APPENDIX A

SUMMARY REPORT
SOIL VAPOR EXTRACTION PILOT TEST

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

ATTACHMENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(Continued)

ACRONYMS AND ABBREVIATIONS

amsl	Above mean sea level
bgs	Below ground surface
CCl_4	Carbon tetrachloride
cfm	Cubic feet per minute
1,1-DCA	1,1-Dichloroethane
1,1-DCE	1,1-Dichloroethene
1,2-DCA	1,2-Dichloroethane
DTSC	California Department of Toxic Substances Control
EPA	U.S. Environmental Protection Agency
Freon 113	Trichlorotrifluoroethane
ft	feet
GAC	Granular activated carbon
H_2O	Water
in.	Inch or inches
in. H_2O	Inches of water
JPL	Jet Propulsion Laboratory
lb	Pound
lbs/hr	Pounds per hour
NASA	National Aeronautics and Space Administration
OU-2	Operable Unit 2 (On-Site Contaminant Source Investigation)
PVC	Polyvinyl chloride
RI/FS	Remedial investigation/feasibility study
ROI	Radius of influence
RORI	Radius of remedial influence
RPM	Remedial Project Manager
RWQCB	California Regional Water Quality Control Board, Los Angeles Region
SVE	Soil vapor extraction
TCE	Trichloroethene
VOC	Volatile organic compound

1.0 INTRODUCTION

Presented in this summary report are the results of a long-term soil vapor extraction (SVE) pilot test conducted in Operable Unit 2 (OU-2) at National Aeronautics and Space Administration's (NASA's) Jet Propulsion Laboratory (JPL) facilities. These facilities are located at 4800 Oak Grove Drive in Pasadena, California and are referred to as "JPL" throughout the rest of this document. Figures A.1-1 and A.1-2 are a Site Location Map and Site Facility Map for the site, respectively.

The test was conducted in the parking lot located between Buildings 18 and 79 (Figure A.1-2). Based on previous investigations at the site, subsurface soils in OU-2 are known to be impacted with volatile organic compound (VOC) vapors, primarily carbon tetrachloride (CCl_4). The Remedial Investigation/Feasibility Study (RI/FS) Work Plan (Ebasco, 1993) and its addenda (Foster Wheeler, 1996a and 1996b) identified the investigative work required to adequately characterize the impacted soil. The investigative work identified in the RI/FS Work Plan consisted of installation and sampling of nested soil vapor monitoring wells. The sampling of these wells has indicated the presence of VOC vapors including CCl_4, chloroform, Freon 113, trichloroethene (TCE), 1,1-dichloroethane (1,1-DCA), 1,2-dichloroethane (1,2-DCA), and 1,1-dichloroethene (1,1-DCE).

Based on the soil types at JPL and the nature and extent of contamination, in situ SVE appears to be a feasible technology for remediating the VOC impacted soils in OU-2. In situ SVE was one of the in situ technologies identified as a potential remedial technology for OU-2 in the 1993 RI/FS Work Plan. During ongoing Remedial Project Manager (RPM) meetings (September 4, 1997, and December 3, 1997) attended by representatives from NASA, JPL, Foster Wheeler Environmental Corporation (Foster Wheeler), the U.S. Environmental Protection Agency (EPA), the California Regional Water Quality Control Board, Los Angeles Region (RWQCB), and the California Department of Toxic Substances Control (DTSC), it was agreed that a pilot test would be conducted to confirm the feasibility of using in situ SVE at the site. In addition, the pilot test would also provide design criteria for implementing a full-scale SVE system at the site. The entire test, including setup and demobilization, was initially expected to require approximately 9 weeks to complete. The initial test was to run in two test phases, Test 1 and Test 2.

The test was started in April 1998 and conducted through June 1998 in accordance with the SVE pilot test work plan contained in Addendum Number 2 to the Field Sampling and Analysis Plan for Performing a Remedial Investigation at Operable Unit 2 (Foster Wheeler, 1998). Based on the results of the test it was decided to extend the test for an additional 9 months, as discussed during the RPM Meeting on July 16, 1998. During the extended portion of the test, noted as the third test phase (Test 3), the SVE system operated from November 1998 and continued, with exception of a few temporary shutdowns, through September 1999. Since then, the SVE system has been placed on standby.

Presented in this report are the scope of the pilot test, equipment used for the test, test procedures, and a summary of the data obtained from the test. A supplementary report will be submitted upon completion of the test.

1.1 PILOT TEST OBJECTIVES

The objectives of the SVE pilot test were to:

- Confirm the feasibility of using SVE at JPL.
- Estimate physical design parameters, such as SVE flow rate from the extraction well at different extraction vacuums, radius of influence (ROI) of a single extraction well, and permeability of the soil to air flow.
- Evaluate VOC concentrations in extracted vapor.

1.2 SCOPE OF WORK

To meet the above objectives, one pilot test well (VE-1) with three discrete screened intervals was installed. Twelve existing monitoring points (with multiple sample ports) in the vicinity of this well were used for monitoring purposes. Additional details regarding the test well and the monitoring points are provided in Section 2.0.

The scope of work required to meet the project objectives consisted of three test phases:

1. Test 1 – Short-term tests: three on individual screens, one on all three screens combined.
2. Test 2 – Long-term test on two combinations of screens: one on all three screens combined and one on Screens B and C combined.
3. Test 3 – This was a continuation of Test 2 on Screens B and C combined and Screen C separately.

In addition, VOC concentrations in individual screens and soil vapor monitoring points were monitored periodically to provide additional data pertaining to SVE effectiveness.

Test 1 was started on April 13, 1998, and was completed on May 7, 1998. Test 2 was started on May 11, 1998, and was completed on June 10, 1998. Test 3 was started on November 2, 1998, and was shut down on September 22, 1999. The SVE system is currently on standby.

1.3 REPORT ORGANIZATION

The remainder of the Report is organized into the following sections:

Section 2.0 – Equipment and Materials: describes the equipment and materials used for the test.

Section 3.0 – Test Procedures: describes the general test procedures performed during Test 1, Test 2, and Test 3.

Section 4.0 – Results and Data Analysis/Interpretation: describes the results of the data collected and various data analyses to meet the project objectives.

Section 5.0 – Conclusions: summarizes conclusions of the SVE pilot test.

Section 6.0 – References.

2.0 EQUIPMENT AND MATERIALS

This section provides descriptions of the extraction well, monitoring wells, and treatment/ sampling equipment used in the SVE pilot test.

2.1 WELLS

During the course of the SVE pilot test, two types of wells were used: a SVE well and monitoring wells. The location of these wells is shown in Figure A.1-2.

2.1.1 Extraction Well

A single vapor extraction test well (VE-1) was used for the SVE pilot test. It is located approximately at the center of the highest soil-vapor contamination. The well consists of three discrete screened intervals (i.e., three separate casings in the same borehole) with a bentonite seal between screens. The screens are designated shallowest to deepest as VE-1A (Screen A), VE-1B (Screen B), and VE-1C (Screen C), respectively. Each casing is constructed of Schedule 80 PVC, and is screened (0.020 inch slots) from 44 to 84 feet below ground surface (bgs), 94 to 134 feet bgs; and 145 to 185 feet bgs as shown in Figure A.2-1. Screens A, B, and C each have inside diameters of 2 inches. The annular space between the screens and the borehole is backfilled with Lonestar RMC® No. 3 sand, and the annular space between the blank casing and the borehole is filled with Enviroplug® No. 16 bentonite granules.

2.1.2 Monitoring Wells

Twelve soil vapor monitoring wells (SVW-25, -26, -27, -28, -32, -33, -34, -35, -36, -37, -38, and -39) were used for monitoring (Figure A.1-2). Each well contains discrete depth-specific monitoring points. These were used to monitor vacuum responses and to collect depth-specific soil vapor samples during the test. In total, there were 110 depth-specific monitoring points available. However, because of the fluctuating water table and other unknown factors, some of the probes were plugged and, therefore, were not continuously monitored. Also, access to some of the soil vapor monitoring wells was not always available.

