1	19.7	2.981	20.7	3.33	0.96
1/7/90 9:19	5386.0	V4C	0.9	19.4	2.965	20.3	3	0.95
1/8/90 10:57	6924.0	V4C	1.2	19.2	2.955	20.4	4	0.94

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	THC $\mu$ L/L	Norm CO2	Norm O2
3/3/90 11:06	Blower to V3 and V4 off for shutdown test 4								
3/3/90 10:00	0	V3A	5.4	14.7	2.688	20.1	1	1	
3/3/90 13:24	138	V3A	5.2	14.9	2.701	20.1	0.96	1.01	
3/3/90 16:38	332	V3A	5.3	15	2.708	20.25	0.97	1.02	
3/4/90 9:46	1360	V3A	5.1	14.4	2.667	19.5	0.94	0.98	
3/4/90 17:23	1817	V3A	5.2	14.4	2.667	19.6	0.96	0.98	
3/5/90 8:13	2707	V3A	5.0	14.3	2.660	19.3	0.93	0.97	
3/5/90 16:48	3222	V3A	5.1	14.2	2.653	19.3	0.94	0.97	
3/6/90 10:17	4271	V3A	5.0	14.1	2.646	19.1	0.93	0.96	
3/3/90 10:02	0	V3B	5.8	14.2	2.653	20	1	1	
3/3/90 13:26	140	V3B	5.7	14.3	2.660	20	0.98	1.01	
3/3/90 16:40	334	V3B	5.7	14.5	2.674	20.2	0.98	1.02	
3/4/90 9:48	1362	V3B	5.3	14.1	2.646	19.4	0.91	0.99	
3/4/90 17:25	1819	V3B	5.4	14.1	2.646	19.5	0.93	0.99	
3/5/90 8:16	2710	V3B	5.1	14.1	2.646	19.2	0.88	0.99	
3/5/90 16:50	3224	V3B	5.1	14.1	2.646	19.2	0.88	0.99	
3/6/90 10:19	4273	V3B	5.1	13.9	2.632	19	0.88	0.98	
3/3/90 10:04	0	V3C	6.0	14.1	2.646	20.1	1	1	
3/3/90 13:28	142	V3C	5.8	14.2	2.653	20	0.97	1.01	
3/3/90 16:42	336	V3C	5.7	14.5	2.674	20.2	0.95	1.03	
3/4/90 9:50	1364	V3C	5.4	14	2.639	19.4	0.9	0.99	
3/4/90 17:27	1821	V3C	5.4	14.1	2.646	19.5	0.9	1	
3/5/90 8:18	2712	V3C	5.2	14	2.639	19.2	0.87	0.99	
3/5/90 16:52	3226	V3C	5.2	14.1	2.646	19.3	0.87	1	
3/6/90 10:21	4275	V3C	6.4	12	2.485	18.4	1.07	0.85	
3/3/90 9:52	0	V4A	0.5	20.5	3.020	21	1	1	
3/3/90 13:30	144	V4A	0.6	20.4	3.016	21	1.2	1	
3/3/90 16:44	338	V4A	0.6	20.5	3.020	21.1	1.2	1	
3/4/90 9:53	1367	V4A	0.8	20	2.996	20.8	1.6	0.98	
3/4/90 17:29	1823	V4A	0.9	20	2.996	20.9	1.8	0.98	
3/5/90 8:23	2717	V4A	1.0	19.5	2.970	20.5	2	0.95	
3/5/90 16:54	3228	V4A	1.1	19.5	2.970	20.6	2.2	0.95	
3/6/90 10:24	4278	V4A	1.2	19.2	2.955	20.4	2.4	0.94	
3/3/90 9:54	0	V4B	0.6	20.3	3.011	20.9	1	1	
3/3/90 13:32	146	V4B	0.7	20.3	3.011	21	1.17	1	
3/3/90 16:46	340	V4B	0.7	20.3	3.011	21	1.17	1	
3/4/90 9:55	1369	V4B	0.8	20	2.996	20.8	1.33	0.99	
3/4/90 17:31	1825	V4B	0.9	20	2.996	20.9	1.5	0.99	
3/5/90 8:25	2719	V4B	1.0	19.5	2.970	20.5	1.67	0.96	
3/5/90 16:56	3230	V4B	1.1	19.5	2.970	20.6	1.83	0.96	
3/6/90 10:26	4280	V4B	1.2	19.2	2.955	20.4	2	0.95	
3/3/90 9:56	0	V4C	0.7	20.2	3.006	20.9	1	1	
3/3/90 13:34	148	V4C	0.7	20.2	3.006	20.9	1	1	
3/3/90 16:48	342	V4C	0.8	20.3	3.011	21.05	1.07	1	
3/4/90 9:57	1371	V4C	0.8	20	2.996	20.8	1.14	0.99	
