N60028_000765
TREASURE ISLAND
SSIC NO. 5090.3.A

CLEAN LONG-TERM ENVIRONMENTAL ACTION NAVY (CLEAN I)
Northern and Central California, Nevada, and Utah
Contract Number N62474-88-D-5086
Contract Task Order 0199, Modification No. 9

Prepared for

DEPARTMENT OF THE NAVY
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FINAL BENCH-SCALE SOIL BIOREMEDIATION TREATABILITY STUDY REPORT

September 17, 1997

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ACRONYMS AND ABBREVIATIONS

BTEX	Benzene, toluene, ethylbenzene, and xylene
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
CTO	Contract Task Order
DI	Deionized
EFA West	Navy Engineering Field Activity West
EPA	United States Environmental Protection Agency
FS	Feasibility Study
FSP	Field Sampling Plan
FTS	Fire Training School
FWP	Final Work Plan
ft^3	Cubic feet
J&A	Jonas and Associates, Inc.
mg/kg	Milligrams per kilogram
mL	Milliliter
NAVSTA TI	Naval Station Treasure Island
NEX	Navy Exchange
NFESC	Naval Facilities Engineering Services Center
NFF	New Fuel Farm
N/P	Nitrate/phosphate
OVA	Organic Vapor Analyzer
PAH	Polynuclear aromatic hydrocarbon
PARCC	Precision, accuracy, representativeness, completeness, and comparability
ppm	Parts Per Million
PRC	PRC Environmental Management, Inc.
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RI	Remedial Investigation
SOP	Standard Operating Procedure
SVOC	Semivolatile Organic Compound

ACRONYMS AND ABBREVIATIONS (Continued)

TI	Treasure Island
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TPH-d	Total Petroleum Hydrocarbons as diesel
TPH-g	Total Petroleum Hydrocarbons as gasoline
TPH-mo	Total Petroleum Hydrocarbons as motor oil
TS	Treatability Study
USDA	United States Department of Agriculture
UST	Underground Storage Tank
VOC	Volatile Organic Compound
X-19/N/P	X-19/nitrate/phosphate
YBI	Yerba Buena Island

EXECUTIVE SUMMARY

Previous investigations at Naval Station Treasure Island (NAVSTA TI) have confirmed the presence of petroleum hydrocarbons in soils at several sites (04/19, 06, 10, 12, 14, 15, 17, 20, 22, and 25). These compounds are known substrates for microbiological growth, and are therefore potential candidates for bioremediation. As the remediation process moves forward at NAVSTA TI, various treatment technologies must be evaluated as possible remedial program options. The bioremediation treatability study described in this report was undertaken to evaluate applicability of this technology to treat soils containing petroleum hydrocarbons at NAVSTA TI.

Since bioremediation is less effective in degrading chlorinated hydrocarbons, herbicides, pesticides, and inorganics, soils affected with those chemicals are not considered prime candidates for bioremediation. This bioremediation treatability study focuses on soils from Sites 06, 14, 22, and 25, which primarily contain petroleum hydrocarbons. Soil samples were collected from those sites and augmented with two potential enhancement solutions. Analyses for various petroleum hydrocarbon constituents were conducted on the samples over a 16-week period and compared to unenhanced control samples.

The results indicate that petroleum hydrocarbon concentrations in the soil samples generally decline faster and to a greater degree when the samples are augmented with biological growth enhancements as compared to control samples. This suggests that bioremediation is a viable remedial technology for petroleum hydrocarbon contaminated soils at NAVSTA TI and should be considered during the development of remedial alternatives in the feasibility study and the corrective action plan (for the petroleum-only sites).

1.0 INTRODUCTION

Tetra Tech EM Inc. (TtEMI), formerly known as PRC Environmental Management, Inc. (PRC), was requested by the U.S. Department of the Navy, Naval Facility Engineering Command, Western Division, now Engineering Field Activity West (EFA West) to perform treatability studies (TS) on soils collected during the remedial investigation and feasibility study (RI/FS) at Naval Station Treasure Island (NAVSTA TI). EFA West has authorized TtEMI to conduct a TS and prepare a TS report under the Comprehensive Long-Term Environmental Action Navy Contract No. N62474-88-D-5086, Contract Task Order (CTO) No. 0199, Modification No. 9.

This draft TS report, which was prepared in partial fulfillment of the task order, describes the TS approach and discusses the results in accordance with the guidance provided in the "Guide for Conducting TS under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)" [U.S. Environmental Protection Agency (EPA) 1992b], and in the "How to Evaluate Alternate Cleanup Technologies for Underground Storage Tank Sites" publication (EPA 1995). This TS is designed to indicate whether bioremediation is a potentially viable remedial technology for soil at NAVSTA TI. Data generated during this TS will support the evaluation of bioremediation during technology screening in the FS/corrective action plan (CAP) process for treating soil at NAVSTA TI.

1.1 BACKGROUND

The NAVSTA TI facility background and sites selected for the TS are discussed in the following sections.

1.1.1 Facility Background

NAVSTA TI is located in San Francisco Bay, midway between San Francisco and Oakland. The facility consists of two contiguous islands: Treasure Island (TI), which is approximately 403 acres, and Yerba Buena Island (YBI), which is approximately 147 acres. TI is a manmade island constructed of materials dredged from San Francisco Bay and YBI is a natural island.

Military activities at NAVSTA TI date back to 1866, when the U.S. government took possession of YBI for defensive fortifications; TI had not yet been constructed. YBI was occupied by the U.S. Army until 1896, when the Navy assumed control. Since then, the Navy has operated the facility for various activities including the Naval Technical Training Center, waterfront facilities, troop and family housing, personnel support, Naval Readiness Command Region 20, a Navy brig, and a Navy and Marine Corps museum.

NAVSTA TI will close on September 30, 1997, when it will be turned over for use by other government or civilian groups.

1.1.2 Potential Contaminants in Soil

The potential contaminants in soil at NAVSTA TI are presented and summarized in the draft Phase I RI report and the summary of validated data for the Phase II RI (PRC 1993 and 1996b) report, and are summarized here. Soils and groundwater at NAVSTA TI contain several general categories of contaminants, which include volatile organic compounds (VOC) such as benzene, toluene, ethylbenzene, and xylenes (BTEX); semivolatile organic compounds (SVOC) such as polynuclear aromatic hydrocarbons (PAH); total petroleum hydrocarbons (TPH); inorganic constituents; and pesticides. After completing the draft initial screening of technologies report (PRC 1994), bioremediation was retained for treatment of BTEX, PAHs, and TPH for Sites 04/19, 06, 10, 12, 14/22, 15, `17, 20, and 25, as well as for other petroleum contaminated sites existing in other programs. Specifically, samples were collected at Sites 06, 14, 15, 20, 22, and 25, because they were determined to be representative of the soil waste types present at NAVSTA TI. These sites are described below.

Site 06. This site is the fire training school (FTS). Contaminated soils have been documented at the FTS during previous investigations and are most likely the result of fire training activities, as well as the four underground storage tanks (UST) that were also located at this site. Two USTs were removed in 1992, and the two remaining USTs were removed in 1995. TPH-diesel (TPH-d), TPH-motor oil (TPH-mo), TPH-gasoline (TPH-g), and several PAHs were detected in the soil during the Phase I and IIB RI (PRC 1993, 1996b).

Site 14. This site is the new fuel farm (NFF) and is the primary distribution and storage area for gasoline, oils, and fuel oils at NAVSTA TI. Contaminated soils and groundwater have been documented at the NFF during previous investigations. This contamination resulted from various pipeline and tank leaks and sludge disposal practices from 1943 onward. The ground surface at the fuel farm was paved in 1980, and sludge disposal and bleeding water from fuel farm tanks ceased. One UST, a 10,000-gallon steel diesel tank, was removed in 1992. Other tanks are aboveground, including two 210,000-gallon gasoline/diesel storage tanks (which were removed in 1995), one 50,000-gallon gasoline/diesel storage tank (which was removed in 1995), and seven 10,000-gallon unleaded gasoline storage tanks. Only two of the remaining tanks are in operation. Results of Phase I and IIB RI samples and analysis indicated the presence of TPH-d, TPH-g, TPH-mo, and benzene, toluene, ethylbenzene, and xylene (BTEX) in Site 14 soil samples (PRC 1993, 1996b).

Site 15. This site is the Old Fuel Farm which consisted of two aboveground 210,000-gallon fuel storage tanks that were later transferred to the NFF (Site 14). Based on available information, there is no history of spills associated with these tanks, but associated underground pipelines may have been abandoned without first draining the remaining fuel in the lines. During the Phase I RI, several PAHs were detected in soil samples (PRC 1993). TPH-d, TPH-g, and TPH-mo and several PAHs were detected in the soil samples collected during the Phase IIB RI (PRC 1996b).

Site 20. This site includes Building 225, which currently houses the Auto Hobby Shop. The site was used as the NAVSTA TI transportation center where vehicles were steam cleaned and degreased. As noted in the Phase I RI, potential sources of contamination include petroleum USTs, drums of hydraulic fluid, and waste fluids drained from vehicles (PRC 1993). TPH-g and TPH-mo were detected in the soil samples collected during the Phase IIB RI (PRC 1996b).

Site 22. The Navy exchange (NEX) service station has been used since about 1946. Six petroleum USTs (four 550-gallon, one 10,000-gallon, and one 25,000-gallon capacity) were removed in 1992. Their dates of installation and abandonment are not documented. Contaminated soils and groundwater were documented at the NEX service station during UST removal activities. This contamination resulted from spills at tank fill pipes and from leaking USTs and product pipes. Results of Phase I and Phase IIB

RI sampling and analysis indicate the presence of TPH-d, TPH-g, TPH-mo, and BTEX in Site 22 soil samples (PRC 1993, 1996b).

Site 25. This site is the Seaplane Maintenance Area located along the southeastern shore of TI. From 1943 to 1958, seaplanes were stored and maintained at this site. Waste materials generated by these operations may include aviation fuel, engine oil lubricants, and cleaning solvents. Three USTs were removed in May 1992 (PRC 1993). TPH-d, TPH-g, and PAHs were detected in the soil samples collected during the Phase IIB RI field investigations (PRC 1996b).

1.2 TREATMENT TECHNOLOGY DESCRIPTION

Soil Bioremediation

Bioremediation generally refers to the breakdown of organic compounds (contaminants) by microorganisms (bacteria and fungi) that use organic compounds as a carbon and energy source. The bioremediation processes convert the organic carbon to harmless end products (typically carbon dioxide, water, and additional biomass). The biodegradation of petroleum hydrocarbons is optimal under aerobic conditions in the presence of adequate primary nutrients such as nitrogen and phosphorous. Bioremediation of soil is therefore typically performed ex-situ where those elements are readily available or applicable.

Field application of bioremediation is an established technology and is in full-scale operation at numerous sites for remediation of soils contaminated with gasoline, diesel, jet fuel, PAHs, BTEX, and VOCs (EPA 1992a). It is well established that petroleum hydrocarbon compounds will be biologically degraded under optimal environmental conditions; however, under natural conditions (such as soil ecosystems), bioremediation is not always an effective remedy. Environmental and other factors can limit the biodegradation rate of the contaminants of concern. For this reason an aerobic ex-situ bench-scale TS was proposed to determine whether bioremediation is a viable treatment option for contaminated soils at NAVSTA TI sites.

1.3 SOIL TYPES

As described in the final work plan (FWP) (PRC 1996a), two soil waste types were identified for the TS by grouping the contaminants. Soil waste type I consisted of PAHs, TPH-d, and TPH-mo from Sites 15 and 20. Soil waste type II consisted of TPH-g, TPH-d, TPH-mo, PAHs, and BTEX from Sites 06, 14, 15, and 22. However, due to difficulties in identifying soil with the desired contaminants and that the contaminants may have degraded with time, the soil collected for the TS did not contain all the contaminants expected. Therefore, this TS report summarizes results for TPH-d and TPH-g contaminated soil. For further information, see Sections 2.2.2.2 and 2.6.