2.2 EXTRACTION/TREATMENT EQUIPMENT

The following subsections provide a description of the extraction/treatment equipment. Figure A.2-2 shows a piping and instrumentation diagram for the pilot test equipment.

2.2.1 Blower Package

Tests 1 and 2

Because of restrictions imposed by the South Coast Air Quality Management District (SCAQMD) Permit to Operate (PTO) (Multiple Locations Permit), extraction blowers operating at the site were limited to a maximum flow rate of 200 cubic feet per minute (cfm) per unit. Hence, two units were used in parallel during the last week of Test 1 and for the entire duration of Test 2. Both extraction systems met the following specifications:

- One trailer mounted, one skid mounted.
- Common 50-gallon knockout tank, level switch, and safety interlock to shut down blower for high water level.
- Vacuum blower, maximum flow 200 cfm, maximum vacuum equivalent to 10 inches of mercury. Blowers 1 and 2 operated at a maximum flow rate of 200 cfm and 100 cfm, respectively.
- Dilution air valve and recirculation air valve to regulate vacuum and flow.

Test 3

For Test 3, the above-mentioned equipment was replaced with a single 20-horsepower positive displacement blower package (skid-mounted). Temporary power connections were provided by JPL.

2.2.2 Treatment System

Tests 1 and 2

The treatment system in Tests 1 and 2 consisted of two 1,000-pound (lb) vapor-phase granular activated carbon (GAC) vessels in series per blower unit (four vessels total). This met the vendor's SCAQMD PTO requirements.

Test 3

The treatment system in Test 3 consisted of two parallel trains of two 2,000-lb vapor-phase GAC vessels in series (four vessels total). In May 1999, the vapor-phase GAC vessels were replaced with vapor-phase GAC vessels fitted with reinforcement boards to withstand higher vacuums.

2.3 SAMPLING/TESTING EQUIPMENT

Various sampling/testing equipment was used for the test, as follows:

- Flow Meter – to measure extracted flow rates.
- Flame Ionization Detector – to analyze extracted soil vapors and treated effluent.

- Tedlar Bags/Summa Canisters – to collect vapor for laboratory analyses.
- Sample Pumps – to collect soil vapor samples.
- Vacuum Gauges – to measure vacuums.
- Vacuum Chamber – to collect vapor samples from the extraction wells and piping while the system was in operation, without contaminating the sample pump.

3.0 TEST PROCEDURES

A general outline of the procedures followed during the performance of Tests 1, 2, and 3 are provided in the following subsections.

3.1 TEST 1 PROCEDURE

Test 1 consisted of applying a vacuum to each of the three-screened intervals of the extraction well individually and all three screens combined (four runs total). During each run, applied vacuum levels were varied on a day-to-day basis. Each vacuum level was applied for an 8-hour day, requiring each run 1 week to complete (baseline sampling/monitoring was performed on day 5). Test 1 ran for 4 weeks total. The vacuum application schedule is further outlined below.

Week	Screen	Day 1	Day 2	Day 3	Day 4
1	VE-1A	Maximum Vacuum	75 percent Maximum Vacuum	50 percent Maximum Vacuum	25 percent Maximum Vacuum
2	VE-1B	Maximum Vacuum	75 percent Maximum Vacuum	50 percent Maximum Vacuum	25 percent Maximum Vacuum
3	VE-1C	Maximum Vacuum	75 percent Maximum Vacuum	50 percent Maximum Vacuum	25 percent Maximum Vacuum
4	VE-1ABC	Maximum Vacuum	75 percent Maximum Vacuum	50 percent Maximum Vacuum	25 percent Maximum Vacuum

Soil vapors were extracted using a single 200 cfm blower and treated using two 1,100-pound carbon vessels in series. Two blowers (an additional 100 cfm blower was added), each followed by a series of carbon vessels (four 1,100-lb carbon vessels total) were used during Week 4 of testing. Field measurements were divided into three categories, Tests 1 and 2: Extraction Well Data (Attachment 1), Tests 1 and 2: Monitoring Well Data (Attachment 2), and Tests 1 and 2: Laboratory Results (Attachment 3). Extraction well data measurements were collected at the extraction well. These measurements included vacuum pressures, flow rates, and extracted vapor concentrations prior to carbon treatment (influent) and after carbon treatment (effluent). In addition, laboratory samples were collected at a minimum of twice per day. All laboratory samples were analyzed for VOCs by EPA Methods 8010/8020 in accordance with RWQCB protocols. Monitoring well data consisted of vacuum response readings at nearby soil vapor monitoring wells SVW-25, -26, and -28. Each monitoring well has a series of depth specific probes where measurements were taken.

3.2 TEST 2 PROCEDURE

Test 2 represented the initial portion of the long-term SVE test. The system was operated continuously for a period of 1 month. Over the first 3 weeks, vacuum pressure of approximately 26 inches of water (in. H_2O) was applied to Screens A, B, and C concurrently, using two blowers. The effluent from each blower was treated by two carbon vessels in series (four 1,100-lb carbon vessels total). During the final week of Test 2, the same vacuum was applied only to Screens B and C concurrently using only one blower[1]. Extracted vapors were treated through a series of two carbon vessels initially and through three carbon vessels during the final days of operation because of potential breakthrough in the primary carbon vessel. Field measurements were essentially identical to those collected during Test 1 and are also presented in Attachments 1, 2, and 3. Toward the end of Test 1, vacuum responses were observed in some of the more distant soil vapor monitoring wells. Hence, for Test 2, vacuum response measurements were also taken at SVW-28, -32, -33, -34, -35, -37, and -38. As can be seen from Figure A.1-2, these are at significant distances from VE-1.

3.3 TEST 3 PROCEDURE

Test 3 represents the final (extended) portion of the long-term SVE test. Test 3 was started on November 2, 1998, shut down on September 22, 1999, and is currently on standby. Vacuum was initially applied only on Screens B and C combined. This optimal combination was chosen after analyzing VOC removal data (see Section 4.0 for data analysis) and based on literature (Shan and others, 1992). During the later portion of the test, vacuum was applied only to Screen C. As with Test 1, field measurements were divided into three categories, Test 3: Extraction Well Data (Attachment 4), Test 3: Monitoring Well Data (Attachment 5) and Test 3: Laboratory Results (Attachment 6). The field measurements are very similar to the data collected during Test 1; however, additional vacuum reading and one additional soil vapor monitoring well (SVW-39) was added. Based on the data review of the initial 3 weeks of operation, the field measurement collection frequency was decreased from that in Tests 1 and 2.

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[1] This was necessitated by mechanical problems with one of the blowers.

4.0 DATA ANALYSIS / INTERPRETATION

Presented in this section are the various data collected to date during the SVE pilot test and an interpretation of this data. All figures generated for Section 4.0 were produced from data in Attachments 1 through 6.

4.1 TEST 1

The primary objective of Test 1 was to determine the effect of applied vacuum on the extraction well screens. Results generated from the data gathered in Test 1 include: vacuum to flow correlations, vacuum response with respect to distance from the extraction well, soil permeability, and VOC removal rates with respect to applied vacuum.

4.1.1 Vacuum versus Flow

As described earlier, Test 1 consisted of applying vacuums to Screens A, B, and C individually and then to Screens A, B, and C combined for four runs at four 8-hour days per run. On day 1 of each run, the blowers were set at maximum capacity. The blower capacity was reduced by 25 percent on day 2, 50 percent on day 3, and 75 percent on day 4 of each run (Table A.3-1). Test 1 extraction well data indicates that extraction flow rates decreased as applied vacuum decreased. Results are plotted as Figure A.4-1 and are discussed in the remainder of this section. Figure A.4-1 was generated based on data presented in Attachment 1.

The maximum applied vacuum to Screen A was recorded at 44 in. H_2O, which produced an extraction flow rate of 174 cfm. As the applied vacuum was reduced (25 percent increments), the flow rate also decreased as expected. The maximum applied vacuum to Screen B was recorded at 70 in. H_2O, which produced an extraction flow rate of 167 cfm. Similar to Screen A, as the applied vacuum on Screen B was reduced the flow rate also decreased. The maximum applied vacuum to Screen C was recorded at 80 in. H_2O, which produced an extraction flow rate of 157 cfm. Applied vacuum to flow rate response was fairly similar to that of Screen B. The results suggest that when extracting from individual screens, Screen A requires the least applied vacuum to produce a given flow rate, while Screen C requires the most applied vacuum to produce the same flow rate.