3/4/90 17:33	1827	V4C	0.9	20	2.996	20.9	1.29	0.99	
3/5/90 8:27	2721	V4C	1.0	19.5	2.970	20.5	1.43	0.97	
3/5/90 16:58	3232	V4C	1.1	19.4	2.965	20.5	1.57	0.96	
3/6/90 10:28	4282	V4C	1.2	19.2	2.955	20.4	1.71	0.95	



TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	THC μL/L	Norm CO2	Norm O2
3/8/90 11:35	Blowers off	(V1 & V2)	for shutdown 4						
3/8/90 9:46	0	V1-1A	5.8	13.5	2.603	19.3	2494	1	1
3/8/90 13:42	127	V1-1A	6.0	12.9	2.557	18.9		1.03	0.96
3/8/90 17:08	333	V1-1A	6.7	11	2.398	17.7		1.16	0.81
3/8/90 22:16	641	V1-1A	7.4	9	2.197	16.4		1.28	0.67
3/9/90 7:44	1209	V1-1A	8.2	6.2	1.825	14.4		1.41	0.46
3/9/90 16:01	1706	V1-1A	9.2	4.1	1.411	13.3		1.59	0.3
3/10/90 6:42	2587	V1-1A	11.0	0.8	-0.223	11.8			
3/8/90 9:59	0	V1-1B	6.5	11.8	2.468	18.3	3719	1	1
3/8/90 13:44	129	V1-1B	6.8	11.6	2.451	18.4		1.05	0.98
3/8/90 17:13	338	V1-1B	7.2	11	2.398	18.2		1.11	0.93
3/8/90 22:18	643	V1-1B	7.6	10.2	2.322	17.8		1.17	0.86
3/9/90 7:46	1211	V1-1B	7.8	8.5	2.140	16.3		1.2	0.72
3/9/90 16:04	1709	V1-1B	8.3	6.8	1.917	15.1		1.28	0.58
3/10/90 6:44	2589	V1-1B	9.8	3.7	1.308	13.5		1.51	0.31
3/10/90 17:30	3235	V1-1B	10.4	1.9	0.642	12.3		1.6	0.16
3/8/90 10:07	0	V1-1C	7.1	11	2.398	18.1	2331	1	1
3/8/90 13:46	131	V1-1C	7.4	10.7	2.370	18.1		1.04	0.97
3/8/90 17:15	340	V1-1C	7.7	10.2	2.322	17.9		1.08	0.93
3/8/90 22:20	645	V1-1C	8.0	10	2.303	18		1.13	0.91
3/9/90 7:48	1213	V1-1C	8.2	8.5	2.140	16.7		1.15	0.77
3/9/90 16:07	1712	V1-1C	8.6	7.1	1.960	15.7		1.21	0.65
3/10/90 6:46	2591	V1-1C	9.8	4.1	1.411	13.9		1.38	0.37
3/10/90 17:32	3237	V1-1C	10.4	2.2	0.788	12.6		1.46	0.2
3/8/90 10:20	0	V1-2A	3.4	16.8	2.821	20.2	908	1	1
3/8/90 13:48	133	V1-2A	4.0	15.3	2.728	19.3		1.18	0.91
3/8/90 17:17	342	V1-2A	4.7	13.2	2.580	17.9		1.38	0.79
3/8/90 22:24	649	V1-2A	5.6	11.2	2.416	16.8		1.65	0.67
3/9/90 7:50	1215	V1-2A	6.6	8.2	2.104	14.8		1.94	0.49
3/9/90 16:10	1715	V1-2A	7.4	6.2	1.825	13.6		2.18	0.37
3/10/90 6:48	2593	V1-2A	9.4	2.3	0.833	11.7		2.76	0.14
3/10/90 17:34	3239	V1-2A	10.5	0.6	-0.511	11.1			
3/8/90 10:27	0	V1-2B	4.5	15	2.708	19.5	1513	1	1
3/8/90 13:50	135	V1-2B	4.8	14.4	2.667	19.2		1.07	0.96
3/8/90 17:19	344	V1-2B	5.4	13.6	2.610	19		1.2	0.91
3/8/90 22:26	651	V1-2B	6.0	12.4	2.518	18.4		1.33	0.83
3/9/90 7:52	1217	V1-2B	6.6	10.2	2.322	16.8		1.47	0.68
3/9/90 16:12	1717	V1-2B	7.3	8.2	2.104	15.5		1.62	0.55
3/10/90 6:50	2595	V1-2B	8.8	4.6	1.526	13.4		1.96	0.31
3/10/90 17:36	3241	V1-2B	9.7	2.4	0.875	12.1		2.16	0.16