2.0 TREATABILITY STUDY APPROACH

This section presents test objectives for the bench-scale bioremediation TS for treating soils at NAVSTA TI sites, experimental design and procedures, test equipment and materials, sample and analysis procedures, data management, and deviations from the work plan.

2.1 TEST OBJECTIVES AND RATIONALE

The primary objectives of the bench-scale bioremediation TS were identified in the TS work plan (PRC 1996a) and are as follows:

- Evaluate whether bioremediation may effectively remediate hydrocarbon contaminated soils at NAVSTA TI sites
- Determine the ability of the bioremediation process to attain site target performance goals
- Evaluate the change in chemical concentration of the contaminants (such as TPH-g and TPH-d) to determine which constituents are most difficult to degrade
- Evaluate whether reductions in contaminant concentrations in NAVSTA TI soils are caused by biodegradation rather than abiotic processes such as volatilization
- Obtain design information required for the next level of testing if screening evaluation is successful

Since cleanup levels have not been established at NAVSTA TI, the Navy proposed the following three tier performance goals for evaluation purposes during this TS:

Contaminant(s)	Performance Goal		
	Tier 1 (mg/kg)	Tier 2 (mg/kg)	Tier 3 (mg/kg)
TPH-d and TPH-mo	1,000	500	200
TPH-g	1,000	500	200
PAH (each)	5	2.5	0.25
BTEX (each)	1	0.5	0.2

Notes:

mg/kg	Milligrams per kilogram
TPH-mo	Total petroleum hydrocarbons as motor oil
TPH-d	Total petroleum hydrocarbons as diesel
TPH-g	Total petroleum hydrocarbons as gasoline
PAH	Polynuclear aromatic hydrocarbon
BTEX	Benzene, toluene, ethylbenzene, and xylene

The lowest TPH performance goal (Tier 3) of 200 milligrams per kilogram (mg/kg) are the TPH cleanup level developed for the salt water ecological protection zone near the Bay at the San Francisco Airport. While the Navy considers this level to be conservative and does not consider it a performance goal suitable to conditions at NAVSTA TI, it is suitable for evaluating the bioremediation TS. The TPH performance goals for Tiers 1 and 2 were selected to be incrementally higher than Tier 3 and to span the range of possible cleanup levels.

The Draft RI Report Addendum No. 3, "Ecotoxicological Testing for the Development of Petroleum Screening Levels (PRC 1997)," combines detailed conservative toxicological analyses with modeling information to develop a total TPH screening level for soil of 430 mg/kg. This concentration is also used in this TS as a performance goal to assess efficacy.

Another performance goal of this TS was to determine if the bioremediation technology will be able to reduce the average contaminant concentration by at least 25 percent over a 16-week period. If all these criteria are met, bioremediation shall be considered a potential treatment technology for the soils at NAVSTA TI sites (EPA 1991).

2.2 EXPERIMENTAL DESIGN AND PROCEDURES

This section briefly describes the field sampling locations and sampling procedures for collecting soil samples for treatability testing. It also describes experimental design, test procedures, and laboratory analysis for the bench-scale bioremediation TS.

2.2.1 Experimental Design

To achieve project objectives, the TS was designed to last 16 weeks, or 112 days. Three tests were performed on the collected soil during this TS: (1) bioremediation with X-19, a commercially-available proprietary innoculant (X-19), Nitrate solution (N), and phosphate solution (P), (2) bioremediation with N/P enhancement, and (3) bioremediation without enhancement (control).

The TS included test soil preparation and sampling and analysis of soil samples collected from the test pans to record the concentrations of the chemicals of interest over time. Six time increments (0, 14, 27, 56, 84, and 112 days) were studied. Since remedy screening does not require a significant amount of replication in the test samples or the analytical tests performed (EPA 1992b), duplicate samples were only collected on days 0 and 112 by TtEMI and on day 27 by the TS subcontractor to assess laboratory analytical accuracy and precision. Field soil sampling, soil preparation, and treatability testing including test procedures and test monitoring are described in the subsequent sections. Sampling and analysis is described in Section 2.3.

2.2.2 Bulk Soil Sample Collection

Bulk soil samples were collected from various sites to represent TPH-affected soil found on NAVSTA TI. This section provides a brief description of sampling locations and sampling procedures used to obtain soil samples for treatability testing. The bench-scale soil bioremediation treatability study, final work plan (FWP) describes in detail the sampling objectives; the type, location, and number of samples to be collected; and the necessary equipment and procedures for collecting the samples (PRC 1996a). After collection of soils at NAVSTA TI sites, the composite samples were prepared in the field as described in Section 2.2.3.

2.2.2.1 Sampling Locations

Sampling locations and depths at Sites 06, 14, 15, 20, 22, and 25 were selected based on Phase I and Phase IIB RI soil analytical results (PRC 1993 and 1996b). Two composite samples were collected; one from NAVSTA TI Sites 15 and 20 and the second from Sites 06, 14, 22, and 25. Sampling points were chosen at locations where previous sampling identified elevated petroleum hydrocarbon concentrations.

2.2.2.2 Sampling Procedure

Field sampling followed the procedures provided in the final work plan (PRC 1996a). A minimum of approximately 1.5 cubic feet (ft^3) of soil was required for each test. Since a maximum of six tests were anticipated, a total of approximately 9 ft^3 of soil was collected to complete the testing for each soil type. The soil samples were collected by excavating test pits with a backhoe. Sample collection was conducted on August 1, 1996.

As discussed in Section 2.6, subsequent baseline analyses indicated that the composite sample collected from Sites 15 and 20 contained no detectable concentrations of petroleum hydrocarbons, while the samples collected from Sites 06, 14, 22, and 25 contained significant concentrations of TPH-g and TPH-d. The TS and this report, therefore, focus on those constituents in that sample.

The soil from NAVSTA TI was placed into stainless steel trays. Two full trays were collected for each of the three tests (X-19/N/P, N/P, and control soil with no enhancement). Dimensions of each stainless steel tray are 12.75 inches wide by 20.75 inches long by 5 inches deep. Soil from each site was placed into appropriate trays at a predetermined thickness to allow for the compositing of equal volumes at the laboratory and for the addition of X-19/N/P.

The subject composite soil sample was collected from Sites 06, 14, 22, and 25. For the X-19/N/P enhancement trays, one inch of soil was taken from the samples collected at each site for a total soil thickness of four inches. For the two N/P enhancement trays and two control trays, 1.25 inches of soil were taken from the samples collected from each site, for a total soil thickness of five inches. Whenever not accepting soil, each tray was kept cool and covered with a wax-based sealing wrap to minimize volatilization and retain intrinsic moisture.

After collecting soil from all the appropriate sites, the stainless steel trays with the soil were immediately transferred from NAVSTA TI to the Bioremediation Treatability Study Laboratory in Concord, California.

2.2.3 Bench-Scale Treatability Testing

The TS was performed in the Bioremediation Treatability Study Laboratory located in the BC Analytical Laboratory in Concord, California. The following sections describe the test procedures and test monitoring followed in the TS laboratory during the period from August 1, 1996 through November 22, 1996.

2.2.3.1 Test Procedures

After receiving the trays with soil in the TS laboratory on August 1, 1996, soil in each of the trays was composited. Mixing of soil in each tray was performed using a clean stainless steel trowel.

On August 2, 1996, N/P, X-19, and moisture were added to the soil in the trays in the laboratory. For N/P enhancement, the Bioremediation Treatability Study Laboratory provided one gallon each of NO_3 and PO_3, both at a concentration of 100 mg/L for nitrate and phosphate, respectively. The N/P solutions were placed into clean spray bottles for application to the soil. A third spray bottle was filled with deionized (DI) water. X-19 Biological Products provided a five gallon bucket of X-19 enhancement. The amount of X-19 added to each tray was based on the experience of the representative from X-19 Biological Products. Mixing of X-19, nitrate, phosphate, and soil from the trays was performed in a clean bucket under a laboratory hood, using a clean stainless steel trowel. The following procedures were performed on the soil:

- Approximately one inch (0.17 ft^3) of X-19 was mixed into the soil for each of the X-19/N/P enhancement trays, resulting in a 28 percent increase in the volume of soil. Approximately 600 milliliters (mL) NO_3 and 600 mL PO_3 were added to the X-19 soil mixture and homogenized. The amount of nitrate and phosphate added was based on the requirements considered appropriate by the representative from X-19 Biological Products
- 500 mL of NO_3 , 500 mL of PO_3 , and 200 mL DI water were added to each of the N/P enhancement trays and mixed into the soil

- 1,200 mL of DI water was added to the two control trays and was mixed for moisture augmentation

In each of the TS trays, moisture was measured using a Lincoln Irrigation Soil Moisture Meter and temperature was measured using an Oakton Temp Tester. After filling out a chain of custody record and labeling the sampling containers, the appropriate soil samples and duplicate samples were collected for day 0. Sampling time was recorded on the chain of custody record. Sampling jars were placed in coolers with chilled blue ice and transferred to the appropriate laboratories for analysis. All trays were covered with sealing wrap and placed back into locked metal cabinets and stored at room temperature in a darkened room.

Periodic measurements collected in the laboratory include moisture, temperature, and VOCs. After collecting initial moisture and temperature measurements on August 2, 1996, weekly measurements of soil moisture and temperature were recorded. Starting on August 2, 1996, and continuing thereafter during each sampling event (days 14, 27, 56, 84, and 112) headspace VOC measurements were made. The methodologies used to collect moisture, temperature, and VOC measurements are presented in Section 2.2.3.2 "Test Monitoring." Laboratory measurement results are presented in Table 1.

Soil moisture augmentation continued following the initial addition of DI water in each of the trays on August 2, 1996. After the collection of weekly moisture and temperature measurements, 25 mL of DI water were added to each tray. The amount of DI water added to each tray was based on a reasonable range in moisture measurements, the consistency of the soil, and a subjective determination by the representative from X-19 Biological Products. This subjective determination was based on the X-19 Biological Products representative's experience of optimal moisture content for the X-19 mixture in various soil types. After adding moisture to the soil in each tray, the trays were then covered with sealing wrap to retain the moisture in the soil.

Procedures used for soil sampling and analyses are discussed in Section 2.3 "Sampling and Analysis." Analytical results are summarized in Section 3.1 "Data Presentation."

2.2.3.2 Test Monitoring

Measurements of moisture, temperature, and headspace VOC were collected periodically in the laboratory. The procedures used to collect these measurements are presented as follows:

Moisture. Prior to collecting any measurement, the moisture meter was calibrated by saturating a small amount of soil from each tray. Moisture measurements were collected from four locations in each soil tray. Measurements were recorded as a range of values for each tray. Prior to augmentation of soil moisture, a total of three ranges in moisture measurements were made and recorded weekly, as shown in Table 1.

Soil Temperature. Soil temperature measurements were made weekly at two locations in each tray. Measurements were recorded with an accuracy of ± 1 degrees Fahrenheit (°F) as an average value for each of the regular and duplicate trays. A total of three average temperature measurements were recorded weekly, as shown in Table 1.

Laboratory Temperature. Starting on August 9, 1996 (day 7), the weekly range of temperature in the metal cabinet was recorded. Measurements were made in °F using a Dial Maximum/Minimum Thermometer. The thermometer displays the high and low temperature since the last resetting. After the measurements were collected, the thermometer high and low markers were reset to the ambient temperature in the cabinet.

Headspace Volatile Organic Compounds. During each soil sampling event, VOC concentrations were measured in the headspace above the soil. On August 3, 1996, the headspace measurement was collected using an OVM Model 580, with a 10.6 electron volt lamp. Subsequent measurements, starting on August 16, 1996, were collected using a Photovac Microtip. Both devices were calibrated using 100 parts per million (ppm) isobutylene prior to the collection of VOC measurements. Approximately 2.5 hours before the collection of a headspace VOC concentration, the sealing wrap was removed from each tray. After opening the trays to the atmosphere for 30 minutes, the trays were covered again with sealing wrap. After two hours, a small slit was cut in the sealing wrap and the OVM probe was placed into the headspace. VOC concentrations were measured in ppm and the maximum VOC measurement recorded.

