APPENDIX A

Summary of SVE System Operation, Maintenance, Repair, and Hydrocarbon Recovery Calculations

A-1. SVE and Treatment System Maintenance and Repair Summary

A-2. SVE and Treatment System Hydrocarbon Recovery Calculations

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ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
C	vapor concentration
gal.	gallon(s)
K	Kelvin
kg	kilograms
kg/m^3	kilograms per cubic meter
L	liters
lbs	pound(s)
m^3/hr	cubic meters per hour
NAPL	non-aqueous phase liquid
O_2	oxygen
PLC	programmable logic controller
ppmv	parts per million by volume
SVE	soil-vapor extraction

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A-1. SVE AND TREATMENT SYSTEM MAINTENANCE AND REPAIR SUMMARY

The primary maintenance interval for the soil-vapor extraction (SVE) and treatment units 249, 335, 344, and 345 is every 360 hours (approximately 2 weeks), as recommended by the system manufacturer. Routine biweekly maintenance includes checking and changing the oil, filters, spark plugs, and spark plug wires; checking the coolant level and adding coolant as needed; cleaning the air filter; and checking all belts, hose connections, battery connections, and emergency contact switches. Monthly maintenance includes all biweekly maintenance and involves replacing distributer caps, rotors, and polyvinyl chloride valves and cleaning the radiators. All biweekly and monthly maintenance requires each unit being serviced to be shut down for approximately 4 hours.

1.1 Scheduled Maintenance

Biweekly maintenance was performed on the SVE and treatment systems from April 23 through the end of June 2012.

1.2 Non-Scheduled Maintenance and Repairs

No non-scheduled maintenance or repairs were performed on the SVE units during Second Quarter 2012.

A-2. SVE AND TREATMENT SYSTEM HYDROCARBON RECOVERY CALCULATIONS

As part of the ongoing Stage 2 abatement action for ST-106 and the interim remedial actions for SS-111, vapor samples from the SVE and treatment systems inlets and exhausts are regularly analyzed on site using a Horiba Mexa 554J emissions analyzer for petroleum hydrocarbon concentration in parts per million by volume (ppmv) and for percent oxygen, carbon monoxide, and carbon dioxide . For consistency with historical reporting, the cumulative mass recovery values reported in Section 2 of the quarterly report for April through June 2012 are those calculated by the programmable logic controller (PLC). This section describes the basic equations and constants that are used, along with the PLC field measurements, to calculate total hydrocarbon recovery volumes.

For the SVE and treatment system associated with the Stage 2 abatement action at ST-106, the PLC-estimated hydrocarbon vapor concentration is used along with the molecular weight of the influent vapor stream, the gas constant, and the standard temperature to calculate the vapor concentration (C) in kilograms per cubic meter (kg/m^3). Vapor stream concentrations are estimated by the PLC in units of ppmv, which can be converted into kg/m^3 for use in the following equation:

where:

Conc	=	vapor concentration (Horiba ppmv reading × 10^{-6})
MW	=	molecular weight of the vapor (120)
R	=	gas constant (0.08205) (liters [L]·atm/mol·K)
T	=	vapor temperature (Kelvin [K]) (273.15 + 20 degrees Celsius[°C] = 293.15°K)

The measured well gas inlet flow rate (cubic meters per hour [m^3/hr]) and hours of operation are then used to calculate recovered mass. Mass removal is estimated using the following conversion:

$$M = CQT$$

where:

M	=	mass removed (kilogram [kg])
C	=	vapor concentration (kg/m^3)
Q	=	extraction flow rate (m^3/hr)
T	=	operational period (hour)

The recovered mass is then converted to equivalent gallons.

The hydrocarbon recovery is calculated for each engine and cumulatively summed over the operational period.

As an example, the mass (kg) of recovered hydrocarbons for Engine E1 during a given period can be calculated using the measured influent vapor concentration (C) from a measurement date in that period (such as 32,400 ppmv), the well-gas inlet flow rate (such as 74.8 m^3/hr), the Engine E1 operational hours during the period (539.9 hours), and the constants defined above as follows:

The non-aqueous phase liquid (NAPL)-equivalent gallons (gal.) of hydrocarbon recovery are calculated by multiplying the recovery mass in pounds (lbs) time a density of 6.2 lbs/gal. NAPL.

To be consistent with historical reporting, the mass of petroleum hydrocarbon biodegradation is estimated by using the following equation published by the Air Force Center for Engineering and the Environment guidance to account for the attenuation of petroleum hydrocarbons by bioventing (Leeson and Hinchee, 1996a and 1996b):

$$HC_{Bio} = (C_{V,bkgd} - C_{V,O2})/100 \times Q \times C_r \times \rho_{O2} \times MW_{O2} \times (28.3\ L/ft^3) \times (kg/1{,}000g) \times (1{,}440\ min/day) \times (2.2\ lbs/kg) \times D \times (1/6.2\ gal/lbs)$$

Where:

HC_{Bio}	=	Mass of hydrocarbons biodegraded (gal)
$C_{V,bkgd}$	=	Concentration of oxygen in background, uncontaminated area (%)
$C_{V,O2}$	=	Concentration of oxygen in extracted off-gas (%)
Q	=	Flow rate (standard cubic feet per minute (scfm)
C_r	=	Mass ratio of hydrocarbon to oxygen degraded based on stoichiometry (1/3.5)
ρ_{O2}	=	density of oxygen (moles/liter), 0.0346 mol/L for Albuquerque, New Mexico and 25ºC
MW_{O2}	=	Molecular weight of oxygen (grams/mole), 32 g/mol for O_2
D	=	Days in Operation during Quarter

Based on this equation and an average oxygen deficit in the internal combustion engine influent vapor, the amount of biodegradation occurring at ST-106 (Unit 249) and SS-111 (Units 335, 345, and 344) to date was estimated and is presented in Table A-1.