3/8/90 10:32	0	V1-2C	4.8	14.7	2.688	19.5	1758	1	1
3/8/90 13:52	137	V1-2C	5.8	13.2	2.580	19		1.21	0.9
3/8/90 17:21	346	V1-2C	6.3	12.7	2.542	19		1.31	0.86
3/8/90 22:28	653	V1-2C	6.6	12.2	2.501	18.8		1.38	0.83
3/9/90 7:54	1219	V1-2C	6.9	10.3	2.332	17.2		1.44	0.7
3/9/90 16:14	1719	V1-2C	7.4	8.6	2.152	16		1.54	0.59
3/10/90 6:52	2597	V1-2C	8.8	5.2	1.649	14		1.83	0.35
3/10/90 17:38	3243	V1-2C	9.5	3	1.099	12.5		1.98	0.2

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	THC μL/L	Norm CO2	Norm O2
3/8/90 10:37	0	V1-3A	1.8	18.3	2.907	20.1	200	1	1
3/8/90 13:54	139	V1-3A	3.0	16.1	2.779	19.1		1.67	0.88
3/8/90 17:23	348	V1-3A	4.0	14.2	2.653	18.2		2.22	0.78
3/8/90 22:30	655	V1-3A	5.0	12.4	2.518	17.4		2.78	0.68
3/9/90 7:58	1223	V1-3A	6.1	9.9	2.293	16		3.39	0.54
3/9/90 16:16	1721	V1-3A	7.0	7.8	2.054	14.8		3.89	0.43
3/10/90 6:54	2599	V1-3A	8.7	4.2	1.435	12.9		4.83	0.23
3/10/90 17:40	3245	V1-3A	9.8	2.8	1.030	12.6		5.44	0.15
3/8/90 10:42	0	V1-3B	4.8	14.2	2.653	19	1840	1	1
3/8/90 13:56	141	V1-3B	5.1	13.6	2.610	18.7		1.06	0.96
3/8/90 17:25	350	V1-3B	5.8	13	2.565	18.8		1.21	0.92
3/8/90 22:34	659	V1-3B	6.3	12.1	2.493	18.4		1.31	0.85
3/9/90 8:00	1225	V1-3B	6.9	10.1	2.313	17		1.44	0.71
3/9/90 16:18	1723	V1-3B	7.4	8.5	2.140	15.9		1.54	0.6
3/10/90 6:56	2601	V1-3B	8.9	5.4	1.686	14.3		1.85	0.38
3/10/90 17:44	3249	V1-3B	9.8	3.4	1.224	13.2		2.04	0.24
3/8/90 10:45	0	V1-3C	6.2	12.4	2.518	18.6	1078	1	1
3/8/90 13:58	143	V1-3C	6.4	12.2	2.501	18.6		1.03	0.98
3/8/90 17:27	352	V1-3C	6.7	12	2.485	18.7		1.08	0.97
3/8/90 22:36	661	V1-3C	7.0	11.5	2.442	18.5		1.13	0.93
3/9/90 8:02	1227	V1-3C	7.3	9.9	2.293	17.2		1.18	0.8
3/9/90 16:20	1725	V1-3C	7.8	8.3	2.116	16.1		1.26	0.67
3/10/90 6:58	2603	V1-3C	9.0	5.3	1.668	14.3		1.45	0.43
3/10/90 17:46	3251	V1-3C	9.9	3.3	1.194	13.2		1.6	0.27
3/8/90 10:49	0	V2-1A	0.6	20.3	3.011	20.9	60	1	1
3/8/90 14:04	149	V2-1A	1.1	18.8	2.934	19.9		1.83	0.93
3/8/90 17:30	355	V2-1A	1.9	17.8	2.879	19.7		3.17	0.88
3/8/90 22:38	663	V2-1A	2.6	16.1	2.779	18.7		4.33	0.79
3/9/90 8:06	1231	V2-1A	3.3	14.1	2.646	17.4		5.5	0.69
3/9/90 16:22	1727	V2-1A	4.3	12.2	2.501	16.5		7.17	0.6
3/10/90 7:06	2611	V2-1A	5.5	9	2.197	14.5		9.17	0.44
3/10/90 17:48	3253	V2-1A	6.8	7.8	2.054	14.6		11.3	0.38
3/8/90 10:53	0	V2-1B	4.8	14.3	2.660	19.1	1610	1	1
3/8/90 14:06	151	V2-1B	5.4	12.7	2.542	18.1		1.13	0.89
3/8/90 17:35	360	V2-1B	6.5	11.4	2.434	17.9		1.35	0.8
3/8/90 22:40	665	V2-1B	7.2	9.9	2.293	17.1		1.5	0.69
3/9/90 8:08	1233	V2-1B	8.3	6.9	1.932	15.2		1.73	0.48