2.3 SAMPLING AND ANALYSIS

Soil samples were collected and analyzed on the following days:

- August 2, 1996 — day 0
- August 9, 1996 — day 7
- August 16, 1996 — day 14
- August 29, 1996 — day 27
- September 27, 1996 — day 56
- October 25, 1996 — day 84
- November 22, 1996 — day 112

Sampling and analysis followed the FWP (PRC 1996a). Soil analysis was performed and managed by BC Analytical, a California- and Naval Facilities Engineering Service Center (NFESC)-certified analytical laboratory.

A summary of the analyses performed on the soil as defined in the FWP is presented in Table 2.

After each round of collection, samples were placed into a cooler containing chilled blue ice. The samples were then transferred to BC Analytical personnel. The Chain-of-Custody Record for the samples was signed by Jonas and Associates, Inc. (J&A), and BC Analytical personnel. For quality control on day 27, duplicate samples were collected and analyzed.

2.4 QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance/quality control (QA/QC) procedures designed to ensure the quality of the data collected during the TS were consistent with the QA/QC procedures described in the TS final work plan (PRC 1996a).

One set of duplicate samples was collected on day 27 for a QA/QC control check of the analyses performed and managed by BC Analytical. Except for plate count, which apparently can have significant variation in results, all of the day 27 QA/QC sample results were similar to the standard day 27 sample

results. An independent data validation was not conducted on the analytical results reported by BC Analytical.

The laboratory analytical data generated from the duplicate samples were validated according to procedures outlined in the Contract Laboratory Program (CLP), National Functional Guidelines for Organic Data Review (EPA 1994a), National Functional Guidelines for Inorganics Data Review (EPA 1994b), and the NAVSTA TI quality assurance project plan (QAPP) (PRC 1991). At each stage of the validation, qualifiers were assigned to the results in the electronic database according to the criteria, protocols, and definitions of the EPA guidelines and QAPP (PRC 1991). The split samples and data were analyzed by Quanterra Environmental Service, in Sacramento, California, and validated by TtEMI. Data were validated by reviewing and evaluating all analytical data for precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters.

Although some qualifiers were added to the data, a final review of the data set indicated that the data are of high overall quality. The data are generally consistent with existing guidelines for definitive data and are usable for the TS. The overall assessment of the sampling program, QA/QC data, and data validation results indicate that the data are generally of acceptable PARCC parameters. All supporting documentation and data are available upon request, including cursory and full validation reports.

2.5 DATA MANAGEMENT

Field activities for field bulk soil sampling were recorded in field notebooks, field data forms, and a project field log book. These field activities include test pit excavation, bulk soil sampling, soil field screening, and backfilling and restoration of test pit excavation areas. Field records are maintained in project files in the TtEMI San Francisco office.

Additionally, treatability test oversight and split sampling activities on days 0 and 112 of treatment at the subcontractor's testing facility were recorded separately in field log books. These log books are maintained in project files in the TtEMI San Francisco office. Laboratory analytical results for split samples are stored in project files in the TtEMI San Francisco office.

Data management for work performed in the TS laboratory include the recording of relevant information collected in the laboratory, proper labeling of analytical samples, documenting the chain of custody of laboratory samples for analyses, and the receipt of laboratory data sheets which have been reviewed and signed by appropriate personnel in the analytical laboratory. The chain-of-custody records for all sampling events are maintained in project files, as are the laboratory reports of analytical results, and the QA/QC laboratory documentation.

2.6 DEVIATIONS FROM THE WORK PLAN

Deviations from the FWP (PRC 1996a) are outlined below:

- Samples were not collected on the basis of PID readings because of malfunctioning of the instrument. All samples were collected on the basis of proximity to selected Phase I and IIB RI sampling locations
- The selected sample location at Site 20 - the Auto Hobby Shop was located approximately 3 to 5 feet east from the originally proposed location because a non-functioning car was parked over the proposed sample location
- The composite samples collected from Sites 15 and 20 (Soil Waste Type I), were found to contain no petroleum hydrocarbons above detection limits immediately after sample collection. Therefore, these samples are not discussed in this report
- The composite samples collected from Sites 06, 14, 22, and 25 (Soil Waste Type II), were found to contain no TPH-mo, PAHs, or BTEX significantly above detection limits immediately after sample collection. Therefore, those compounds are not substantially discussed in this report
- As stated in Attachment A-1 on page A-1 of the FWP, "The project is to be completed by November 21, 1996." This date was based on an earlier schedule. The sampling phase of the TS was completed on November 22, 1996
- On page 13, the FWP instructs, "Add X-19 additive at a mix ratio of approximately 30 percent by volume, plus a mild nitrate solution to two test pans." On August 2, 1996, during the preparation of the TS trays in the laboratory, the representative from Biological Products stated that in addition to nitrate solution, a phosphate solution should also be added to the X-19 soil mixture. For the trays with the X-19 soil mixture, 600 mL of PO_3 at a phosphate solution concentration of 100 mg/L was added along with the nitrate solution
- As stated in Attachment A-1 on page A-3 of the FWP, "Soil moisture will then be measured and, if necessary, raised to approximately 28 to 30 percent by volume." The

amount of moisture added to the soil in each tray was based on the experience of the representative from Biological Products with X-19. This amount was found to be less than the 28 to 30 percent presented in the Work Plan. The analytical results indicate moisture ranged from 7.6 to 19 percent, with an average of 11 percent. The decrease in moisture is considered appropriate due to the predominance of sand, which at 28 percent to 30 percent moisture can become saturated, resulting in anaerobic conditions

- As stated in Section 3.3.2 of the FWP, the mass of volatile constituents (including BTEX) volatilized during the treatment period was not estimated because concentrations of BTEX were low or not detected in the soil

3.0 RESULTS

The results of the TS, a discussion of biodegradation rates, and comparison of results to test objectives are presented and discussed in the following sections.

3.1 DATA PRESENTATION

Data for the TS include analytical results collected during six sampling rounds from August 2, 1996, through November 22, 1996 and the weekly measurements of temperature and moisture. BC Analytical managed and performed most of the analyses required for the study. Other laboratories include Soil and Plant Laboratory, Inc., for sieve analysis/clay content and Truesdail Laboratories, Inc., for hydrocarbon biodegraders. The following sections discuss the analytical results and laboratory measurements.

3.2 RESULTS

All the soil trays had heterotrophic bacteria plate counts. Initial plate counts were significantly elevated in the soil enhanced with X-19/N/P, with significantly lower plate counts in the N/P and control trays (Table 3). In general, plate counts remained elevated throughout the TS in the X-19/N/P soil trays, while plate count results for N/P soil trays did not exhibit a discernible trend.

Nitrogen and phosphorus concentrations were also elevated in the X-19/N/P enhanced soil compared to the N/P enhanced soil and the control soil (Table 3).

All of the soils were slightly basic in character. Average pH for the X-19/N/P enhanced soil was 7.95 (Table 3). The average pH for the N/P enhanced soil was 8.85 and the control tray had an average pH of 8.5.

Moisture content remained fairly constant in the X-19/N/P enhanced soil, ranging from 11 to 19 percent (Table 3). Moisture content for the N/P enhanced tray ranged from 8.6 to 13 percent. The control soil had moisture content ranging from 7.6 to 12 percent.

The TOC content in the control soil was measured at 140 mg/kg (Table 3).

Figure 1 presents TPH-g concentrations as a function of time for X-19/N/P and N/P enhanced soils and the control soils. TPH-g was initially detected in all the trays (Table 4). In the X-19/N/P enhanced soil, TPH-g concentrations decreased from 82 mg/kg at day 0 to 0.22 mg/kg on day 27. This represents a 99.7 percent decrease in TPH-g concentrations for the X-19/nitrate/phosphate enhanced soil. TPH-g was not detected in X-19/N/P enhanced soil for the day 56, 84, and 112 sampling events. For N/P enhanced soil, the initial TPH-g concentration of 450 mg/kg at day 0 decreased to 2.1 mg/kg on day 84, representing a reduction of 99.5 percent. TPH-g was not detected in the N/P enhanced soil on day 112. For the control soil, the initial TPH-g concentration of 280 mg/kg at day 0 decreased to 12 mg/kg at day 112, representing a reduction of 95.7 percent. These results indicate that the soil enhanced with X-19/N/P was the most effective in decreasing the concentration of TPH-g in the soil. The N/P enhanced soil and the control also experienced a rapid decrease in TPH-g concentrations. A majority of the reductions of the concentrations of TPH-g occurred in the first 27 days of the TS.

Figure 2 presents TPH-d concentrations as a function of time for X-19/N/P and N/P enhanced soils and control soils. TPH-d was detected in all samples (Table 4). In the X-19/N/P enhanced soil, the initial TPH-d concentration of 1,110 mg/kg decreased to 250 mg/kg detected on day 27 and was reduced to 100 mg/kg by day 112. This represents a 90.9 percent decrease in TPH-d for X-19/N/P enhanced soil. For the N/P enhanced soil, the initial TPH-d concentration of 2,100 mg/kg decreased to 600 mg/kg by day 112, representing a decrease of 71.4 percent. The control soil started with an initial TPH-d concentration of 1,400 mg/kg and remained fairly constant with a concentration of 1,200 mg/kg by

day 112. These results indicate that the soil enhanced with X-19/N/P was most effective in decreasing the concentration of TPH-d in the soil.

Baseline (day 0) and final concentrations (day 112) for TPH-d and TPH-g are summarized in the following table:

BASELINE AND FINAL CONTAMINANT CONCENTRATIONS

Soil Waste Enhancement	Contaminant Type	Contaminant Concentration (mg/kg)		Percent Reduction
		Day 0	Day 112	
X-19/N/P	TPH-d	1,100	100	90.9
	TPH-g	82	ND (0.05)	100
N/P	TPH-d	2,100	600	71.4
	TPH-g	450	ND (0.05)	100
Control soil (no enhancement)	TPH-d	1,400	1,200	14.3
	TPH-g	280	12	95.7

Notes:

ND	not detected (detection limit in parenthesis)
mg/kg	milligrams per kilogram
TPH-d	total petroleum hydrocarbons as diesel
TPH-g	total petroleum hydrocarbons as gasoline
X-19/N/P	X-19/nitrate/phosphate
N/P	nitrate/phosphate

Of the 17 metals analyzed in the sample collected at day 0 from the control soil, 10 metals had detectable concentrations (Table 5). These included arsenic (2.8 mg/kg), barium (6.4 mg/kg), beryllium (0.12 mg/kg), chromium (14 mg/kg), cobalt (5.2 mg/kg), copper (3.2 mg/kg), nickel (21 mg/kg), lead (11 mg/kg); vanadium (14 mg/kg), and zinc (14 mg/kg). All of these concentrations are relatively low and should not inhibit biodegradation.

The sieve analysis/clay analysis of the control soil showed 6.3 percent gravel (Table 6). The fraction finer than gravel was comprised of 96.1 percent sand, 0.8 percent silt, and 3.1 percent clay. The USDA soil classification for the sample is sand.

Weekly monitoring data collected at the TS laboratory included temperature, moisture, and volatile organics in the headspace above the soil (Table 1). The soil temperature ranged from 65°F to 73°F. Room temperature in the TS laboratory ranged from 60°F to 74°F. Moisture remained relatively constant in the soil, with elevated moisture in the X-19/N/P enhanced soil. The additional moisture in this soil was primarily due to adding 28 percent X-19, which contains a humic substrate that can retain moisture. The OVA measured initial VOC concentrations in the control trays of 251 ppm and 198 ppm, which decreased to 18 ppm and 25 ppm by day 112. For the X-19/N/P enhanced soil and N/P enhanced soil, the VOC concentrations measured with an OVA were 33 and 35 ppm at day 27. VOCs were not detected in subsequent measurements collected on days 56, 84, and 112. For the N/P enhanced soil, the VOCs detected with the OVA were measured at concentrations of 20 and 21 ppm at day 27, and decreased to 0 ppm by day 112.