The maximum applied vacuum to Screens A, B, and C combined was recorded at 25 in. H_2O, which produced an extraction flow rate of 277 cfm.

4.1.2 Vacuum Responses

Responses to the applied vacuum at the extraction well were measured at various soil vapor monitoring wells within the vicinity of VE-1. As described in Section 2.1.2, each soil vapor monitoring well contains several depth-specific probes. The probes were used to measure vacuum responses at various depths and distances from the extraction well. Four monitoring zones, based on elevation, have been designated for the purpose of data analysis (Figure A.4-2). Zone 1 includes the subsurface areas at an elevation greater than 1,151 feet above mean sea level (amsl); Zone 2 covers the elevation interval of 1,151 feet to 1,101 feet amsl; Zone 3 covers the elevation interval of 1,051 feet to 1,001 feet amsl; and Zone 4 covers the elevation interval of 1,051 feet to 1,001 feet amsl. Elevations for Zones 2, 3 and 4 were designated to correspond to screened interval elevations at Screens A, B, and C [Screen elevations: A (1,146 feet to 1,106 feet.), B (1,096 feet to 1,056 feet), C (1,046 feet to 1,006 feet)], respectively. For a given monitoring well, the responses at the probes (for each zone) were averaged. Thus, for each monitoring well there is one "average" vacuum response for each of the four zones.

It should be noted that the locations of the three screens (A, B, and C) were selected based on the depth of the VOC-impacted zone only, and do not reflect site geology. Similarly, Zones 2, 3, and 4 correspond to the same depths as screens A, B, and C, respectively. Zone 1 corresponds to the unscreened portion of the extraction well.

During Test 1, responses were measured in monitoring wells SVW-25, -26, and -28. The results were plotted with respect to distance from VE-1 for all the extracting scenarios (Figures A.4-3 through A.4-6). As expected, the figures show that average vacuum responses were generally highest in the zone that corresponds to the extracting well screen and decreased with distance. For example, Figure A.4-3 illustrates that while extracting from Screen A, the greatest average vacuum responses were noted in Zone 2. Overall, Zone 1 showed the least average vacuum responses, which is expected since there is no extraction screen at the Zone 1 elevation. To some extent, this indicates that surface leakage is minimal based on the lack of responses in Zone 1 for the two closest soil vapor monitoring wells. This may be attributable to the fact that almost 90 percent of JPL is capped. Furthermore, as discussed later, vacuum responses during Tests 2 and 3 were noted in wells at a significant distance from VE-1, which again points to minimal surface leakage.

Based on Figure A.4-3, while extracting from Screen A, Zone 2 showed good vacuum responses in all three monitoring wells. Vacuum response averages in Zone 2 ranged from 0.7 in. H_2O to 1.8 in. H_2O. Zones 1, 3, and 4 did not show good responses with the exception of Zone 1 at well SVW-26 (response of 1.63 in. H_2O).

Based on Figure A.4-4, while extracting from Screen B, Zone 3 showed the best vacuum responses. While extracting from Screen B, vacuum response averages in Zone 3 ranged from 0.38 in. H_2O to 2.05 in. H_2O. Average vacuum responses for the other zones were below 0.85 in. H_2O.

Based on Figure A.4-5, while extracting from Screen C, the best average vacuum responses were recorded in Zone 4 (monitoring points were not available for Zone 4 in SVW-28,). Average vacuum responses in Zone 4 ranged from 1.20 in. H_2O to 2.95 in. H_2O. In addition, Zone 3 showed a significant average vacuum response reading while extracting from Screen C. Average vacuum responses in Zone 3 were recorded as high as 1.37 in. H_2O (SVW-25). Relatively low average vacuum responses were recorded at Zones 1 and 2.

Based on Figure A.4-6, while extracting from all three screens combined, Zones 2, 3, and 4 showed good vacuum responses. Overall, the best average vacuum responses were recorded in Zone 3 where they ranged from 0.53 in. H_2O to 2.63 in. H_2O. For Zone 2 and Zone 4, average vacuum responses ranged, respectively, from 0.0 in. H_2O to 1.9 in. H_2O and from 0.95 in. H_2O to 2.25 in. H_2O. Vacuum responses in Zone 1 were relatively low (less than 0.01 in. H_2O) with the exception of the response at SVW-26, which showed an average vacuum response of 0.95 in. H_2O.

4.1.3 Soil Permeability

Soil permeability is a measure of the ability of soil to allow airflow through its pore spaces. The following mathematical equation can be used to calculate permeability (Johnson and others, 1990):

$$\frac{Q}{H} = \pi \frac{k}{\mu} P_e \frac{[1-(P_m / P_e)^2]}{\ln(R_e / D_m)} \qquad (1)$$

Where:

Q = Flow [cfm, cm^3/s]

H = Screen interval [ft, cm]

K = Soil Permeability to air flow [darcy, cm^2]

μ = Viscosity of air [centipoise, g/cm-s]

P_e = Extraction well vacuum [inches H_2O, $g/cm\text{-}s^2$]

P_m = Monitoring well response [inches H_2O, $g/cm\text{-}s^2$]

R_e = Extraction well radius [ft, cm]

D_m = Distance of monitoring well from extraction well [ft, cm]

π = 3.14

ln = Natural logarithm

Based on equation 1, soil permeability was calculated for the test site. Using data collected during Test 1, soil permeabilities were calculated for Zones 2, 3 and 4. Soil permeability calculations are presented in Table A.4-1. Zone 2 calculations were based on vacuum response data [date and time, respectively (April 13, 1998, 12:15)] from the monitoring probes in Zone 2 of monitoring wells SVW-25, -26, and -28. Similarly, calculations for Zones 3 and 4 were based on vacuum response data (April 20, 1998, 10:00 and April 27, 1998, 14:00) from the monitoring probes in Zones 3 and 4 of monitoring wells SVW-25, -26, and -28. Results indicate that Zone 2 is the most permeable of the three zones. The estimated soil permeability value for Zone 2 is

12.60 darcy. The estimated soil permeability values for Zones 3 and 4 are 6.83 darcy and 5.72 darcy, respectively.

4.1.4 VOC Analysis

As discussed previously, the OU-2 RI (Foster Wheeler Environmental, 1999) indicated subsurface soils at OU-2 were impacted by VOCs, primarily CCl_4, Freon 113, TCE, and 1,1-DCE. The majority of the contamination extracted during Test 1 was CCl_4. Trace amounts of Freon 113 were also extracted. A total of approximately 11.1 lbs of VOCs (10.7 lbs of CCl_4 and 0.4 lbs of Freon 113) were extracted during Test 1. Extraction rate calculations are presented in Table A.4-2 and cumulative VOC removals are plotted on Figure A.4-7.

CCl_4 concentrations with respect to applied vacuum are plotted in Figure A.4-8. Since CCl_4 was at the highest concentration, only CCl_4 concentrations were plotted for the purpose of this analysis. The figure suggests that VOC concentrations did not vary significantly with vacuum during Test 1.

4.2 TEST 2

The objectives of Test 2 were to verify the vacuum responses observed during Test 1, to determine the ROI for the site, and to determine VOC removal rates trends over time.

4.2.1 Vacuum Responses

As with Test 1, vacuum responses due to the applied vacuum at the extraction well were measured at monitoring wells within the vicinity of VE-1. However, because of the high vacuum responses observed at distant soil vapor monitoring wells during Test 1, additional monitoring wells (at further distances) were observed during Test 2. Vacuum response measurements were taken at SVW-25, -26, -27, -28, -32, -33, -34, -35, -37, and -38. Since additional monitoring wells were available during Test 2, additional data were available to confirm that significant responses were present in the monitoring zones (Zones 1 to 4) at much further distances. Vacuum responses were noted as far as 771 feet away (SVW-38). Similar to Test 1, the average vacuum response in each zone with respect to distance from VE-1 was plotted for both extracting scenarios (Figures A.4-9 through A.4-10). Again, as in Test 1, the plots suggest that average vacuum responses are generally highest in the zones that correspond to the extracting well screens and decreased with distance. For example, Figure A.4-9 illustrates that when extracting from the combined Screens A, B, and C, Zones 2, 3, and 4 showed significant average vacuum response, whereas Zone 1 generally showed minimal average vacuum responses. These results, along with the decrease with distance, indeed imply that the observed vacuum responses are due to the operation of the SVE system.