3/9/90 16:24	1729	V2-1B	9.4	4.7	1.548	14.1		1.96	0.33
3/10/90 7:08	2613	V2-1B	10.8	2.3	0.833	13.1		2.25	0.16
3/10/90 17:50	3255	V2-1B	11.3	1.4	0.336	12.7		2.35	0.1
3/8/90 10:57	0	V2-1C	5.8	12.9	2.557	18.7	5550	1	1
3/8/90 14:08	153	V2-1C	6.1	12.4	2.518	18.5		1.05	0.96
3/8/90 17:45	370	V2-1C	6.5	12.1	2.493	18.6		1.12	0.94
3/8/90 22:42	667	V2-1C	6.8	11.2	2.416	18		1.17	0.87
3/9/90 8:10	1235	V2-1C	7.3	9.2	2.219	16.5		1.26	0.71
3/9/90 16:26	1731	V2-1C	8.2	7.2	1.974	15.4		1.41	0.56
3/10/90 7:10	2615	V2-1C	9.5	4	1.386	13.5		1.64	0.31
3/10/90 17:52	3257	V2-1C	10.5	2.3	0.833	12.8		1.81	0.18

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	THC μL/L	Norm CO2	Norm O2
3/8/90 11:00	0	V2-2A	0.1	20.8	3.035	20.9	60	1	1
3/8/90 14:10	155	V2-2A	0.2	20.2	3.006	20.4		2	0.97
3/8/90 17:47	372	V2-2A	0.6	19.3	2.960	19.9		6	0.93
3/8/90 22:44	669	V2-2A	1.0	18.2	2.901	19.2		10	0.88
3/9/90 8:24	1249	V2-2A	1.9	15.7	2.754	17.6		19	0.75
3/9/90 16:28	1733	V2-2A	3.1	13.2	2.580	16.3		31	0.63
3/10/90 7:12	2617	V2-2A	4.4	9.2	2.219	13.6		44	0.44
3/10/90 17:54	3259	V2-2A	6.3	6.5	1.872	12.8		63	0.31
3/8/90 11:05	0	V2-2B	4.1	16.1	2.779	20.2	2430	1	1
3/8/90 14:12	157	V2-2B	4.4	15.2	2.721	19.6		1.07	0.94
3/8/90 17:49	374	V2-2B	5.0	14.1	2.646	19.1		1.22	0.88
3/8/90 22:46	671	V2-2B	5.8	12.7	2.542	18.5		1.41	0.79
3/9/90 8:26	1251	V2-2B	6.7	9.3	2.230	16		1.63	0.58
3/9/90 16:30	1735	V2-2B	7.7	7	1.946	14.7		1.88	0.43
3/10/90 7:14	2619	V2-2B	9.5	2.5	0.916	12		2.32	0.16
3/10/90 17:56	3261	V2-2B	10.5	0.7	-0.357	11.2			
3/8/90 11:10	0	V2-2C	6.0	13.6	2.610	19.6	5112	1	1
3/8/90 14:16	161	V2-2C	6.5	12.6	2.534	19.1		1.08	0.93
3/8/90 17:52	377	V2-2C	7.0	11.8	2.468	18.8		1.17	0.87
3/8/90 22:48	673	V2-2C	7.3	10.7	2.370	18		1.22	0.79
3/9/90 8:28	1253	V2-2C	7.8	7.8	2.054	15.6		1.3	0.57
3/9/90 16:32	1737	V2-2C	8.9	5.2	1.649	14.1		1.48	0.38
3/10/90 7:16	2621	V2-2C	10.3	1	0.000	11.3		1.72	0.07
3/10/90 17:58	3263	V2-2C	11.1	0	0.000	11.1		1.85	0
3/8/90 11:15	0	V2-3A	0.5	20.5	3.020	21	115	1	1
3/8/90 14:18	163	V2-3A	1.3	18.2	2.901	19.5		2.6	0.89
3/8/90 17:54	379	V2-3A	2.3	16.5	2.803	18.8		4.6	0.8
3/8/90 22:50	675	V2-3A	3.1	15	2.708	18.1		6.2	0.73
3/9/90 8:34	1259	V2-3A	4.2	12	2.485	16.2		8.4	0.59
3/9/90 16:34	1739	V2-3A	5.6	9.8	2.282	15.4		11.2	0.48
3/10/90 7:20	2625	V2-3A	7.0	6.4	1.856	13.4		14	0.31
3/10/90 18:00	3265	V2-3A	8.6	4.2	1.435	12.8		17.2	0.2
3/8/90 11:19	0	V2-3B	4.5	15.1	2.715	19.6	1150	1	1
3/8/90 14:20	165	V2-3B	4.9	13.9	2.632	18.8		1.09	0.92