3.3 BIODEGRADATION RATES

Degradation of most organic compounds in soil systems is typically described by monitoring their disappearance in a soil through time. A first order decay model can be used to approximate the temporal decay of organic compounds. This model assumes a linear relationship between time and concentration may be described by the equation given below:

$$\frac{dC}{dt} = -kC \tag{1}$$

where:

k	=	first order rate constant (1/Time)
C	=	contaminant concentration (mass/mass)

After integration of equation 1 and rearrangement of the integrated equation, equation 2 may be used to graphically determine the rate constant (k) as follows:

$$\ln\left(\frac{C_t}{C_o}\right) = -kt \tag{2}$$

where:

C_t = concentration of constituent remaining at time t

C_o = initial concentration of constituent

A plot of $\ln\left(\frac{C_t}{C_o}\right)$ versus t is linear with a slope of $-k$.

The rate constant is independent of the concentration of the constituent; therefore, the results of different studies can be compared. The rate constant can also be stated as the half-life of the constituent, which is the time required to reduce the initial concentration by 50 percent. It is calculated as follows:

$$T_{\frac{1}{2}} = \frac{0.693}{k} \tag{3}$$

where:

$T_{½}$ = half-life

Linear regression was used to fit the data in Table 4 for TPH-g and for TPH-d degradation using the above model (Equation 2). The least-square best fitting curves are superimposed on the data in Figures 3, 4, and 5 for TPH-g degradation, and in Figures 6 and 7 for TPH-d degradation. The estimated first-order decay constants for TPH-g are k = 0.066 for soil waste enhanced with X-19/N/P; k = 0.064 for soil waste enhanced with N/P; and k = 0.019 for control soil waste. The estimated first-order decay constants for TPH-d are k = 0.021 for soil waste enhanced with X-19/N/P and k = 0.008 for soil waste enhanced with N/P. The TPH-g half-lives corresponding to these rate constants are 10 days, 11 days, and 37 days for soil enhanced with X-19/N/P, N/P, and control samples, respectively. The TPH-d half-lives corresponding to these rate constants (computed using Equation 3) are 33 days and 87 days for soil enhanced with X-19/N/P and N/P, respectively.

Based on the biodegradation half-lives determined in this study, it is expected that reduction of TPH-g to less than the Tier 3 performance goal of 200 mg/kg would be quicker using either X-19/N/P or N/P enhancements than without enhancement. Reduction of TPH-d to less than Tier 3 cleanup level would be quicker using X-19/N/P enhancement than with N/P enhancement.

The estimated treatment times (using the rate constants determined in this study in equation 2) to achieve the Tier 3 performance goals for TPH-g and TPH-d degradation are presented below for a range of hypothetical initial concentrations in the soil at NAVSTA TI sites. The treatment times for TPH-g degradation are shorter and almost equivalent for both X-19/N/P and N/P enhancements. Unenhanced treatment will take a longer time but nevertheless achieve the desired performance goal. The treatment times for TPH-d are significantly lower for X-19/N/P enhancement than for N/P enhancement, which is in turn much shorter than unenhanced treatment. The estimated treatment times to achieve the Tier 3 goals for TPH-g and TPH-d are summarized below:

	Estimated Treatment Time (days) to Achieve Tier 3 Performance Goals				
	TPH-g			**TPH-d**	
Hypothetical Initial Concentration (mg/kg)	**X-19/N/P**	**N/P**	**No enhancement**	**X-19/N/P**	**N/P**
500	14	14	48	-	-
1,000	24	25	85	-	-
5,000	49	51	170	152	413
10,000	59	61	207	185	502
15,000	-	-	-	204	554

Notes:

mg/kg	milligrams per kilogram
N/P	nitrate/phosphate
TPH-g	total petroleum hydrocarbons as gasoline
TPH-d	total petroleum hydrocarbons as diesel
X-19/N/P	X-19/nitrate/phosphate

3.4 COMPARISON TO TEST OBJECTIVES

Both TPH-d and TPH-g concentrations achieved Tier 3 performance goals for the soil enhanced with X-19/N/P. The following are comparisons of the test results with performance goals and test objectives:

- For soil enhanced with X-19/N/P, the initial concentration of 1,100 mg/kg TPH-d, exceeding the Tier 1 performance goal, decreased to the Tier 3 performance goal of 200 mg/kg in approximately 27 days. This represents a decrease in concentration of 82 percent. By day 56, the TPH-d concentration was 60 mg/kg, representing an overall decrease of 95 percent. TPH-d concentrations increased to 100 mg/kg by day 112, however, the concentrations are still less than the Tier 3 performance goal

- For soil enhanced with N/P, the soil experienced a significant decrease in the TPH-d concentration. The initial TPH-d concentration of 2,100 mg/kg at day 0 decreased to a concentration of 600 mg/kg at day 112, representing a 71.4 percent decrease. However, the TPH-d concentrations did not meet the Tier 2 (500 mg/kg) and Tier 3 (200 mg/kg) performance goals. For the control soil (no enhancement), the TPH-d concentrations did not meet the Tier 2 and Tier 3 performance goals

- For soil enhanced with X-19/N/P, the initial TPH-g concentration of 82 mg/kg was less than the Tier 3 performance goal of 200 mg/kg. By day 27, the TPH-g concentration was 0.22 mg/kg, representing a decrease of 99.7 percent. For the N/P enhanced soil, the initial TPH-g concentration of 450 mg/kg, which is less than the Tier 2 performance goal, decreased to 17 mg/kg by day 14, and is less than the Tier 3 performance goal of 200 mg/kg. This represents an overall decrease in concentration of 96 percent. For the control soil, the initial TPH-g concentration of 280 mg/kg (less than the Tier 2 performance goal) decreased to 82 mg/kg (less than the Tier 3 performance goal) by day 14, representing a decrease in the concentration of 71 percent

- With the exception of the TPH-d in the control sample, all subject constituents experienced a decline in concentration of at least 25 percent

- With the exception of the TPH-d in the N/P and control samples, all subject constituents were below the petroleum screening level of 430 mg/kg of total TPH at the conclusion of the test

4.0 SUMMARY AND RECOMMENDATIONS

This section presents the summary and recommendations for the bench-scale bioremediation TS for treating soils at NAVSTA TI sites.

4.1 SUMMARY

The TS may be summarized as follows:

- Bioremediation using X-19/N/P enhancement is an effective treatment method to remediate TPH-g and TPH-d in contaminated soils at NAVSTA TI sites and can be used to attain site target cleanup levels

- The fact that inoculated and/or amended samples experienced a more rapid and complete decline in petroleum hydrocarbon concentrations than the control sample indicates that biological activity may be identified as the responsible remedial mechanism

- Based on the test procedures used and test results of the study, design information can be generated for bioremediation of TPH-d and TPH-g for pilot-scale or full-scale field application

- No soil elements including total metal concentrations of 96 mg/kg significantly impaired microbiological activity

- The treatment times for TPH-g degradation are almost same for both X-19/N/P and N/P enhancement, whereas the treatment times are longer for no enhancement. The treatment times for TPH-d are significantly lower for X-19/N/P enhancement than for N/P enhancement

- The enhancement of soil with X-19/N/P was effective in reducing TPH-d and TPH-g concentrations to levels which met Tier 3 performance goals and petroleum screening levels

- Soil pH and temperature were within the range generally considered acceptable for enhanced biological treatment of available organics

- Analytical data for plate count and hydrocarbon utilizing bacteria are not sufficient to evaluate the growth of bacterial population density on available organics and nutrients enhanced with X-19/N/P or enhanced with N/P

In summary, the TS results demonstrate that soil bioremediation with X-19/N/P is a viable remedial alternative for treating TPH-g and TPH-d in contaminated soils at NAVSTA TI sites. Enhancement of the site soils with N/P with adjustment of the soil moisture content would also be capable of degrading TPH-g and TPH-d in contaminated soils at NAVSTA TI sites. However, for TPH-d this approach requires a longer treatment period compared to X-19/N/P enhancement. The treatment of the various hydrocarbons in contaminated soils in ex-situ biopiles may be accomplished in one to seven months of operation using X-19/N/P enhancement. The actual treatment time will be a function of contaminant types, nutrient concentrations, temperature and moisture.

4.2 RECOMMENDATIONS

The following are recommendations based on the bioremediation TS:

- Enhancing soil with X-19/N/P or N/P is recommended for bioremediation of TPH-g
- Enhancing soil with X-19/N/P is recommended for bioremediation of TPH-d
- Include bioremediation as a treatment alternative for soils from NAVSTA TI that are contaminated with petroleum constituents. Collect additional data as necessary to perform technology comparisons and design calculations

5.0 REFERENCES

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TABLE 1

LABORATORY MEASUREMENTS
SOIL BIOREMEDIATION TREATABILITY STUDY
NAVAL STATION TREASURE ISLAND

Soil Amendment	Day	Date	Temperature °F	Moisture Percent	OVA VOCs ppm
X19, N, P	0	8/2/96	71	8 - 9	-
X19, N, P	7	8/9/96	71	8 - 9	-
X19, N, P	14	8/16/96	67	8 - 9	-
X19, N, P	21	8/23/96	65	8 - 9	-
X19, N, P	27	8/29/96	71/72	7 - 9	33/35
X19, N, P	35	9/6/96	65	7 - 9	-
X19, N, P	42	9/13/96	66	7 - 9	-
X19, N, P	49	9/20/96	68	7 - 9	-
X19, N, P	56	9/27/96	65	7 - 9	0.0/0.0
X19, N, P	63	10/4/96	68	7 - 9	-
X19, N, P	70	10/11/96	67/68	6 - 9	-
X19, N, P	77	10/18/96	69	7 - 9	-
X19, N, P	84	10/25/96	73	8 - 9	0.0/0.0
X19, N, P	91	11/1/96	71	7 - 9	-
X19, N, P	98	11/8/96	70/71	7 - 9	-
X19, N, P	105	11/15/96	68/69	6 - 9	-
X19, N, P	112	11/22/96	67	6 - 9	0.0/0.0
N, P	0	8/2/96	71	5 - 9	-
N, P	7	8/9/96	71/70	3 - 5	-
N, P	14	8/16/96	67	6 - 7	-
N, P	21	8/23/96	65	5 - 7	-
N, P	27	8/29/96	70/72	5 - 9	20/21
N, P	35	9/6/96	65	6 - 8	-
N, P	42	9/13/96	66	5 - 7	-
N, P	49	9/20/96	67	5 - 8	-
N, P	56	9/27/96	64/65	5 - 8	0.0/2.2
N, P	63	10/4/96	67/68	5 - 8	-
N, P	70	10/11/96	67	5 - 7	-
N, P	77	10/18/96	68	5 - 8	-
N, P	84	10/25/96	72	6 - 8	6.2/7.0
N, P	91	11/1/96	70	5 - 8	-
N, P	98	11/8/96	69/70	5 - 9	-
N, P	105	11/15/96	67/68	5 - 8	-
N, P	112	11/22/96	67/68	5 - 8	0.0/0.0
Control	0	8/2/96	71	5 - 9	-
Control	3	8/5/96	-	-	251/198
Control	7	8/9/96	70	3 - 5	-

TABLE 1 (Continued)