To demonstrate that the observed vacuum responses were truly a function of the applied vacuum to the extraction well, vacuum response tests were performed. These tests consisted of cycling the SVE system on and off while recording vacuum responses. The results have been plotted with respect to time (Figures A.4-11 through A.4-20) and clearly show that the vacuum responses were a function of the applied vacuum. It should be noted that in these figures actual vacuum responses were plotted and not the average "zone" vacuum responses. As can be seen in Figure A.4-11 through A.4-20 when the SVE system was shut down and time was allowed for the subsurface to reach equilibrium, the vacuum responses were generally at a minimum (zero or close to zero). Also, when the SVE system was restarted, vacuum responses immediately (within 1 to 2 hours) started to rebound. Similarly, when the SVE system was shut down, vacuum responses immediately decreased in magnitude. Thus, the results of the vacuum response tests confirm that the vacuum responses in the soil vapor monitoring wells were caused by the applied vacuum at the extraction well.

4.2.2 ROI Estimation

The ROI is described as a mathematical estimate of the upper limit of distance at which the effects of extraction can be observed. These effects are usually measured as vacuum responses at the monitoring wells. Generally, the ROI is defined as the distance from the extraction well at which the response is 1.0 percent of the applied vacuum.

To determine ROI at the site, vacuum-response data was normalized and plotted as Figures A.4-21 and A.4-22. Figure A.4-21 indicates that while extracting from Screens A, B, and C combined, the ROIs for Zones 2, 3, and 4 are approximately 665, 950, and 1,000 feet, respectively. Figure A.4-22 indicates that while extracting from Screens B and C combined, the ROIs for Zones 2, 3, and 4 are 215, 900, and 900 feet, respectively.

It is recognized that these ROIs are somewhat higher than expected. As discussed in Section 4.3.3, a different approach (using actual reduction in VOC concentrations in soil vapor monitoring wells) may be warranted.

4.2.3 VOC Analysis

The majority of the contamination extracted during Test 2 was CCl_4. Trace amounts of Freon 113 were also extracted. A total of approximately 62.6 lbs of VOCs (57.0 lbs of CCl_4 and 4.6 lbs of Freon 113) were extracted during Test 2. Extraction rate calculations are presented in Table A.4-3 and cumulative VOC removals are plotted on Figure A.4-23. Generally, the data indicate that the VOC removal rates decreased with time (Figure A.4-24). While applying vacuums to Screens A, B, and C combined, the VOC removal rates ranged from 0.23 pounds per hour (lbs/hr) to 0.10 lbs/hr. While applying vacuums to Screens B and C combined, the VOC removal rates ranged from 0.11 lbs/hr to 0.08 lbs/hr.

Removal rates are a function of extracted flow rates and VOC concentration in the extracted vapors. During Test 2, the two primary carbon vessels were prematurely exhausted on two separate occasions. Testing at the carbon vendor's laboratory indicated high VOC loading although VOC removals based on laboratory analyses of the extracted soil vapor and flow rates did not indicate that carbon capacity had been reached. This indicates that one or more slugs of

VOCs may have been extracted. The amount of VOCs extracted during Tests 1 and 2, based on a 44.6 percent loading as reported by the carbon vendor, is 1,784 pounds (44.6 percent of 4,000 pounds – two vessels each with 1,000 pounds, on two occasions). Attachment 7 shows the results of the analyses on the first batch of exhausted carbon. This is only an estimate and actual VOC removal may have been lower since the analysis was based on carbon samples collected from the vessel near the inlet ports. This also includes the 73.7 pounds based on the laboratory analyes of the vapors. Hence, an estimated 800 pounds (approximately 20 percent loading) of VOCs were assumed to be removed in addition to the 73.7 pounds. Since this removal could not be substantiated by laboratory results of vapor analyses, it was not included in the removal rate calculations.

4.3 TEST 3

The objectives of Test 3 were to confirm the results of Test 2 (verification of vacuum responses, ROI, and VOC removal trends), determine the radius of remediation influence (RORI), and conduct system optimization tests.

4.3.1 Vacuum Responses

For Test 3, vacuum responses due to the applied vacuum at the extraction well were measured at monitoring wells SVW-25, -26, -27, -28, -32, -33, -34, -35, -36, -37, -38, and -39. As with Test 2, vacuum response tests were conducted to demonstrate that the observed vacuum responses were truly a function of the applied vacuum to the extraction well. As with Test 2, the results have been plotted with respect to time (Figures A.4-25 through A.4-34) and once again clearly show that the vacuum responses were a function of the applied vacuum.

4.3.2 ROI Estimation (Vacuum)

Test 3 consisted of extracting from Screens B and C combined from November 2, 1998, through September 8, 1999. The final portion of Test 3 extended from September 8, 1999, through September 22, 1999, and consisted of extracting from Screen C only. As in Test 2, the ROI is defined as the distance from the extraction well at which the response is a minimum of 1.0 percent of the applied vacuum. Plots similar to those generated for Test 2 (normalized vacuum response plots) were prepared to confirm the ROI. These are shown in Figures A.4-35 and A.4-36. Based on Figure A.4-35, while extracting from combined Screens B and C, the ROIs for Zones 2, 3, and 4 are estimated at 65, 460, and greater than 1,000 feet, respectively. Based on Figure A.4-36, while extracting from Screen C only, ROIs for Zones 2, 3, and 4 were reduced to 25, 350, and 520 feet, respectively. The results of the ROI analysis conducted for Test 2 and Test 3 indicate that the ROI for Zones 3 and 4, while extracting from combined Screens B and C is 460 feet. To be conservative, 460 feet is designated as the effective ROI for the site.

4.3.3 ROI Estimation (Remediation)

The ROI, based on vacuum response, is estimated to be on the order of 460 feet for Zones 3 and 4 while extracting from combined Screens B and C. However, this ROI may not be representative of the actual area that the extraction well is capable of remediating based on literature and previous experience. Hence, an alternate method for estimating the influence of remediation was used. This consists of estimating the "radius of remediation influence" (RORI), which is defined as the distance at which a significant the reduction of VOC levels is observed in monitoring wells (as opposed to observed vacuum responses). Since the objective of SVE is to reduce VOC levels in the subsurface, this method is expected to be more realistic than the vacuum response ROI method.

Prior to initiating Test 3 (May 1998) and after the SVE system was placed on standby (October 1999), soil vapor monitoring was conducted to evaluate SVE effectiveness. VOC percent reductions for CCl_4 and Freon 113 concentrations as of October 1999 (compared to May 1998 VOC concentrations) are plotted in Figures A.4-37 through A.4-42, for Zones 2, 3, and 4. For the purpose of this analysis, it has been assumed that an effective RORI will extend to the point of 50 percent VOC reduction. Based on this assumption, reductions of CCl_4 greater than 50 percent extend beyond 1,000 feet for Zone 2, approximately 675 feet for Zone 3, and approximately 720 feet for Zone 4. Reductions in Freon 113 greater than 50 percent have been estimated to extend beyond 1,000 feet for Zone 2, and to 340 and 380 feet for Zones 3 and 4, respectively. The results indicate that the remedial effectiveness is much greater for CCl_4 than for Freon 113. A 75% reduction in CCl_4 concentrations occurred at approximately 550 feet, 425 feet, and 450 feet away from the extraction well in Zones 2, 3, and 4, respectively. Therefore, for CCl_4, which is the primary VOC of concern, as assumed RORI (based on 75% reduction in concentrations) of 400 feet would be appropriate.