3/8/90 17:56	381	V2-3B	5.6	13	2.565	18.6		1.24	0.86
3/8/90 22:52	677	V2-3B	6.2	11.8	2.468	18		1.38	0.78
3/9/90 8:36	1261	V2-3B	7.1	9.4	2.241	16.5		1.58	0.62
3/9/90 16:36	1741	V2-3B	8.0	7.5	2.015	15.5		1.78	0.5
3/10/90 7:22	2627	V2-3B	9.5	4.2	1.435	13.7		2.11	0.28
3/10/90 18:02	3267	V2-3B	10.6	2.4	0.875	13		2.36	0.16
3/8/90 11:23	0	V2-3C	6.8	12.1	2.493	18.9	3323	1	1
3/8/90 14:22	167	V2-3C	6.6	12.1	2.493	18.7		0.97	1
3/8/90 17:58	383	V2-3C	7.2	11	2.398	18.2		1.06	0.91
3/8/90 22:54	679	V2-3C	7.5	10	2.303	17.5		1.1	0.83
3/9/90 8:38	1263	V2-3C	8.2	7.5	2.015	15.7		1.21	0.62
3/9/90 16:38	1743	V2-3C	9.4	5.5	1.705	14.9		1.38	0.45
3/10/90 7:24	2629	V2-3C	10.8	2.2	0.788	13		1.59	0.18
3/10/90 18:04	3269	V2-3C	11.8	0.4	-0.916	12.2			

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	THC μL/L	Norm CO2	Norm O2
3/9/90 9:20	Blower for V3 off for shutdown test 4A								
3/9/90 8:55	0	V3 disch	2.7	17.5	2.862	20.2	895	1	1
3/9/90 11:30	130	V3 disch	2.5	17.3	2.851	19.8	719	0.93	0.99
3/9/90 16:40	440	V3 disch	2.9	17.3	2.851	20.2	654	1.07	0.99
3/10/90 7:35	1335	V3 disch	3.2	16.5	2.803	19.7	95	1.19	0.94
3/10/90 18:15	1975	V3 disch	3.4	15.9	2.766	19.3	32	1.26	0.91
3/11/90 3:00	2500	V3 disch	3.5	15.3	2.728	18.8	22	1.3	0.87
3/11/90 17:53	3393	V3 disch	3.8	14.7	2.688	18.5	7	1.41	0.84
3/12/90 8:15	4255	V3 disch	3.9	14.3	2.660	18.2	8	1.44	0.82
3/9/90 9:00	0	V3A	2.8	17.3	2.851	20.1	40.0	1	1
3/9/90 11:35	135	V3A	2.7	17.2	2.845	19.9	40.0	0.96	0.99
3/9/90 16:50	450	V3A	3.1	17.3	2.851	20.4	37.0	1.11	1
3/10/90 7:40	1340	V3A	3.1	16.5	2.803	19.6	7.0	1.11	0.95
3/10/90 18:20	1980	V3A	3.4	16.1	2.779	19.5	0.0	1.21	0.93
3/11/90 3:05	2505	V3A	3.4	15.5	2.741	18.9	1.0	1.21	0.9
3/11/90 18:10	3410	V3A	3.8	14.9	2.701	18.7	0.0	1.36	0.86
3/12/90 8:25	4265	V3A	3.8	14.4	2.667	18.2	1.0	1.36	0.83
3/9/90 9:05	0	V3B	2.9	17.2	2.845	20.1	65.0	1	1
3/9/90 11:40	140	V3B	2.8	17.2	2.845	20	50.0	0.97	1
3/9/90 17:00	460	V3B	3.1	17.2	2.845	20.3	31.0	1.07	1
3/10/90 7:45	1345	V3B	3.2	16.4	2.797	19.6	6.0	1.1	0.95
3/10/90 18:25	1985	V3B	3.3	15.9	2.766	19.2	2.0	1.14	0.92
3/11/90 3:10	2510	V3B	3.5	15.3	2.728	18.8	2.0	1.21	0.89
3/11/90 18:15	3415	V3B	3.8	14.8	2.695	18.6	2.0	1.31	0.86
3/12/90 8:30	4270	V3B	3.8	14.2	2.653	18	3.0	1.31	0.83
3/9/90 9:10	0	V3C	2.0	17.2	2.845	19.2	30.0	1	1
3/9/90 11:45	145	V3C	2.8	17.1	2.839	19.9	34.0	1.4	0.99
3/9/90 17:10	470	V3C	3.1	17.2	2.845	20.3	40.0	1.55	1
3/10/90 7:50	1350	V3C	3.2	16.4	2.797	19.6	10.0	1.6	0.95
3/10/90 18:30	1990	V3C	3.3	16	2.773	19.3	2.0	1.65	0.93