LABORATORY MEASUREMENTS
SOIL BIOREMEDIATION TREATABILITY STUDY
NAVAL STATION TREASURE ISLAND

Soil Amendment	Day	Date	Temperature °F	Moisture Percent	OVA VOCs ppm
Control	14	8/16/96	66/67	7 - 9	161/136
Control	21	8/23/96	64/65	5 - 8	-
Control	27	8/29/96	69/70	7 - 9	44/61
Control	35	9/6/96	65	5 - 8	-
Control	42	9/13/96	66	5 - 7	-
Control	49	9/20/96	67	5 - 8	-
Control	56	9/27/96	64/65	5 - 8	26/45
Control	63	10/4/96	67/68	4 - 7	-
Control	70	10/11/96	67	5 - 9	-
Control	77	10/18/96	68	5 - 8	-
Control	84	10/25/96	72	6 - 8	36/40
Control	91	11/1/96	69/70	6 - 8	-
Control	98	11/8/96	69	5 - 8	-
Control	105	11/15/96	68	5 - 8	-
Control	112	11/22/96	67	5 - 8	18/25
TS			**Δ Temp./week**		
Cabinet	**Day**	**Date**	**°F**		
--	7	8/9/96	65 - 71		
--	14	8/16/96	58 - 73		
--	21	8/23/96	57 - 65		
--	27	8/29/96	64 - 72		
--	35	9/6/96	64 - 70		
--	42	9/13/96	65 - 71		
--	49	9/20/96	66 - 72		
--	56	9/27/96	62 - 70		
--	63	10/4/96	65 - 70		
--	70	10/11/96	65 - 70		
--	77	10/18/96	66 - 72		
--	84	10/25/96	64 - 74		
--	91	11/1/96	66 - 72		
--	98	11/8/96	64 - 72		
--	105	11/15/96	62 - 70		
--	112	11/22/96	60 - 70		

TABLE 2

ANALYTICAL METHODS PERFORMED
SOIL BIOREMEDIATION TREATABILITY STUDY
NAVAL STATION TREASURE ISLAND

Analysis	Method	Day						
		0	7	14	27	56	84	112
Moisture	160.3	x	--	x	x	x	x	x
TPH-d	8015M	x	--	x	x	x	x	x
TPH-mo	8015M	x	--	x	x	x	x	x
TPH-g	8015M	x	--	x	x	x	x	x
PAHs	8270	x	--	x	x	x	x	x
BTEX	8020	x	--	x	x	x	x	x
Nitrogen	351.2	x	--	x	x	x	x	x
Phosphorus	365.4	x	--	x	x	x	x	x
Hydrocarbon Biodegraders	SM9215B/HUB	x	--	--	x	x	--	--
pH	9045	x	--	--	x	x	--	--
Sieve Analysis/Clay Content (control tray only)	USDA	x	--	--	--	--	--	--
Total Organic Carbon (control tray only)	9060M	x	--	--	--	--	--	--
Metals (control tray only)	6010, 7060[a], 7740[b], and 7471[c]	x	--	--	--	--	--	--

Notes:

'x'	Indicates analytical method performed
'--'	Indicates analytical method not performed
HUB	hydrocarbon-utilizing bacteria
TPH-g	total petroleum hydrocarbons as gasoline
TPH-d	total petroleum hydrocarbons as diesel
TPH-mo	total petroleum hydrocarbons as motor oil
PAH	polynuclear aromatic hydrocarbon
BTEX	Benzene, toluene, ethylbenzene, xylene
USDA	United States Department of Agriculture
a	arsenic by graphite furnace
b	antimony by graphite furnace
c	mercury by cold vapor atomic absorption

TABLE 3

ANALYTICAL RESULTS FOR PLATE COUNT, HYDROCARBON-UTILIZING BACTERIA, NITROGEN, PHOSPHORUS, pH, MOISTURE, AND TOTAL ORGANIC CARBON SOIL BIOREMEDIATION TREATABILITY STUDY NAVAL STATION TREASURE ISLAND

Sample I.D.	Day	Sampling Date	Matrix	Lab	Plate Count (9215B) CFU/g	HUB MPN/g	Nitrogen (351.2) mg/kg	Phosphorus (P/365.4) mg/kg	Total Phosphorus (P04/365.4) mg/kg	pH (9045) Units	Moisture (D2216) Percent	TOC (9060) mg/kg
X19, N, P												
D0-T2-X19	0	8/2/96	soil	BCA	4,500,000	-	2,300	500	1,530	8.1	13	-
D14-T2-X19	14	8/16/96	soil	BCA	-	-	2,400	750	2,300	-	12	-
D27-T2-X19	27	8/29/96	soil	BCA	5,000,000	230	2,600	510	1,500	7.9	11	-
3 (QA/QC)	27	8/29/96	soil	BCA	9,000,000	93	2,100	700	2,200	7.9	12	-
D56-T2-X19	56	9/27/96	soil	BCA	-	230,000	5,000	660	2,000	7.9	14	-
D84-T2-X19	84	10/25/96	soil	BCA	-	-	1,200	440	1,300	-	19	-
D112-T2-X19	112	11/22/96	soil	BCA	-	-	1,900	450	1,400	-	15	-
N, P												
D0-T2-NP	0	8/2/96	soil	BCA	350,000	-	77	300	910	8.6	11	-
D14-T2-NP	14	8/16/96	soil	BCA	-	-	220	420	1,300	-	8.6	-
D27-T2-NP	27	8/29/96	soil	BCA	28,000,000	930	170	390	1,200	9.1	7.6	-
2 (QA/QC)	27	8/29/96	soil	BCA	650,000	430	150	320	970	8.9	8.8	-
D56-T2-NP	56	9/27/96	soil	BCA	-	93,000	170	380	1,200	8.8	9.3	-
D84-T2-NP	84	10/25/96	soil	BCA	-	-	440	520	1,600	-	13	-
D112-T2-NP	112	11/22/96	soil	BCA	-	-	170	360	1,100	-	9.4	-

TABLE 3 (Continued)

ANALYTICAL RESULTS FOR PLATE COUNT, HYDROCARBON-UTILIZING BACTERIA, NITROGEN, PHOSPHORUS, pH, MOISTURE, AND TOTAL ORGANIC CARBON SOIL BIOREMEDIATION TREATABILITY STUDY NAVAL STATION TREASURE ISLAND

Sample I.D.	Day	Sampling Date	Matrix	Lab	Plate Count (9215B) CFU/g	HUB MPN/g	Nitrogen (351.2) mg/kg	Phosphorus (P/365.4) mg/kg	Total Phosphorus (P04/365.4) mg/kg	pH (9045) Units	Moisture (D2216) Percent	TOC (9060) mg/kg
CONTROL												
D0-T2-C	0	8/2/96	soil	BCA	120,000	-	88	190	580	9.0	11	140
D14-T2-C	14	8/16/96	soil	BCA	-	-	110	300	930	-	9.5	-
D27-T2-C	27	8/29/96	soil	BCA	17,000,000	7,500	89	200	610	8.3	7.6	-
1 (QA/QC)	27	8/29/96	soil	BCA	11,000,000	150	86	200	600	8.4	8.1	-
D56-T2-C	56	9/27/96	soil	BCA	-	23,000	110	280	870	8.4	9.8	-
D84-T2-C	84	10/25/96	soil	BCA	-	-	48	210	630	-	12	-
D112-T2-C	112	11/22/96	soil	BCA	-	-	80	220	660	-	8.0	-

Notes:

X19 X19 Soil Amendment

N, P Nitrogen, Phosphorous

BCA BC Analytical, Inc.

CFU Colony-Forming Units

HUB Hydrocarbon-Utilizing Bacteria in Most Probable Number/Gram. Plate Count and HUB performed by Truesdail Laboratories, Inc.

mg/kg Milligrams per kilogram

ND (0.2) Not Detected (laboratory detection limit in parenthesis)

TABLE 4

ANALYTICAL AND PERCENT REDUCTION RESULTS FOR TPH-GASOLINE AND TPH-DIESEL
SOIL BIOREMEDIATION TREATABILITY STUDY
NAVAL STATION TREASURE ISLAND

Sample I.D.	Day	Sampling Date	Matrix	Lab	TPH-Gasoline (8020/8015M) mg/kg	Reduction Percent	TPH-Diesel (8015M) mg/kg	Reduction Percent
X19, N, P								
D0-T2-X19	0	8/2/96	soil	BCA	82	0.0	1,100	0.0
D14-T2-X19	14	8/16/96	soil	BCA	40	51.2	600	45.5
D27-T2-X19	27	8/29/96	soil	BCA	0.22	99.7	250	77.3
3 (QA/QC)	27	8/29/96	soil	BCA	0.075	99.9	200	81.8
D56-T2-X19	56	9/27/96	soil	BCA	ND(0.5)	100.0	60	94.6
D84-T2-X19	84	10/25/96	soil	BCA	ND(0.05)	100.0	110	90.0
D112-T2-X19	112	11/22/96	soil	BCA	ND(0.05)	100.0	100	90.9
N, P								
D0-T2-NP	0	8/2/96	soil	BCA	450	0.0	2,100	0.0
D14-T2-NP	14	8/16/96	soil	BCA	17	96.2	870	58.6
D27-T2-NP	27	8/29/96	soil	BCA	4.1	99.1	300	85.7
2 (QA/QC)	27	8/29/96	soil	BCA	26	94.2	720	65.7
D56-T2-NP	56	9/27/96	soil	BCA	25	94.4	380	81.9
D84-T2-NP	84	10/25/96	soil	BCA	2.1	99.5	610	71.0
D112-T2-NP	112	11/22/96	soil	BCA	ND(0.5)	100.0	600	71.4
CONTROL								
D0-T2-C	0	8/2/96	soil	BCA	280	0.0	1,400	0.0
D14-T2-C	14	8/16/96	soil	BCA	82	70.7	1,100	21.4
D27-T2-C	27	8/29/96	soil	BCA	15	94.6	1,400	0.0

TABLE 4 (Continued)

ANALYTICAL AND PERCENT REDUCTION RESULTS FOR TPH-GASOLINE AND TPH-DIESEL
SOIL BIOREMEDIATION TREATABILITY STUDY
NAVAL STATION TREASURE ISLAND

Sample I.D.	Day	Sampling Date	Matrix	Lab	TPH-Gasoline (8020/8015M) mg/kg	Reduction Percent	TPH-Diesel (8015M) mg/kg	Reduction Percent
1 (QA/QC)	27	8/29/96	soil	BCA	35	87.5	1,300	7.1
D56-T2-C	56	9/27/96	soil	BCA	62	77.9	980	30.0
D84-T2-C	84	10/25/96	soil	BCA	47	83.2	1,600	–14.3
D112-T2-C	112	11/22/96	soil	BCA	12	95.7	1,200	14.3

Notes:

BCA	BC Analytical, Inc.
mg/kg	Milligrams per kilogram
ND(0.25)	Not Detected (laboratory detection limit in parenthesis)
QA/QC	Quality assurance/quality control
X19	X19 Soil Amendment
N, P	Nitrogen, Phosphorous
TPH	Total Petroleum Hydrocarbons

TABLE 5

ANALYTICAL RESULTS FOR METALS
SOIL BIOREMEDIATION TREATABILITY STUDY
NAVAL STATION TREASURE ISLAND

Sample I.D.	Day	Sampling Date	Matrix	Lab	Metals	Concentration (mg/kg)
D0-T2-C	0	8/2/96	Soil	BCA	Antimony, Sb	ND (10)
					Arsenic, As	2.8
					Barium, Ba	6.4
					Beryllium, Be	0.12
					Cadmium, Cd	ND (1)
					Chromium, Cr	14
					Cobalt, Co	5.2
					Copper, Cu	3.2
					Lead, Pb	11
					Mercury, Hg	ND (0.1)
					Molybdenum, Mo	ND (2)
					Nickel, Ni	21
					Selenium, Se	ND (0.4)
					Silver, Ag	ND (1)
					Thallium, Tl	ND (7)
					Vanadium, V	14
					Zinc, Zn	14

Notes:

mg/kg	Milligrams per kilogram
BCA	BC Analytical, Inc.
ND (0.1)	Not detected (laboratory detection limit in parenthesis)

TABLE 6

ANALYTICAL RESULTS FOR SOIL GRAIN SIZE SAMPLING
SOIL BIOREMEDIATION TREATABILITY STUDY
NAVAL STATION TREASURE ISLAND

Sample I.D.	Day	Sampling Date	Matrix	Lab	Gravel		Grain Size Fraction (Percent of Sample Passing Through 2 mm Screening)					USDA Soil Classification
							Sand			Silt (percent)	Clay (percent)	
					Coarse (percent)	Fine (percent)	Very Coarse (percent)	Coarse (percent)	Medium to Very Fine (percent)			
D0-T2-C	0	8/2/96	soil	SPL	1.2	5.1	7.0	21.1	68.0	0.8	3.1	Sand

Notes:

mm Millimeter

SPL Soil and Plant Laboratory, Inc.