4.3.4 Pore Volume Exchange Rate

Pore volume exchange rate (PVER) is an indirect means of determining the number of SVE wells required at a site. PVER may be defined as the rate at which one complete pore volume of the impacted soil is exchanged. The number of wells required would then be based on an adequate number of pore volumes exchanged within a reasonable time frame.

For VE-1, when extracting from B and C (which corresponds to the majority of the VOC impact), the PVER is estimated as follows:

$$\text{Time for 1 pore volume exchange, days} = \frac{\pi \text{ x } RORI^2 \text{ x n x H}}{Q \text{ x } 1440 \text{ min/day}} \quad (2)$$

Where:

RORI = 400 feet (it is assumed that this is the zone within which effective air exchange occurs)

n = Effective soil porosity (air), assumed to be 0.20

H = Height of soil column through which flow occurs

Q = Flow = 393 cfm

Based on the lack of vacuum responses in Zone 1, and the minimal responses in Zone 2, "H" was assumed to be equal to the thickness of Zones 3 and 4 combined, i.e., 100 feet. This translates to 1 pore volume approximately every 18 days.

4.3.5 VOC Analysis

The majority of the contamination extracted during Test 2 was CCl_4. Trace amounts of Freon 113 and TCE were also extracted. A total of approximately 125.9 lbs of VOCs (113.2 lbs of CCl_4, 11.2 lbs of Freon 113, and 2.5 lbs of TCE) were extracted during Test 2. Extraction rate calculations are presented in Table A.4-4, and cumulative VOC removals are plotted on Figure A.4-43. Test 3 results confirm Test 2 results and indicate that VOC removal rates will decrease over a long period of time (Figure A.4-44). During the initial startup of Test 3, the total VOC removal rates were as high as 0.11 lbs/hr and dropped as low as 0.004 lbs/hr (system in operation). These results indicate that VOC concentrations in the extracted vapor were reduced by over 95 percent over the duration of the test.

4.3.6 System Optimization

During Test 3, the following operational strategies were explored in order to maximize the efficiency of the SVE system (these methods involved equipment upgrades and changes in how the SVE system was being operated):

- Extracting from only Screen C to effect greater remediation in Zone 4, which is closest to the water table.
- Cycling the treatment system on and off for periods of time and monitor effects on system performance.

4.3.6.1 Screen C Extraction

On September 8, 1999, Screen B was closed off and only Screen C remained open. By closing Screen B, the applied vacuum increased from approximately 73 in. H_2O (for combined Screens B and C) to an applied vacuum of approximately 100 in. H_2O. In order to operate the SVE system at increased vacuum, the existing vapor-phase GAC adsorbers were replaced with vessels retrofitted with two reinforcement bands of the same size and configurations. The system operated for 2 weeks with only Screen C open; thus, more time may be needed to evaluate the true effectiveness under these operating parameters. However, preliminary results indicate that extracting from a single screen may reduce the radius of influence (Section 4.3.1) in certain zones.

4.3.6.2 System Cycling

In an effort to increase the system performance, cycling tests were done from May 1999 through July 1999. The VOC removal rates had decreased by approximately an order of magnitude (0.11 lbs/hr to 0.021 lbs/hr) since start-up of Test 3.

In looking at the VOC removal rate data from May through July (Figure A.4-45), the following observations can be made:

- The VOC removal rate initially rebounded following start-up of the system but the magnitude of the rebound decreased with each subsequent shutdown.
- Within each operation interval, the removal rates declined before the system was shut down.
- Overall, removal rates remained at least an order of magnitude below the levels of the initial startup of Test 3 and were consistently lower than the last period prior to cycling.

Based on these observations, cycling did not significantly enhance the performance of the SVE system. However, cycling will be continued to further evaluate its potential in enhancing effectiveness.

5.0 TEST RESULTS AND CONCLUSIONS

The test results indicated that SVE is indeed a feasible technology for remediation of the VOC-impacted soils in OU-2. Following are some of the key results of the pilot test:

- All three screens were able to extract significant quantities of soil vapor with flow-rates ranging from 157 to 174 cfm from each screen at vacuums ranging from 44 to 80 inches of water.
- Vacuum responses were noted as far as 771 feet away from the extraction well. Normalized vacuum responses of greater than or equal to 1 percent of the exerted vacuum were observed at least 460 feet away.
- A 75 percent reduction in CCl_4 (the primary constituent of interest) levels was observed approximately 450 feet away from the extraction well in Zone 4 (approximately the bottom 50 feet of the vadose zone). In Zones 2 and 3, 75 percent reductions in CCl_4 levels were observed 550 and 425 feet away from the extraction well, respectively.
- VOC concentrations in the extracted vapor were reduced by over 95 percent over the duration of the test.
- VOC removal rates of up to 0.10 lbs/hr were noted for CCl_4, with an overall removal of approximately 180 lbs of CCl_4 between May 1998 and October 1999.
- Total VOC removal rates of up to 0.11 lbs/hr were noted, with an overall removal of approximately 200 lbs between May 1998 and October 1999. An additional 850 lbs of VOCs (total) may have been removed on two separate occasions.

It should be noted that while an RORI of 400 feet is valid based on the SVE test data, a more conservative RORI may be warranted for selecting the number of wells for the full-scale system.

6.0 REFERENCES

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TABLES

TABLE A.4-1
SOIL PERMEABILITY CALCULATIONS

Extraction Well = VE-1A				
Monitoring Well Data - Zone 2, 4/13/99 12:15				
Extraction Well Radius (R_e)	inch	1		
	cm	2.54		
Air viscosity (μ)	g/cm-s	0.00018		
		SVW-25	SVW-26	SVW-28
Distance	ft	53.8	101.4	167.4
Distance (D_m)	cm	1639.8	3090.7	5102.4
Screen Interval	ft	40	40	40
Screen Interval	cm	1219.2	1219.2	1219.2
Extraction Flow Rate	cfm	179	179	179
Extraction Flow Rate (Q)	cm^3/s	84479.1	84479.1	84479.1
Extraction Vacuum (gage)	inches H_2O	44	44	44
Extraction Vacuum (abs)	$g/cm\text{-}s^2$	900757.72	900757.72	900757.72
Measured Vacuum (gage)	inches H_2O	1.8	1.25	0.7
Measured Vacuum (abs)	$g/cm\text{-}s^2$	1005502.8	1006867.9	1008233.1
$\ln[R_e/D_m]$		-6.47	-7.10	-7.61
$[1-(P_m/P_e)^2]$		-0.25	-0.25	-0.25
Permeability	cm^2	1.159E-07	1.256E-07	1.326E-07
	darcy	11.71	12.68	13.40
Average Permeability	cm^2	1.25E-07		
	darcy	12.60		

TABLE A.4-1
SOIL PERMEABILITY CALCULATIONS

Extraction Well = VE-1B				
Monitoring Well Data- Zone 3, 4/20/99 10:00				
Extraction Well Radius (R_e)	inch	1		
	cm	2.54		
Air viscosity (μ)	g/cm-s	0.00018		
		SVW-25	SVW-26	SVW-28
Distance	ft	53.8	101.4	167.4
Distance (D_m)	cm	1639.8	3090.7	5102.4
Screen Interval	ft	40	40	40
Screen Interval	cm	1219.2	1219.2	1219.2
Extraction Flow Rate	cfm	162	162	162
Extraction Flow Rate (Q)	cm^3/s	76455.9	76455.9	76455.9
Extraction Vacuum (gage)	inches H_2O	70	70	70
Extraction Vacuum (abs)	$g/cm\text{-}s^2$	836222.86	836222.86	836222.86
Measured Vacuum (gage)	inches H_2O	2.03	2.05	0.25
Measured Vacuum (abs)	$g/cm\text{-}s^2$	1004931.9	1004882.2	1009350
$\ln[R_e/D_m]$		-6.47	-7.10	-7.61
$[1-(P_m/P_e)^2]$		-0.44	-0.44	-0.46
Permeability	cm^2	6.262E-08	6.877E-08	7.155E-08
	darcy	6.32	6.95	7.23
Average Permeability	cm^2			6.76E-08
	darcy			6.83