References

Leeson, A., and R. Hinchee. 1996a. *Principles and Practices of Bioventing, Volume I: Bioventing Principles.* Prepared by Battelle Memorial Institute, Columbus, Ohio, for Catherine M. Vogel, Environics Directorate of the Armstrong Laboratory, Tyndall AFB, Florida Protection Agency; Gregory D. Sayles, National Risk Management Research Laboratory, U.S. Environmental, Brooks AFB, Texas; and Lt. Colonel Ross N. Miller, AFCEE, Technology Transfer Division. September 29.

Leeson, A., and R. Hinchee. 1996b. *Principles and Practices of Bioventing, Volume II: Bioventing Design.* Prepared by Battelle Memorial Institute, Columbus, Ohio, for Catherine M. Vogel, Environics Directorate of the Armstrong Laboratory, Tyndall AFB, Florida Protection Agency; Gregory D. Sayles, National Risk Management Research Laboratory, U.S. Environmental, Brooks AFB, Texas; and Lt. Colonel Ross N. Miller, AFCEE, Technology Transfer Division. September 29.

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TABLE A-1

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Table A-1

Calculation of NAPL Mass Degraded by Bioventing

January 2011 through June 2012[a, c]

Kirtland Air Force Base, New Mexico

		Unit 249 (ST-106)			Unit 335 (Well KAFB-1065)			Unit 345 (Well KAFB-1066)			Unit 344 (Well KAFB-1068)			All Units
Date	Background Oxygen (%)	Oxygen Inlet[b] (%)	Mass Degraded (lbs/period)	Mass Degraded (gal/period)	Oxygen Inlet[b] (%)	Mass Degraded (lbs/period)	Mass Degraded (gal/period)	Oxygen Inlet[b] (%)	Mass Degraded (lbs/period)	Mass Degraded (gal/period)	Oxygen Inlet[b] (%)	Mass Degraded (lbs/period)	Mass Degraded (gal/period)	Total Mass Degraded (gal/period)
1/31/2011	18.02	12.3	3,926	633	14.3	1,198	193	16.0	1,255	202	16.8	1,038	167	1,196
2/28/2011	18.02	12.3	4,180	674	14.3	889	143	16.0	1,617	261	16.8	1,048	169	1,247
3/31/2011	18.02	12.3	4,896	790	14.3	988	159	16.0	1,202	194	16.8	885	143	1,286
4/30/2011	18.9	19.9	0	0	14.3	1,137	183	20.3	0	0	15.3	2,750	444	627
5/31/2011	18.7	11.0	7,007	1,130	15.4	538	87	20.2	0	0	15.9	2,549	411	1,628
6/30/2011	17.2	11.0	5,457	880	11.9	1,027	166	14.4	1,079	174	15.6	692	112	1,332
7/31/2011	19.7	12.1	6,356	1,025	14.3	1,134	183	19.4	172	28	16.9	2,212	357	1,593
8/31/2011	19.8	12.1	7,077	1,141	14.2	1,401	226	16.6	1,150	186	16.8	2,152	347	1,900
9/30/2011	17.8	15.8	1,857	300	14.8	413	67	15.9	675	109	17.1	309	50	525
10/31/2011 [d]		System was not in operation			System was not in operation			System was not in operation			System was not in operation			
11/30/2011 [d]		System was not in operation			System was not in operation			System was not in operation			System was not in operation			
12/31/2011 [d]		System was not in operation			System was not in operation			System was not in operation			System was not in operation			
1/31/2012 [d]		System was not in operation			System was not in operation			System was not in operation			System was not in operation			
2/28/2012 [d]		System was not in operation			System was not in operation			System was not in operation			System was not in operation			
3/31/2012 [d]		System was not in operation			System was not in operation			System was not in operation			System was not in operation			
Apr 2012 - Jun 2012	21.0	15.2	6,226.0	1,004.0	15.5	39,988.0	6,450.0	17.4	15,192.0	2,450.0	15.9	6,955.0	1,122.0	11,026
Total 1/2011 to 3/2011			13,002	2,097		3,076	496		4,074	657		2,970	479	3,729
Total 4/2011 to 6/2011			12,464	2,010		2,703	436		1,079	174		5,991	966	3,587
Total 7/2011 to 9/2011			15,290	2,466		2,948	476		1,998	322		4,673	754	4,018
Total 10/2011 to 12/2011			0	0		0	0		0	0		0	0	0
Total 1/2012 to 3/2012			0	0		0	0		0	0		0	0	0
Total 4/2012 to 6/2012			6,226	1,004		39,988	6,450		15,192	2,450		6,955	1,122	11,026
Total 1/2011 to 6/2012			46,982	7,578		48,715	7,858		22,343	3,603		20,589	3,321	22,360

Notes:

a. All operating values are based on RSI-ICE System PLC (computer program) technical data.

b. Oxygen concentrations are based on field measurements during the March 2011 through December 2011 sampling events.

c. Calculations are based on equation described in the appendix text.

d. All systems were shut down in October 2011 through March 2012 for the Radius of Influence (ROI) tests and pneulog tests.