3/11/90 3:15	2515	V3C	3.5	15.4	2.734	18.9	1.0	1.75	0.9
3/11/90 18:20	3420	V3C	3.8	14.9	2.701	18.7	1.0	1.9	0.87
3/12/90 8:35	4275	V3C	3.8	14.2	2.653	18	2.0	1.9	0.83

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2	
4/24/90	13:00	Bowers off							
4/24/90	9:06	0	V1-1A	9.1	7.7	2.041	16.8	1	1
4/24/90	16:00	180	V1-1A	9.4	7.1	1.960	16.5	1.033	0.922
4/24/90	22:08	548	V1-1A	10.4	4.4	1.482	14.8	1.143	0.571
4/25/90	8:04	1144	V1-1A	11.5	1.4	0.336	12.9	1.264	0.182
4/25/90	16:17	1637	V1-1A	12	0.1	-2.303	12.1		
4/24/90	9:08	0	V1-1B	9.4	7.6	2.028	17	1	1
4/24/90	16:04	184	V1-1B	9.4	7.6	2.028	17	1	1
4/24/90	22:10	550	V1-1B	9.7	6.9	1.932	16.6	1.032	0.908
4/25/90	8:06	1146	V1-1B	10.4	4.6	1.526	15	1.106	0.605
4/25/90	16:18	1638	V1-1B	10.8	2.9	1.065	13.7	1.149	0.382
4/25/90	21:54	1974	V1-1B	11.5	1.8	0.588	13.3	1.223	0.237
4/24/90	9:10	0	V1-1C	9.6	7.5	2.015	17.1	1	1
4/24/90	16:06	186	V1-1C	9.5	7.5	2.015	17	0.99	1
4/24/90	22:12	552	V1-1C	9.8	7.1	1.960	16.9	1.021	0.947
4/25/90	8:08	1148	V1-1C	10.3	5.1	1.629	15.4	1.073	0.68
4/25/90	16:20	1640	V1-1C	10.8	3.3	1.194	14.1	1.125	0.44
4/25/90	21:56	1976	V1-1C	11.4	2.2	0.788	13.6	1.188	0.293
4/24/90	9:12	0	V1-2A	5.6	13.3	2.588	18.9	1	1
4/24/90	16:08	188	V1-2A	6.5	10.9	2.389	17.4	1.161	0.82
4/24/90	22:14	554	V1-2A	7.9	6.3	1.841	14.2	1.411	0.474
4/25/90	8:10	1150	V1-2A	9.5	2.2	0.788	11.7	1.696	0.165
4/25/90	16:22	1642	V1-2A	10.3	0		10.3		
4/24/90	9:14	0	V1-2B	6.3	12.1	2.493	18.4	1	1
4/24/90	16:10	190	V1-2B	7	11	2.398	18	1.111	0.909
4/24/90	22:16	556	V1-2B	7.8	8.9	2.186	16.7	1.238	0.736
4/25/90	8:12	1152	V1-2B	9.1	5.5	1.705	14.6	1.444	0.455
4/25/90	16:24	1644	V1-2B	10	3.1	1.131	13.1	1.587	0.256
4/25/90	21:58	1978	V1-2B	10.9	1.4	0.336	12.3	1.73	0.116
4/24/90	9:16	0	V1-2C	7.7	10.2	2.322	17.9	1	1
4/24/90	16:12	192	V1-2C	8.2	9.7	2.272	17.9	1.065	0.951
4/24/90	22:20	560	V1-2C	8.6	8.8	2.175	17.4	1.117	0.863
4/25/90	8:14	1154	V1-2C	9.3	6.2	1.825	15.5	1.208	0.608
4/25/90	16:26	1646	V1-2C	9.8	4	1.386	13.8	1.273	0.392
4/25/90	22:00	1980	V1-2C	10.8	2.3	0.833	13.1	1.403	0.225
4/24/90	9:18	0	V1-3A	4.6	14.2	2.653	18.8	1	1
4/24/90	16:14	194	V1-3A	6.3	11.2	2.416	17.5	1.37	0.789
4/24/90	22:24	564	V1-3A	7.8	8.5	2.140	16.3	1.696	0.599
4/25/90	8:16	1156	V1-3A	9.1	5.1	1.629	14.2	1.978	0.359
4/25/90	16:28	1648	V1-3A	10	2.9	1.065	12.9	2.174	0.204
4/25/90	22:02	1982	V1-3A	11.2	1.2	0.182	12.4	2.435	0.085
4/24/90	9:20	0	V1-3B	7.5	10.5	2.351	18	1	1
4/24/90	16:16	196	V1-3B	7.7	10.3	2.332	18	1.027	0.981