TABLE A.4-1
SOIL PERMEABILITY CALCULATIONS

Extraction Well = VE-1C			
Monitoring Well Data- Zone 4, 4/27/99 14:00			
Extraction Well Radius (R_e)	inch	1	
	cm	2.54	
Air viscosity (μ)	g/cm-s	0.00018	
		SVW-25	SVW-26
Distance	ft	53.8	101.4
Distance (D_m)	cm	1639.8	3090.7
Screen Interval	ft	40	40
Screen Interval	cm	1219.2	1219.2
Extraction Flow Rate	cfm	163	163
Extraction Flow Rate (Q)	cm^3/s	76927.9	76927.9
Extraction Vacuum (gage)	inches H_2O	80	80
Extraction Vacuum (abs)	$g/cm\text{-}s^2$	811401.76	811401.76
Measured Vacuum (gage)	inches H_2O	2.95	1.2
Measured Vacuum (abs)	$g/cm\text{-}s^2$	1002648.3	1006992
$\ln[R_e/D_m]$		-6.47	-7.10
$[1-(P_m/P_e)^2]$		-0.53	-0.54
Permeability	cm^2	5.473E-08	5.862E-08
	darcy	5.53	5.92
Average Permeability	cm^2		5.67E-08
	darcy		5.72

TABLE: A.4-2
TEST 1: VOC ANALYSIS

Week	Day	Date / Time	Operating Hours *hr*	Avgerage Vacuum *in.* H_2O	Average Flowrate *cfm*	CCl4 Average Concentration mg/m^3	CCl4 Removal Rate *lb/hr*	CCl4 Removed *lb*	Cumulative CCl4 Removed *lb*	Freon 113 Average Concentration mg/m^3	Freon 113 Removal Rate *lb/hr*	Freon 113 Removed *lb*	Cumulative Freon 113 Removed *lb*	Total VOCs Removed *lb*
1	1	4/13/98 10:00	6	44	174	157	0.102	0.61	0.61	0	0.000	0.00	0.00	0.61
1	2	4/14/98 10:00	8	32	139	153	0.080	0.64	1.25	11	0.006	0.05	0.05	1.30
1	3	4/15/98 10:00	8	20	102	170	0.065	0.52	1.77	13	0.005	0.04	0.09	1.86
1	4	4/16/98 10:00	8	10	58	170	0.037	0.3	2.07	0	0.000	0.00	0.09	2.16
		4/19/98 10:00	0	0	0		0.000	0	2.07		0.000	0.00	0.09	2.16
2	1	4/20/98 10:00	8	70	167	253	0.158	1.27	3.34	0	0.000	0.00	0.09	3.43
2	2	4/21/98 10:00	8	52	143	260	0.139	1.11	4.45	0	0.000	0.00	0.09	4.54
2	3	4/22/98 10:00	8	34	109	237	0.097	0.77	5.22	0	0.000	0.00	0.09	5.31
2	4	4/23/98 10:00	8	17	60	263	0.059	0.47	5.69	17	0.004	0.03	0.12	5.81
		4/26/98 10:00	0	0	0		0.000	0	5.69		0.000	0.00	0.12	5.81
3	1	4/27/98 10:00	8	80	157	123	0.072	0.58	6.27	0	0.000	0.00	0.12	6.39
3	2	4/29/98 10:00	8	59	136	150	0.076	0.61	6.88	11	0.006	0.04	0.16	7.04
3	3	4/30/98 8:00	8	40	101	140	0.053	0.42	7.3	0	0.000	0.00	0.16	7.46
3	4	4/30/98 16:00	8	20	62	163	0.038	0.3	7.6	3	0.001	0.01	0.17	7.77
		5/3/98 10:00	0	0	0		0.000	0	7.6		0.000	0.00	0.17	7.77
4	1	5/4/98 10:00	8	25	277	151	0.157	1.25	8.85	10	0.010	0.08	0.25	9.10
4	2	5/5/98 10:00	5	19	229	173	0.148	0.74	9.59	13	0.011	0.06	0.31	9.90
4	3	5/6/98 10:00	7	13	166	167	0.104	0.73	10.32	13	0.008	0.06	0.37	10.69
4	4	5/7/98 10:00	7	6	103	167	0.064	0.45	10.77	13	0.005	0.04	0.41	11.18

TABLE A.4-3
TEST 2: VOC ANALYSIS

Week	Day	Date/Time	Anemometer Flowrate ABC	Anemometer Flowrate BC	CCl4 Average Concentration	CCl4 Removal Rate	CCl4 Removed	Cumulative CCl4 Removed	Freon 113 Average Concentration	Freon 113 Removal Rate	Freon 113 Removed	Cumulative Freon 113 Removed	Total VOCs Removed
			cfm	cfm	mg/m3	lb/hr	lb	lb	mg/m3	lb/hr	lb	lb	lb
		5/11/98 6:59	0		0	0.000		10.485	0	0.000		0.367	10.852
1	1	5/11/98 7:00	275	--	205	0.211	0.002	10.487	17	0.018	0.000	0.367	10.854
1	1	5/11/98 8:00	274	--	205	0.210	0.211	10.697	17	0.017	0.017	0.385	11.082
1	1	5/11/98 9:00	275	--	205	0.211	0.211	10.908	17	0.018	0.017	0.402	11.310
1	1	5/11/98 11:00	281	--	205	0.216	0.427	11.335	17	0.018	0.035	0.437	11.772
1	1	5/11/98 14:00	273	--	205	0.210	0.638	11.973	17	0.017	0.053	0.490	12.463
1	2	5/12/98 7:00	272	--	100	0.102	2.647	14.619	0	0.000	0.148	0.638	15.257
1	2	5/12/98 9:00	278	--	100	0.104	0.206	14.825	0	0.000	0.000	0.638	15.463
1	2	5/12/98 12:00	274	--	100	0.103	0.310	15.135	0	0.000	0.000	0.638	15.773
1	3	5/13/98 8:00	276	--	120	0.124	2.266	17.401	5	0.005	0.052	0.690	18.091
1	3	5/13/98 10:00	274	--	120	0.123	0.001	17.403	5	0.005	0.000	0.690	18.093
1	3	5/13/98 12:00	282	--	120	0.127	0.250	17.653	5	0.005	0.010	0.700	18.353
1	3	5/13/98 14:00	268	--	120	0.120	0.247	17.900	5	0.005	0.010	0.711	18.611
1	4	5/14/98 7:00	286	--	120	0.128	2.116	20.016	5	0.005	0.088	0.799	20.814
1	4	5/14/98 11:00	285	--	120	0.128	0.513	20.529	5	0.005	0.021	0.820	21.349
1	4	5/14/98 14:00	287	--	120	0.129	0.385	20.914	5	0.005	0.016	0.836	21.750
1	5	5/15/98 9:00	276	--	120	0.124	2.403	23.317	5	0.005	0.100	0.936	24.253
1	5	5/15/98 11:30	278	--	120	0.125	0.311	23.628	5	0.005	0.013	0.949	24.578
1	5	5/15/98 14:30	278	--	120	0.125	0.375	24.003	5	0.005	0.016	0.965	24.968
2	1	5/19/98 14:00	270	--	160	0.162	0.001	24.005	13	0.013	0.000	0.965	24.970
2	2	5/20/98 8:00	253	--	160	0.152	2.820	26.825	15	0.014	0.246	1.211	28.036
2	2	5/20/98 11:00	257	--	160	0.154	0.458	27.283	15	0.014	0.043	1.254	28.537
2	2	5/20/98 14:00	267	--	160	0.160	0.471	27.754	15	0.015	0.044	1.298	29.052
2	3	5/21/98 8:00	264	--	150	0.148	2.774	30.528	0	0.000	0.135	1.433	31.961
2	3	5/21/98 9:29	264		150	0.148	0.220	30.748	0	0.000	0.000	1.433	32.181
2	3	5/21/98 14:45	267		150	0.150	0.001	30.751	0	0.000	0.000	1.433	32.184
2	3	5/21/98 15:00	267	--	150	0.150	0.037	30.788	0	0.000	0.000	1.433	32.221
2	4	5/22/98 7:00	255	--	92	0.088	1.902	32.690	8.2	0.008	0.063	1.496	34.186
2	4	5/22/98 14:00	275	--	92	0.095	0.639	33.329	8.2	0.008	0.057	1.553	34.882
3	1	5/26/98 8:00	252	--	100	0.094	8.508	41.837	10	0.009	0.804	2.357	44.195
3	1	5/26/98 12:00	288	--	100	0.108	0.404	42.242	10	0.011	0.040	2.398	44.639
3	1	5/26/98 14:00	259	--	100	0.097	0.205	42.447	10	0.010	0.020	2.418	44.865