USDA United States Department of Agriculture

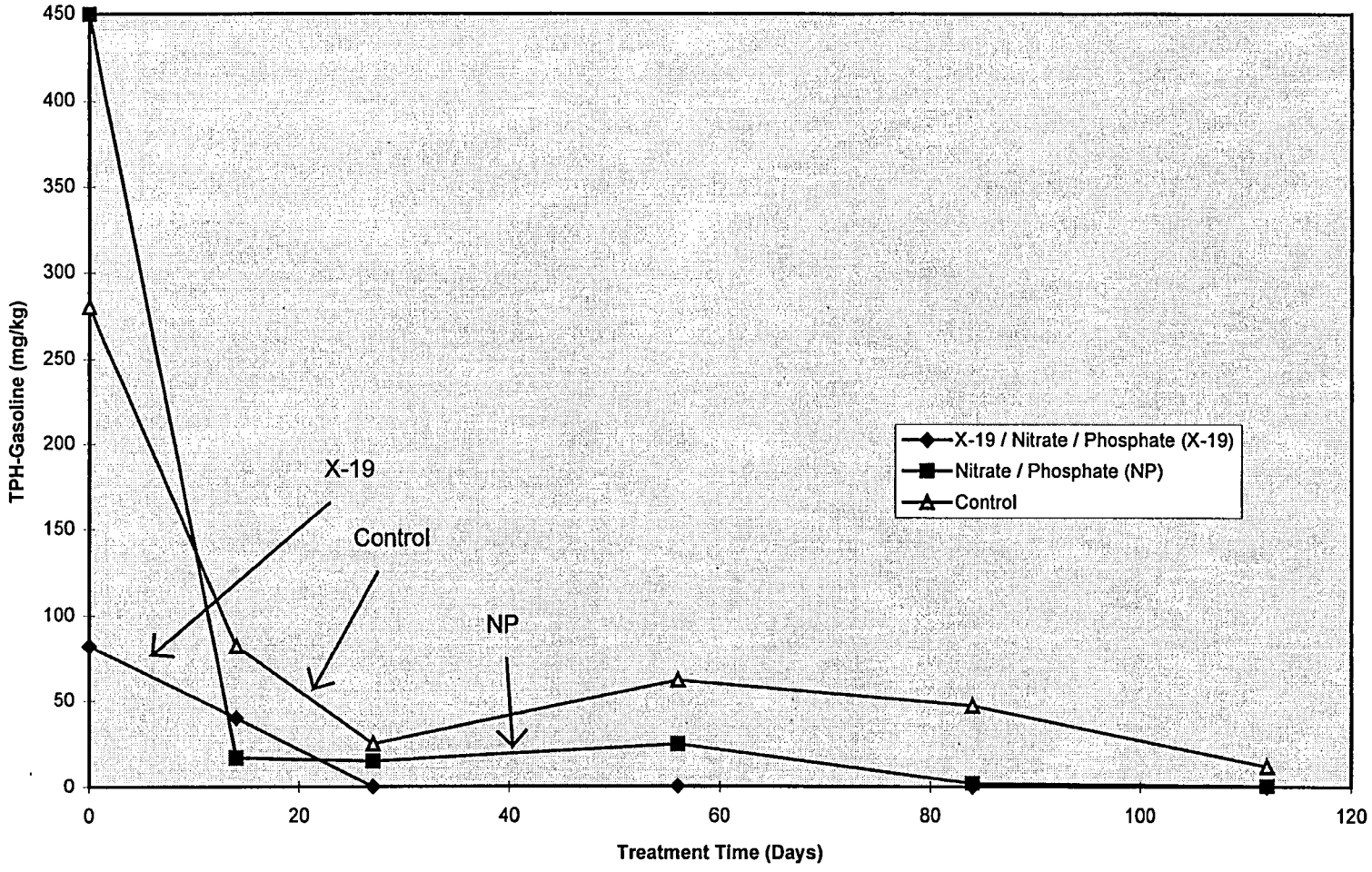

FIGURE 1. Residual TPH-Gasoline Concentrations as a Function of Time

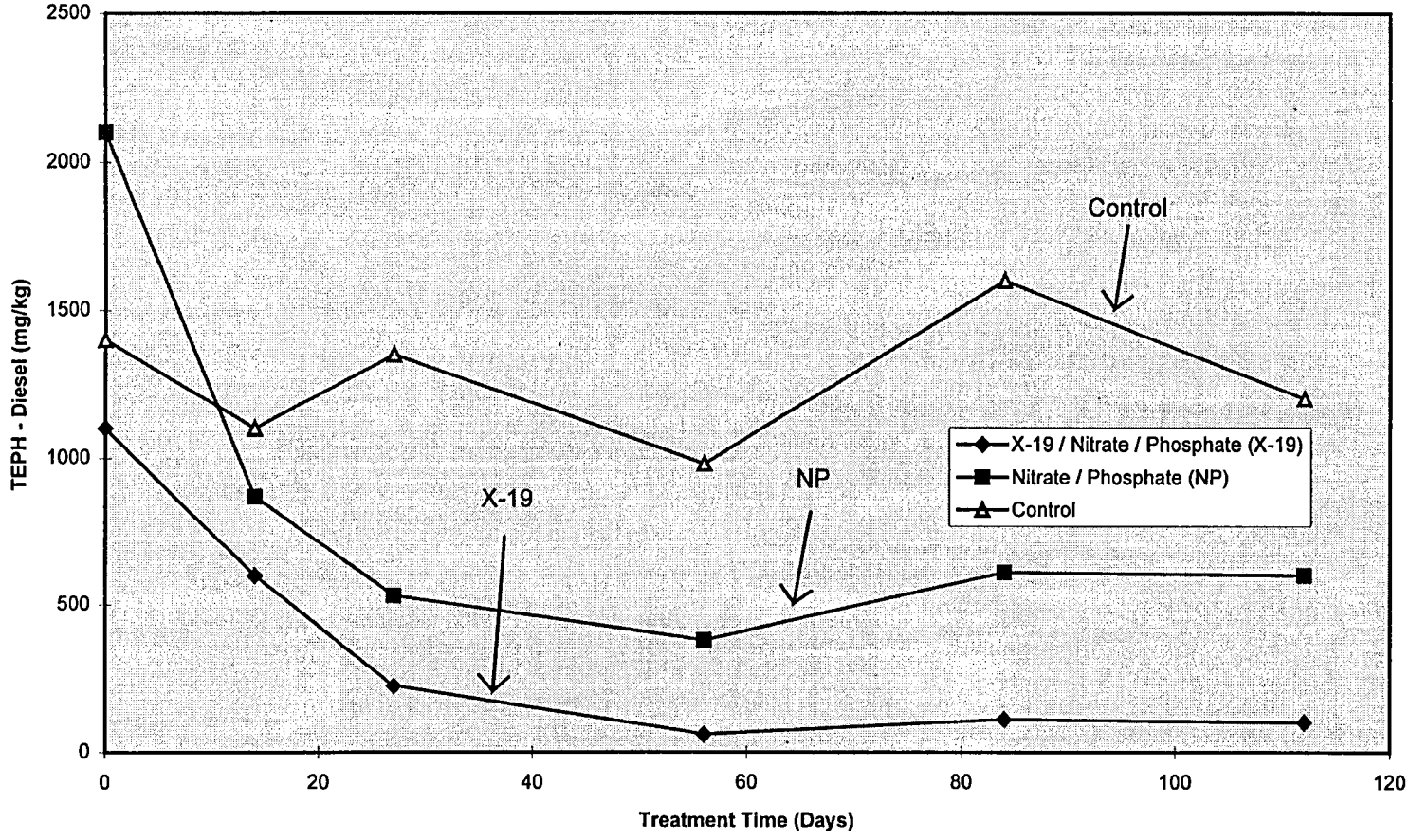

FIGURE 2. Residual TPH-Diesel Concentrations as a Function of Time

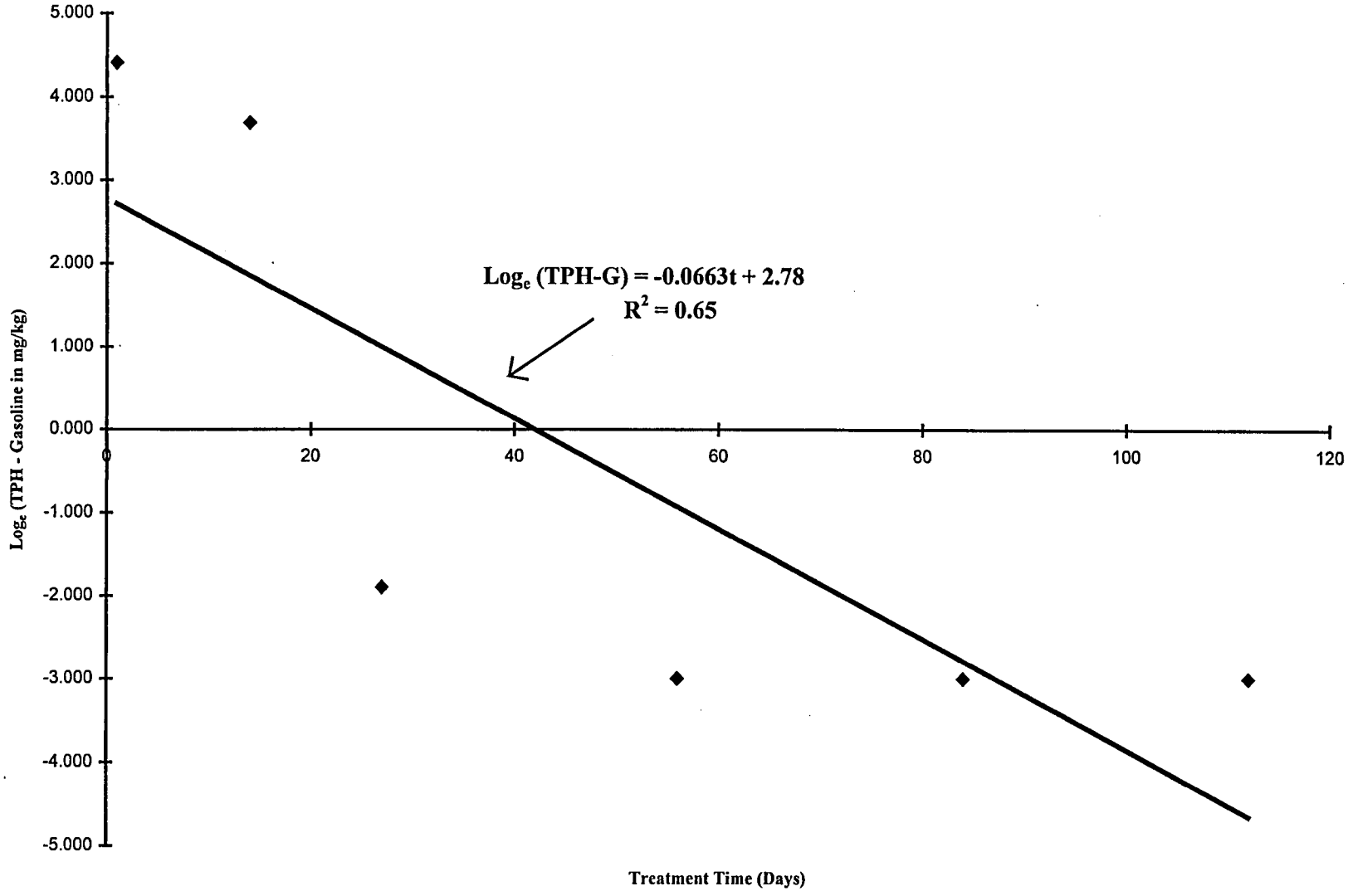

Figure 3. Biodegradation of TPH - Gasoline With X-19/Nitrate/Phosphate

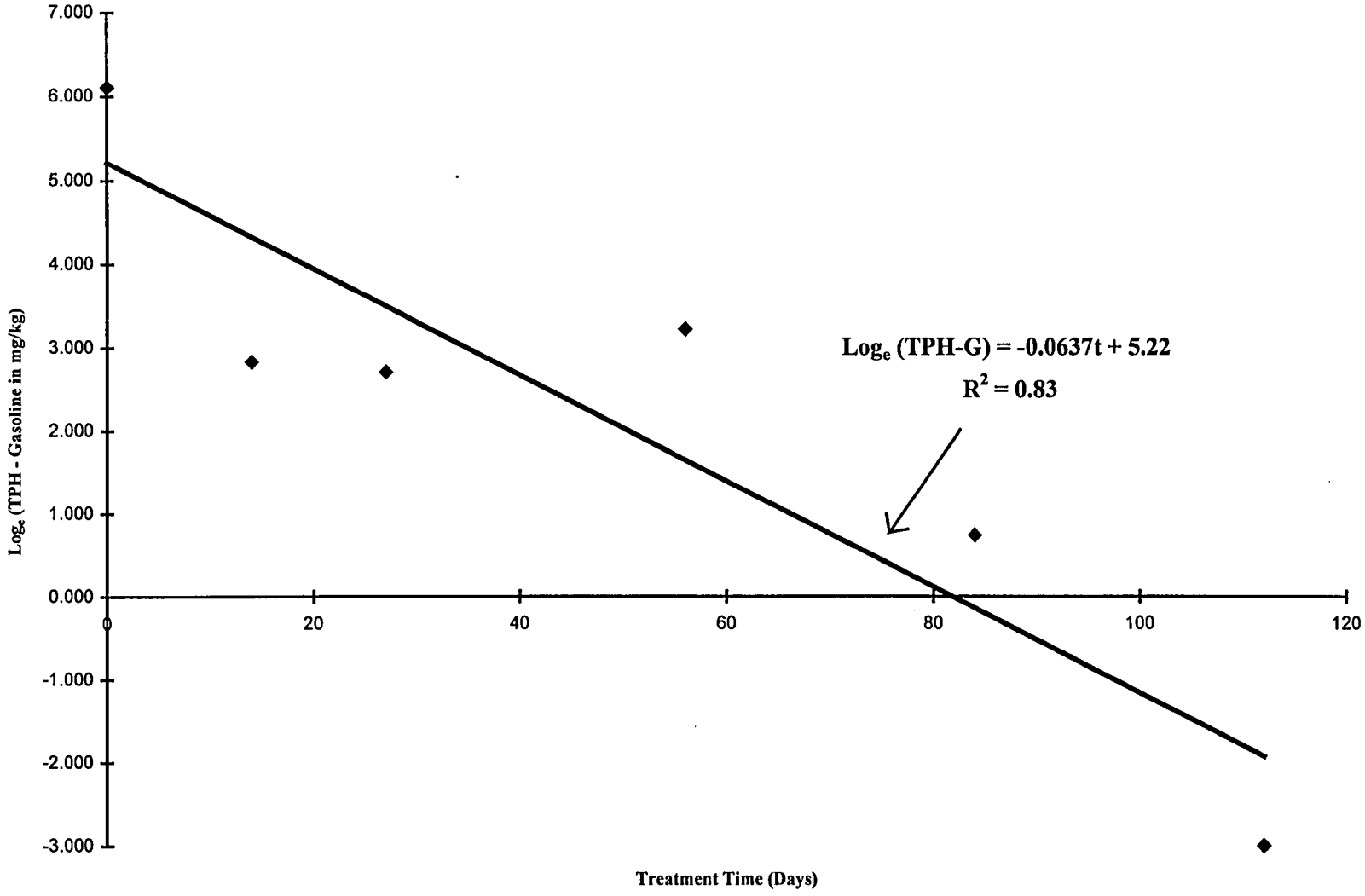

Figure 4. Biodegradation of TPH-Gasoline With Nitrate/Phosphate

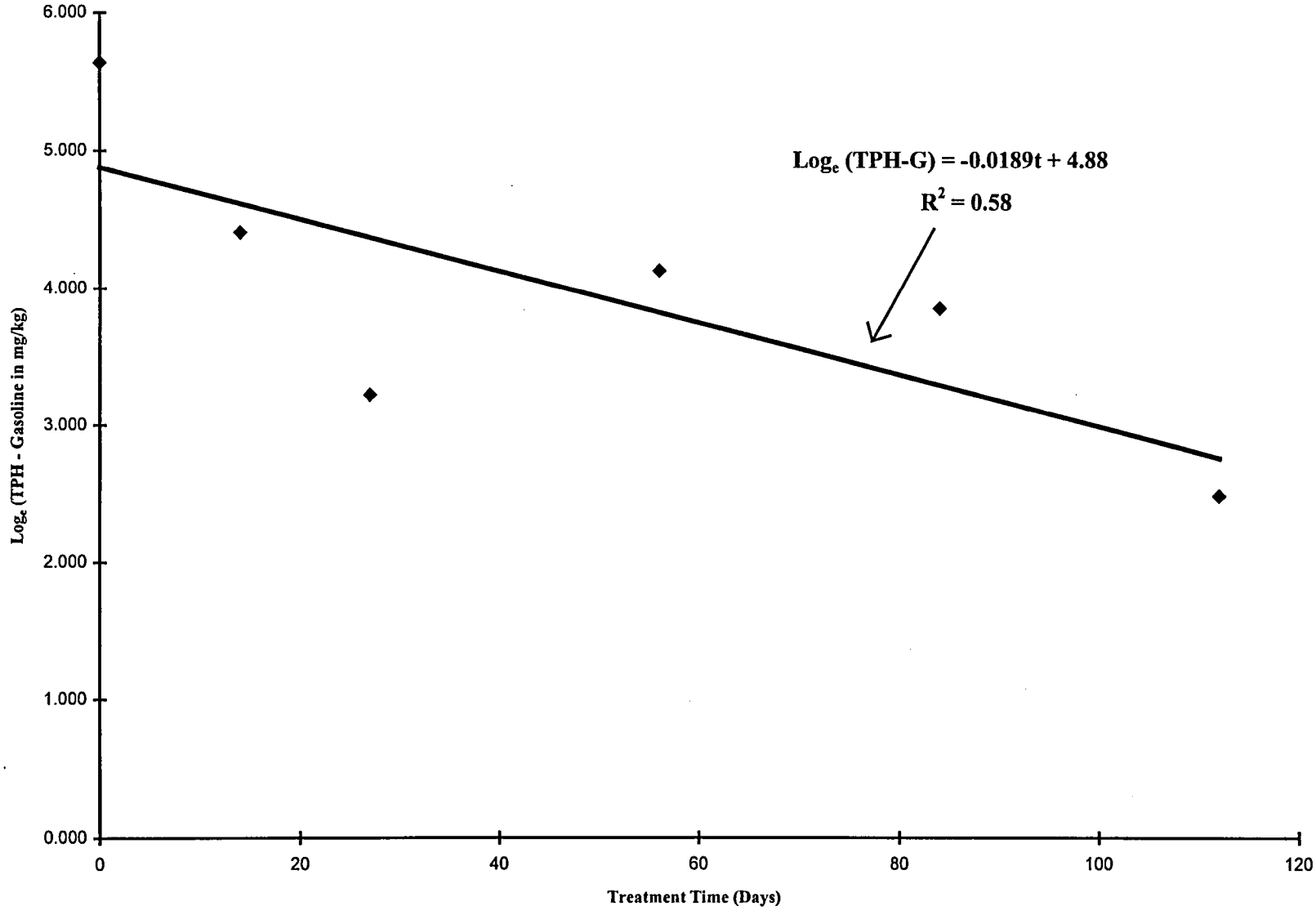

Figure 5. Biodegradation of TPH - Gasoline With Control

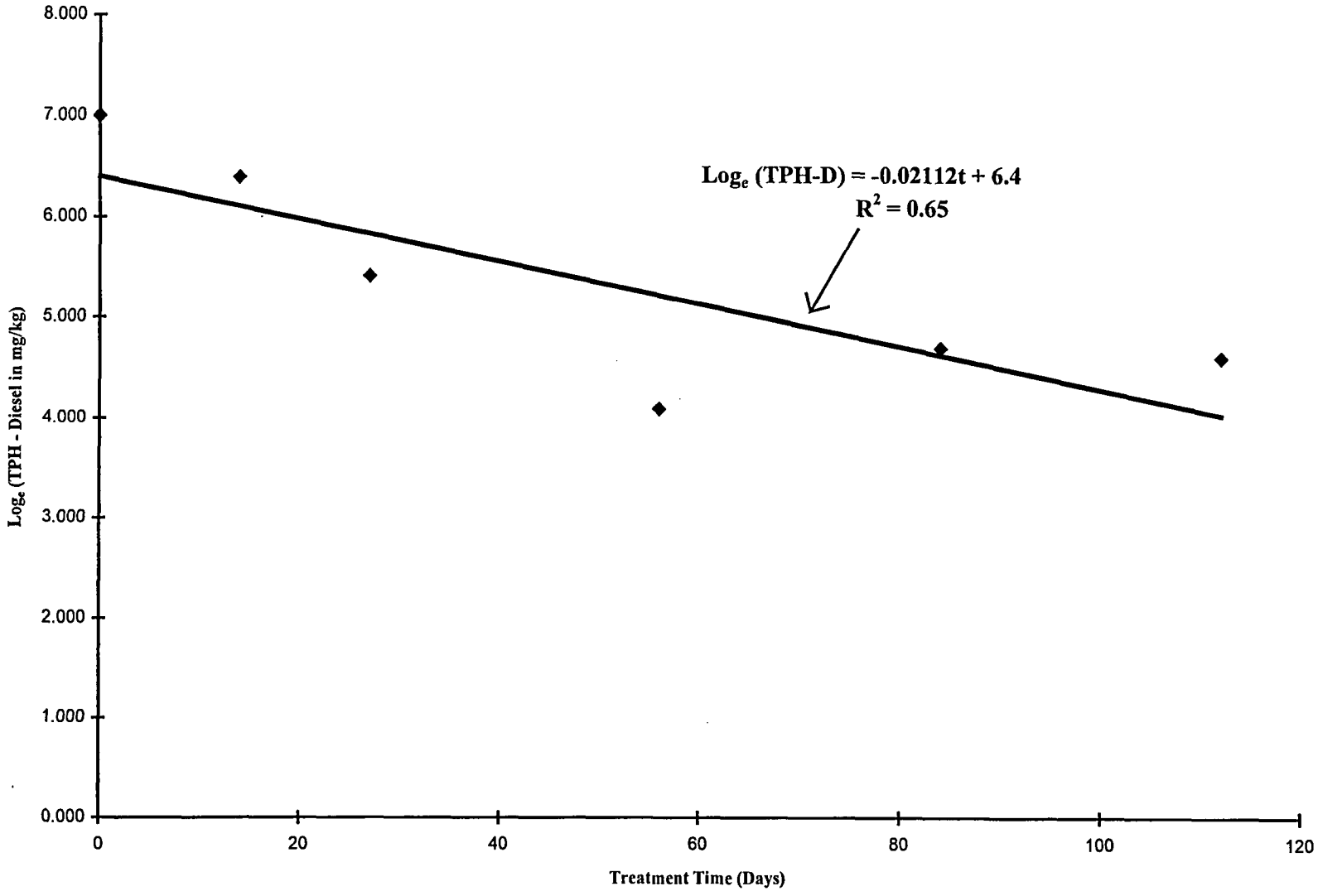

Figure 6. Biodegradation of TPH-Diesel With X-19/Nitrate/Phosphate

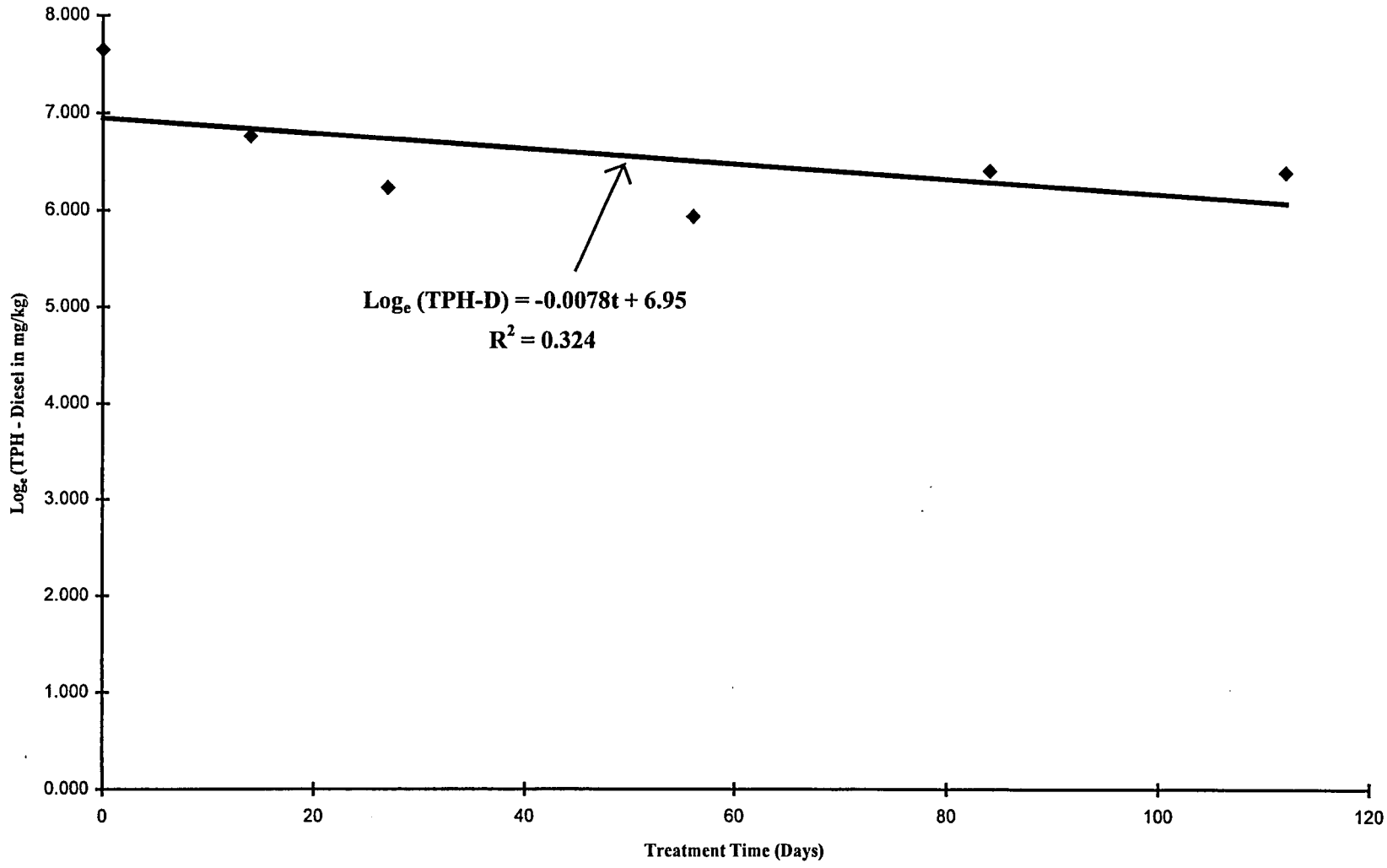

Figure 7. Biodegradation of TPH-Diesel With Nitrate/Phosphate

APPENDIX

RESPONSE TO REGULATORY AGENCY COMMENTS ON THE DRAFT BENCH-SCALE SOIL BIOREMEDIATION TREATABILITY STUDY REPORT

RESPONSE TO AGENCY COMMENTS ON THE DRAFT BENCH SCALE SOIL BIOREMEDIATION TREATABILITY STUDY REPORT

This document presents the responses of the Department of the Navy, Engineering Field Activity West (EFA WEST) to comments from the regulatory agencies on the "Draft Bench Scale Soil Bioremediation Treatability Study Report" for Naval Station Treasure Island (NAVSTA TI) dated July 8, 1997. The comments were submitted jointly by the California Department of Toxic Substances Control (DTSC) and the Regional Water Quality Control Board, San Francisco Bay Region (RWQCB).

GENERAL COMMENTS

1. **Comment:** **The bioremediation treatability study did not meet one of the original goals, which was to test the effectiveness of the process on representative contaminants, including motor oil, BTEX and polynuclear aromatic hydrocarbons. The report lacks an explanation of why additional soil samples were not obtained to meet this objective. Please provide explanation. (DTSC)**

   Response: Substrate sample locations for the treatability study (TS) were selected based on their proximity to areas of soil known to contain the target contaminants. Portions of the substrate samples were sent for baseline analysis while the TS began. By the time the Navy received the analytical results showing an absence of several target contaminants, the TS was already several weeks under way.

   Additionally, polynuclear aromatic hydrocarbons (PAHs) have only been detected in approximately 10 percent of soil samples in which TPH was also detected. Benzene, toluene, ethylbenzene, and xylene (BTEX) has only been detected at three of the NAVSTA TI installation restoration sites, while the contaminants most frequently encountered at NAVSTA TI include total petroleum hydrocarbons (TPH)-gas and TPH-diesel, which were present in the TS test soils. Consequently, the TS successfully covers the majority of contaminants in TI soils considered for bioremediation.

2. **Comment:** **Besides the decreasing concentrations of TPH, from the results of this treatability study, what is a good indicator that bioremediation is occurring. (RWQCB)**

   Response: The addition of biological nutrients or innoculants resulted in significant reductions of TPH-diesel concentrations, while the TPH-diesel control sample saw no decline in concentration over the duration of the study. This indicates that biological activity is the mechanism responsible for the concentration reductions.