4/24/90	22:26	566	V1-3B	8.3	9	2.197	17.3	1.107	0.857
4/25/90	8:18	1158	V1-3B	9.3	6.2	1.825	15.5	1.24	0.59
4/25/90	16:30	1650	V1-3B	10	4.2	1.435	14.2	1.333	0.4
4/25/90	22:04	1984	V1-3B	10.8	2.8	1.030	13.6	1.44	0.267

TABLE D-1. IN SITU RESPIRATION DATA (CONTINUED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
4/24/90 9:22	0	V1-3C	8	10	2.303	18	1	1
4/24/90 16:18	198	V1-3C	8.2	9.9	2.293	18.1	1.025	0.99
4/24/90 22:28	568	V1-3C	8.7	9.1	2.208	17.8	1.088	0.91
4/25/90 8:20	1160	V1-3C	9.2	6.8	1.917	16	1.15	0.68
4/25/90 16:32	1652	V1-3C	9.8	4.6	1.526	14.4	1.225	0.46
4/25/90 22:06	1986	V1-3C	10.7	3.2	1.163	13.9	1.338	0.32
4/24/90 9:30	0	V2-1A	1.7	18.5	2.918	20.2	1	1
4/24/90 16:20	200	V2-1A	3.1	16.2	2.785	19.3	1.824	0.876
4/24/90 22:30	570	V2-1A	4.1	13.3	2.588	17.4	2.412	0.719
4/25/90 8:22	1162	V2-1A	5.4	10.5	2.351	15.9	3.176	0.568
4/25/90 16:34	1654	V2-1A	6.5	9	2.197	15.5	3.824	0.486
4/25/90 22:08	1988	V2-1A	7.7	6.5	1.872	14.2	4.529	0.351
4/26/90 8:20	2600	V2-1A	8.9	4.5	1.504	13.4	5.235	0.243
4/24/90 9:32	0	V2-1B	7.8	9.2	2.219	17	1	1
4/24/90 16:22	202	V2-1B	9	7	1.946	16	1.154	0.761
4/24/90 22:32	572	V2-1B	10.6	4.2	1.435	14.8	1.359	0.457
4/25/90 8:24	1164	V2-1B	11.9	1.9	0.642	13.8	1.526	0.207
4/25/90 16:35	1655	V2-1B	12.2	0.9	-0.105	13.1		
4/24/90 9:34	0	V2-1C	9.9	6.2	1.825	16.1	1	1
4/24/90 16:24	204	V2-1C	10.2	6.1	1.808	16.3	1.03	0.984
4/24/90 22:34	574	V2-1C	10.8	5	1.609	15.8	1.091	0.806
4/25/90 8:26	1166	V2-1C	11.5	2.6	0.956	14.1	1.162	0.419
4/25/90 16:36	1656	V2-1C	12.2	1.1	0.095	13.3	1.232	0.177
4/24/90 9:36	0	V2-2A	0.6	20.2	3.006	20.8	1	1
4/24/90 16:26	206	V2-2A	1.2	18.3	2.907	19.5	2	0.906
4/24/90 22:36	576	V2-2A	2.8	15.8	2.760	18.6	4.667	0.782
4/25/90 8:28	1168	V2-2A	4.2	11.9	2.477	16.1	7	0.589
4/25/90 16:38	1658	V2-2A	5.4	9.7	2.272	15.1	9	0.48
4/25/90 22:10	1990	V2-2A	6.5	7.8	2.054	14.3	10.83	0.386
4/26/90 8:22	2602	V2-2A	7.4	5.3	1.668	12.7	12.33	0.262
4/24/90 9:38	0	V2-2B	9.4	8.3	2.116	17.7	1	1
4/24/90 16:28	208	V2-2B	8.4	9.5	2.251	17.9	0.894	1.145
4/24/90 22:38	578	V2-2B	9.5	7.5	2.015	17	1.011	0.904
4/25/90 8:30	1170	V2-2B	10.6	3.9	1.361	14.5	1.128	0.47
4/25/90 16:40	1660	V2-2B	11.2	1.7	0.531	12.9	1.191	0.205
4/25/90 22:12	1992	V2-2B	12.4	0.4	-0.916	12.8		
4/24/90 9:40	0	V2-2C	12.8	3.3	1.194	16.1	1	1
4/24/90 16:30	210	V2-2C	12.6	4.5	1.504	17.1	0.984	1.364
4/24/90 22:40	580	V2-2C	12.7	3.7	1.308	16.4	0.992	1.121
4/25/90 8:32	1172	V2-2C	13.1	1.1	0.095	14.2	1.023	0.333