TABLE A.4-3
TEST 2: VOC ANALYSIS

Week	Day	Date/Time	Anemometer Flowrate ABC	BC	CCl4 Average Concentration	CCl4 Removal Rate	CCl4 Removed	Cumulative	Freon 113	Freon 113	Freon 113 Removed	Cumulative Freon 113 Removed	Total VOCs Removed
			cfm	*cfm*	*mg/m3*	*lb/hr*	*lb*				*lb*	*lb*	*lb*
3	1	5/26/98 16:00	265	--	100	0.099	0.196				0.020	2.438	45.081
3	1	5/26/98 23:00	268	--	100	0.100	0.698				0.070	2.508	45.849
3	2	5/27/98 16:01	--	160	160	0.096	0.001				0.000	2.508	45.851
3	4	5/29/98 7:50	--	160	160	0.096	3.816				0.382	2.889	50.049
4	1	6/1/98 8:00	--	166	160	0.099	7.047				0.682	3.572	57.777
4	1	6/1/98 13:30	--	155	160	0.093	0.529				0.050	3.621	58.356
4	2	6/2/98 6:14	--	155	160	0.093	1.554				0.146	3.767	60.055
4	2	6/2/98 8:00	--	157	140	0.082	0.001				0.000	3.767	60.057
4	2	6/2/98 8:30	--	157	140	0.082	0.041				0.004	3.771	60.102
4	2	6/2/98 11:00	--	158	140	0.083	0.206				0.022	3.794	60.331
4	2	6/2/98 13:00	--	156	140	0.082	0.165				0.018	3.811	60.513
4	3	6/3/98 7:00	--	152	140	0.080	1.453				0.151	3.962	62.117
4	3	6/3/98 10:30	--	158	140	0.083	0.284				0.028	3.990	62.429
4	3	6/3/98 11:15	--	159	140	0.083	0.062				0.006	3.996	62.498
4	4	6/4/98 10:15	--	155	120	0.070	1.759				0.183	4.179	64.440
4	4	6/4/98 12:00	--	158	120	0.071	0.123				0.013	4.192	64.576
4	4	6/4/98 15:00	--	161	120	0.072	0.215				0.023	4.216	64.814
4	5	6/5/98 9:30	--	165	140	0.086	1.469				0.158	4.374	66.442
4	5	6/5/98 12:00	--	162	140	0.085	0.214				0.023	4.397	66.679
4	5	6/5/98 14:00	--	159	140	0.083	0.168				0.018	4.415	66.865
5	1	6/8/98 7:10	--	158	120	0.071	5.029				0.542	4.956	72.435
5	1	6/8/98 10:05	--	159	120	0.071	0.208				0.023	4.979	72.665
5	1	6/8/98 10:44	--	159	120	0.071	0.046				0.005	4.984	72.717
5	1	6/8/98 10:45	--	0	0	0.000	0.001				0.000	4.984	72.718