3. **Comment:** **Alameda Naval Air Station (ANAS) presented the results of their treatability study for bioremediation, conducted by UC Berkeley, to interested parties on August 11, 1997. The Navy should share this information among the different bases. ANAS identified good indicators for bioremediation at their sites. (RWQCB)**

Response: Comment noted. The TI team will seek to obtain a copy of NAS Alameda's TS results.

SPECIFIC COMMENTS

4. **Comment:** **Introduction: The report should include a discussion of the proposed end use of the treated soil. What are the effects of the commercial product on potential end use(s)? Please also include the rationale for selecting this specific product X-19. (DTSC)**

Response: The treated soil would typically be used as backfill material in the excavations. The soil also could be used for landscaping or could be transported to an off-site recycling or landfill facility. X-19 biodegrades during the treatment process, resulting in additional organic content and slightly increased volume. It has been used commercially for many years in similar applications, is reasonably priced, and is readily available.

5. **Comment:** **Section 1.3, Soil Types: Please explain why additional samples containing the desired contaminants were not obtained. (DTSC)**

Response: See the response to Comment 1.

6. **Comment:** **Section 2.1, Test Objectives and Rationale: There are five primary objectives listed in this section, it [is] unclear whether the study addressed all of the objectives. (RWQCB)**

(A) Evaluate whether bioremediation may effectively remediate hydrocarbon contaminated soils at NAVSTA TI sites

- **Do we have enough data to assume bioremediation will work at all the TPH contaminated sites?**
- **Maybe motor oil and/or PAHs will be the drivers for cleanup, will follow up studies be performed to determine if those constituents will bioremediate using X19 and N/P.**

(B) Determine the ability of the bioremediation process to attain site target performance goal.

- **Is intrinsic (natural) bioremediation an option in obtaining the cleanup goals? If so, what are the biodegradation rates for intrinsic bioremediation?**

(C) Evaluate the change in chemical concentration of the contaminants to determine which constituents are most difficult to degrade.

- **This was not discussed in this document, please elaborate.**

(D) Evaluate whether reductions in contaminant concentrations in NAVSTA TI soils are caused by biodegradation rather than abiotic processes such as volatilization.

- **Please elaborate on this point as well.**

(E) Obtain design information required for the next level of testing if screen evaluation is successful.

- **What are the data gaps and next steps associated with this treatability study?**

Response:

(A) The fact that bioremediation was effective in this study shows that TI soils contain microorganisms capable of degrading TPH and are not significantly toxic. Since TI soils are generally homogenous, we can expect bioremediation to degrade TPH at all sites. Bioremediation has proven to be successful in degrading motor oil and PAHs at many sites around the country. Since we know that bioremediation is viable at TI, it is probable that those compounds will also be amenable to biodegradation at TI.