4/25/90 16:42	1662	V2-2C	13	0		13		
4/24/90 9:42	0	V2-3A	0.9	19.5	2.970	20.4	1	1
4/24/90 16:32	212	V2-3A	2.8	16.5	2.803	19.3	3.111	0.846
4/24/90 22:42	582	V2-3A	4.2	13.9	2.632	18.1	4.667	0.713
4/25/90 8:34	1174	V2-3A	5.5	10.3	2.332	15.8	6.111	0.528
4/25/90 16:44	1664	V2-3A	6.8	8.2	2.104	15	7.556	0.421
4/25/90 22:14	1994	V2-3A	7.6	7.2	1.974	14.8	8.444	0.369
4/26/90 8:24	2604	V2-3A	8.2	4.9	1.589	13.1	9.111	0.251

TABLE D-1. IN SITU RESPIRATION DATA (CONCLUDED)

mo/day/yr/time	Elapsed Time (min)	Location	CO2 (%)	O2 (%)	In O2	CO2+O2 (%)	Norm CO2	Norm O2
4/24/90 9:44	0	V2-3B	6.5	12.4	2.518	18.9	1	1
4/24/90 16:34	214	V2-3B	6.7	12	2.485	18.7	1.031	0.968
4/24/90 22:44	584	V2-3B	7.6	10.2	2.322	17.8	1.169	0.823
4/25/90 8:36	1176	V2-3B	8.8	6.8	1.917	15.6	1.354	0.548
4/25/90 16:46	1666	V2-3B	9.5	4.6	1.526	14.1	1.462	0.371
4/25/90 22:16	1996	V2-3B	10.6	3.4	1.224	14	1.631	0.274
4/26/90 8:26	2606	V2-3B	11.2	1.9	0.642	13.1	1.723	0.153
4/24/90 9:46	0	V2-3C	10.2	7.2	1.974	17.4	1	1
4/24/90 16:36	216	V2-3C	9.5	8.2	2.104	17.7	0.931	1.139
4/24/90 22:46	586	V2-3C	10	7.1	1.960	17.1	0.98	0.986
4/25/90 8:38	1178	V2-3C	10.8	4.1	1.411	14.9	1.059	0.569
4/25/90 16:48	1668	V2-3C	11.5	1.9	0.642	13.4	1.127	0.264
4/25/90 22:18	1998	V2-3C	12.4	0.8	-0.223	13.2		
4/24/90 9:55	0	V3A	1.5	19.2	2.955	20.7	1	1
4/25/90 8:40	1180	V3A	1.7	18.6	2.923	20.3	1.133	0.969
4/25/90 16:56	1676	V3A	2	18.4	2.912	20.4	1.333	0.958
4/26/90 8:32	2612	V3A	2.2	18.2	2.901	20.4	1.467	0.948
4/24/90 9:58	0	V3B	1.5	19.2	2.955	20.7	1	1
4/25/90 8:42	1182	V3B	1.8	18.6	2.923	20.4	1.2	0.969
4/25/90 16:58	1678	V3B	1.9	18.4	2.912	20.3	1.267	0.958
4/26/90 8:34	2614	V3B	2.2	18.2	2.901	20.4	1.467	0.948
4/24/90 10:00	0	V3C	1.6	19.2	2.955	20.8	1	1
4/25/90 8:44	1184	V3C	1.8	18.6	2.923	20.4	1.125	0.969
4/25/90 17:00	1680	V3C	1.9	18.4	2.912	20.3	1.188	0.958
4/26/90 8:36	2616	V3C	2.2	18.2	2.901	20.4	1.375	0.948
4/24/90 10:04	0	V4A	1.3	19.5	2.970	20.8	1	1
4/25/90 8:50	1190	V4A	1.3	19.3	2.960	20.6	1	0.99
4/25/90 17:02	1682	V4A	1.2	19.8	2.986	21	0.923	1.015
4/26/90 8:38	2618	V4A	1.5	19.3	2.960	20.8	1.154	0.99
4/24/90 10:06	0	V4B	1.4	19.4	2.965	20.8	1	1
4/25/90 8:52	1192	V4B	1.4	19.2	2.955	20.6	1	0.99
4/25/90 17:04	1684	V4B	1.3	19.6	2.976	20.9	0.929	1.01
4/26/90 8:40	2620	V4B	1.5	19.3	2.960	20.8	1.071	0.995
4/24/90 10:08	0	V4C	1.6	19.2	2.955	20.8	1	1
4/25/90 8:54	1194	V4C	1.5	19.2	2.955	20.7	0.938	1
4/25/90 17:06	1686	V4C	1.5	19.4	2.965	20.9	0.938	1.01
4/26/90 8:42	2622	V4C	1.6	19.2	2.955	20.8	1	1