TABLE: A.4-4
TEST 3: VOC ANALYSIS

Date	Time *hours*	Date/Time	Time Of Operation *min*	Flowrate ABC *cfm*	CCl4 Average Concentration *mg/m3*	CCl4 Removal Rate *lb/hr*	CCl4 Removed *lb*	Cumulative CCl4 Removed *lb*	Freon 113 Average Concentration *mg/m3*	Freon 113 Removal Rate *lb/hr*	Freon 113 Removed *lb*	Cumulative Freon 113 Removed *lb*	TCE Avgerage Concentration *mg/m3*	TCE Removal Rate *lb/h*	Ave. TCE Removed *lb*	Cumulative TCE Removed *lb*	Total VOCs removed *lb/h*	Total VOCs Removed *lb*
11/2/98	10:50	11/2/98 10:50	1330	242	35	0.032	0.70	68.43	0	0.000	0.00	4.98	0	0	0	0	0.032	73.41
11/3/98	9:00	11/3/98 9:00	1380	242	82	0.074	1.71	70.14	0	0.000	0.00	4.98	0	0	0	0	0.074	75.12
11/4/98	8:00	11/4/98 8:00	1470	242	110	0.100	2.44	72.59	11	0.010	0.24	5.22	0	0	0	0	0.110	77.81
11/5/98	8:30	11/5/98 8:30	1410	228	110	0.094	2.21	74.79	13	0.011	0.26	5.49	0	0	0	0	0.105	80.28
11/6/98	8:00	11/6/98 8:00	4410	256	100	0.096	7.05	81.84	12	0.012	0.85	6.33	0	0	0	0	0.107	88.17
11/9/98	9:30	11/9/98 9:30	1410	260	85	0.083	1.95	83.79	0	0.000	0.00	6.33	0	0	0	0	0.083	90.12
11/10/98	9:00	11/10/98 9:00	1440	257	76	0.073	1.76	85.54	10	0.010	0.23	6.56	0	0	0	0	0.083	92.11
11/11/98	9:00	11/11/98 9:00	1440	253	76	0.072	1.73	87.27	9.8	0.009	0.22	6.79	0	0	0	0	0.081	94.06
11/12/98	9:00	11/12/98 9:00	1440	258	73	0.071	1.69	88.97	0	0.000	0.00	6.79	0	0	0	0	0.071	95.75
11/13/98	9:00	11/13/98 9:00	4320	258	67	0.065	4.66	93.63	8.7	0.008	0.61	7.39	0	0	0	0	0.073	101.02
11/16/98	9:00	11/16/98 9:00	2880	258	64	0.062	2.97	96.60	8.9	0.009	0.41	7.80	0	0	0	0	0.070	104.40
11/18/98	9:00	11/18/98 9:00	1440	262	60	0.059	1.41	98.01	8.2	0.008	0.19	8.00	0	0	0	0	0.067	106.01
11/19/98	9:00	11/19/98 9:00	1440	260	54	0.053	1.26	99.27	7	0.007	0.16	8.16	0	0	0	0	0.059	107.43
11/20/98	9:00	11/20/98 9:00	4320	240	68	0.061	4.40	103.68	7.9	0.007	0.51	8.67	0	0	0	0	0.068	112.35
11/23/98	9:00	11/23/98 9:00	15840	262	51	0.050	13.21	116.89	6.7	0.007	1.74	10.41	0	0	0	0	0.057	127.30
12/4/98	9:00	12/4/98 9:00	5760	262	48	0.047	4.52	121.41	8.6	0.008	0.81	11.22	0	0	0	0	0.056	132.63
12/8/98	9:00	12/8/98 9:00	8700	262	38	0.037	5.41	126.82	6.1	0.006	0.87	12.09	0	0	0	0	0.043	138.91
12/14/98	10:00	12/14/98 10:00	12960	262	36	0.035	7.63	134.45	6.1	0.006	1.29	13.38	0	0	0	0	0.041	147.83
12/23/98	10:00	12/23/98 10:00	10080	262	35	0.034	5.77	140.22	5.3	0.005	0.87	14.25	0	0	0	0	0.040	154.48
12/30/98	10:00	12/30/98 10:00	9990	262	30	0.029	4.90	145.13	5	0.005	0.82	15.07	0	0	0	0	0.034	160.20
1/6/99	8:30	1/6/99 8:30	10230	262	16	0.016	2.68	147.81	0	0.000	0.00	15.07	0	0	0	0	0.016	162.88
1/13/99	11:00	1/13/99 11:00	11520	262	21	0.021	3.96	151.76	0	0.000	0.00	15.07	0	0	0	0	0.021	166.83
1/21/99	11:00	1/21/99 11:00	5040	262	24	0.024	1.98	153.74	0	0.000	0.00	15.07	0	0	0	0	0.024	168.81
1/26/99	11:00	1/26/99 11:00	0	0	0	0.000	0.00	153.74	0	0.000	0.00	15.07	0	0	0	0	0.000	168.81
1/28/99	11:00	1/28/99 11:00	20190	131	0	0.000	0.00	153.74	0	0.000	0.00	15.07	0	0	0	0	0.000	168.81
2/11/99	11:30	2/11/99 11:30	11430	131	15	0.007	1.40	155.14	0	0.000	0.00	15.07	0	0	0	0	0.007	170.21
2/19/99	10:00	2/19/99 10:00	0	0	0	0.000	0.00	155.14	0	0.000	0.00	15.07	0	0	0	0	0.000	170.21
3/30/99	12:00	2/19/99 10:00	0	0	0	0.000	0.00	155.14	0	0.000	0.00	15.07	0	0	0	0	0.000	170.21
3/31/99	15:00	3/31/99 15:00	11370	332	13	0.016	3.06	158.21	0	0.000	0.00	15.07	0	0	0	0	0.016	173.28
4/8/99	12:30	4/8/99 12:30	8610	332	13	0.016	2.32	160.53	0	0.000	0.00	15.07	0	0	0	0	0.016	175.60
4/14/99	12:00	4/14/99 12:00	9840	262	0	0.000	0.00	160.53	0	0.000	0.00	15.07	0	0	0	0	0.000	175.60
4/21/99	11:00	4/21/99 11:00	11340	370	0	0.000	0.00	160.53	0	0.000	0.00	15.07	0	0	0	0	0.000	175.60
4/29/99	8:00	4/29/99 8:00	120	369	0	0.000	0.00	160.53	0	0.000	0.00	15.07	0	0	0	0	0.000	175.60
5/3/99	12:00	5/3/99 12:00	0	0	0	0.000	0.00	160.53	0	0.000	0.00	15.07	0	0	0	0	0.000	175.60
5/4/99	1:30	5/4/99 1:30	3450	370	9.8	0.014	0.78	161.31	1.4	0.002	0.11	15.18	2.7	0.0037	0.215	0.21	0.019	176.71
5/6/99	11:00	5/6/99 11:00	7200	374	12	0.017	2.02	163.33	3.2	0.004	0.54	15.72	2.7	0.0038	0.454	0.67	0.025	179.71
5/11/99	11:00	5/11/99 11:00	4350	373	8.3	0.012	0.84	164.17	0	0.000	0.00	15.72	0	0	0	0.67	0.012	180.56
5/14/99	11:30	5/14/99 11:30	8580	375	8.5	0.012	1.71	165.87	0	0.000	0.00	15.72	2	0.003	0.401	1.07	0.015	182.66
5/20/99	10:30	5/20/99 10:30	0	375	6.8	0.010	0.00	165.87	0	0.000	0.00	15.72	0	0	0	1.07	0.010	182.66
5/21/99	12:00	5/21/99 12:00	0	0	0	0.000	0.00	165.87	0	0.000	0.00	15.72	0	0	0	1.07	0.000	182.66
5/26/99	12:00	5/26/99 12:00	0	0	0	0.000	0.00	165.87	0	0.000	0.00	15.72	0	0	0	1.07	0.000	182.66
5/27/99	14:45	5/27/99 14:45	7200	371	0	0.000	0.00	165.87	0	0.000	0.00	15.72	0	0	0	1.07	0.000	182.66
6/1/99	9:30	6/1/99 9:30	8730	371	9.3	0.013	1.88	167.76	2.2	0.003	0.44	16.16	3.2	0.0044	0.65	1.72	0.020	185.64
6/7/99	11:00	6/7/99 11:00	240	397	6.7	0.010	0.04	167.80	0	0.000	0.00	16.16	2.2	0.0033	0.01	1.73	0.013	185.69
6/8/99	12:00	6/8/99 12:00	0	0	0	0.000	0.00	167.80	0	0.000	0.00	16.16	0	0	0	1.73	0.000	185.69
6/30/99	12:00	6/30/99 12:00	0	0	0	0.000	0.00	167.80	0	0.000	0.00	16.16	0	0	0	1.73	0.000	185.69
7/1/99	16:00	7/1/99 16:00	8400	377	3	0.004	0.59	168.39	0	0.000	0.00	16.16	0	0	0	1.73	0.004	186.28
7/7/99	12:00	7/7/99 12:00	8400	377	6.8	0.010	1.34	169.73	0	0.000	0.00	16.16	0	0	0	1.73	0.010	187.63
7/13/99	8:00	7/13/99 8:00	2910	372	6	0.008	0.41	170.14	0	0.000	0.00	16.16	0	0	0	1.73	0.008	188.03
7/15/99	8:30	7/15/99 8:30	4320	373	6.2	0.009	0.62	170.76	0	0.000	0.00	16.16	2.1	0.0029	0.21	1.94	0.012	188.87
7/21/99	10:00	7/21/99 10:00	0	373	0.0	0.000	0.00	170.76	0	0.000	0.00	16.16	0	0	0	1.94	0.000	188.87
7/26/99	12:00	7/26/99 12:00	0	0	0.0	0.000	0.00	170.76	0	0.000	0.00	16.16	0	0	0	1.94	0.000	188.87

TABLE: A.4-4
TEST 3: VOC ANALYSIS

Date	Time *hours*	Date/Time	Time Of Operation *min*	Flowrate ABC *cfm*	CCl4 Average Concentration *mg/m3*	CCl4 Removal Rate *lb/hr*	CCl4 Removed *lb*	Cumulative CCl4 Removed *lb*	Freon 113 Average Concentration *mg/m3*	Freon 113 Removal Rate *lb/hr*	Freon 113 Removed *lb*	Cumulative Freon 113 Removed *lb*	TCE Avgerage Concentration *mg/m3*	TCE Removal Rate *lb/h*	Ave. TCE Removed *lb*	Cumulative TCE Removed *lb*	Total VOCs removed *lb/h*	Total VOCs Removed *lb*
7/27/99	11:00	7/27/99 11:00	4200	373	7.0	0.010	0.68	171.45	0	0.000	0.00	16.16	2.0	0.0028	0.2	2.14	0.013	189.75
7/30/99	9:00	7/30/99 9:00	8640	373	6.0	0.008	1.21	172.65	0	0.000	0.00	16.16	2.0	0.0028	0.4	2.54	0.011	191.36
8/5/99	9:00	8/5/99 9:00	8670	370	5.4	0.007	1.08	173.74	0	0.000	0.00	16.16	0	0.0000	0.0	2.54	0.007	192.44
8/11/99	9:30	8/11/99 9:30	12930	371	5.9	0.008	1.77	175.50	0	0.000	0.00	16.16	0	0.0000	0.0	2.54	0.008	194.21
8/20/99	9:00	8/20/99 9:00	7260	373	5.8	0.008	0.98	176.48	0	0.000	0.00	16.16	0	0.0000	0.0	2.54	0.008	195.19
8/25/99	10:00	8/25/99 10:00	20100	376	5.2	0.007	2.45	178.94	0	0.000	0.00	16.16	0	0.0000	0.0	2.54	0.007	197.64
9/8/99	9:00	9/8/99 9:00	10080	373	5.5	0.008	1.29	180.23	0	0.000	0.00	16.16	0	0.0000	0.0	2.54	0.008	198.93
9/15/99	9:00	9/15/99 9:00	10080	370	2.9	0.004	0.68	180.90	0	0.000	0.00	16.16	0	0.0000	0.0	2.54	0.004	199.61
9/22/99	9:00	9/22/99 9:00	180	373	4.0	0.006	0.02	180.92	0	0.000	0.00	16.16	0	0.0000	0.0	2.54	0.006	199.62
9/23/99	10:00	9/23/99 10:00	0	0	0.0	0.000	0.00	180.92	0	0.000	0.00	16.16	0	0.0000	0	2.54	0.000	199.62