(B) The fact that TPH-diesel concentrations did not decline significantly in the control sample suggests that intrinsic bioremediation will not be an acceptably rapid option for those hydrocarbons or for longer or more complex hydrocarbons.

(C) Generally, TPH-diesel concentrations fell more slowly than TPH-gasoline, suggesting that the longer hydrocarbons are more difficult to degrade.

(D) Please see the response to Comment 2. Also, Table 1 in the TS report shows the airborne volatile organic compound (VOC) concentrations in the headspace above the sample trays at different time intervals throughout the TS. Organic volatilization was detected in all trays early on, but after day 27, volatilization ceased to occur at significant levels in the bioremediation test trays.

(E) The Navy believes that this TS presents an adequate basis for the inclusion of bioremediation as a treatment option to be considered in subsequent engineering analyses. The TS also presents sufficient general information applicable to full-scale bioremediation of TI soils, should it be a selected option.

7. **Comment:** **Section 2.2.1, Experimental Design: Please include a description of the commercial products - its physical characteristics, effects on moisture content, claims made by vendor, etc. Does the product increase bulk? If so, by how much? (DTSC)**

Response: According to the vendor, the product is similar to an organic mulch. It does not directly affect moisture content, but it does hold moisture better than many soils with which it is mixed. It does initially increase bulk, but biodegrades during the treatment process, leaving a small increase in bulk of less than 10 percent.

8. **Comment:** **Section 2.6, Deviations from the workplan: Please include an explanation of why a functioning PID instrument could not be obtained. (DTSC)**

Response: On the day of the substrate sample collection, the equipment supplier had no other such instruments that could be delivered to NAVSTA TI. To avoid delays, substrate samples were collected based on proximity to known contaminant concentrations.

9. **Comment:** **Section 3.2, Results: Please explain the apparent increases in TPH-d toward the end of the experiment. (DTSC)**

Response: Minor variations in contaminant concentrations are inevitable in the study trays. Each periodic analysis from any single tray is necessarily run on a different sample of soil, which will reflect that variability. The magnitudes of the occasional apparent increase in TPH concentrations fall within the normal range of that variability.

10. **Comment:** **Section 4.1, Summary: Please address the role of volatilization (see Objectives, page 5). (DTSC)**

Response: Table 1 shows the airborne VOC concentrations in the headspace above the sample trays at different time intervals throughout the study. Organic volatilization was detected early on, but after day 27, volatilization ceased to occur at significant levels in the bioremediation test trays, while the control trays continued to exhibit significant volatilization, albeit at a declining rate. These results are consistent with the observed declines in TPH concentrations in the bioremediation trays, and suggest that bioremediation plays a much more significant role than volatilization in TPH reductions.