Metallurgical Laboratory (MetLab) Treatability Study: An Analysis of Passive Soil Vapor Extraction Wells (PSVE) FY1999 Update

by

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Executive Summary

The results to date on the treatability study of the PSVE system at the MetLab of the Savannah River Site indicate the technology is performing well. Well concentrations are decreasing and contour maps of the vadose zone soil gas plume show a decrease in the extent of the plume. In the 18 months of operation approximately 200 pounds of chlorinated organic contaminants have been removed by natural barometric pumping of wells fitted with BaroBall valves (low pressure check valves). The mass removal estimates are approximate since the flow rates are estimated, the concentration data is based on exponential fits of a limited data set, and the concentration data is normalized to the average CO₂ concentrations.

The concentration values presented in this report should be taken as the general trend or order of magnitude of concentration until longer-term data is collected. These trends are of exponentially decreasing concentration showing the same characteristics as the concentration trends at the SRS Miscellaneous Chemical Basin after three years of PSVE (Riha et. al., 1999).

Mass removal during this time frame is primarily attributed to residual contamination in the coarse grained material and some contaminant mass transfer from the finer grained zones to coarse zones where the majority of the PSVE flow is achieved. Removal from the fine grained sediments will be limited by the mass transfer from these zones to the coarse grained zones.

The PSVE system has required minimal operating and maintenance costs and can be expected to operate continuously for at least 10 years with no intervention. All of the vadose zone extraction wells installed can also be used with an active vapor extraction system.

The PSVE system is performing well in a cost-effective manner. It is recommended that this system be allowed to continue operating to verify and monitor the anticipated contaminant removal rates.

Background

Site Description

The Metallurgical Laboratory (MetLab) waste unit is located in the A/M areas of the SRS. During the 1950's to the early 1980's, solvents were used in MetLab facilities to degrease fuel and target tubes prior to use in other facilities at SRS. The solvents used during this period were primarily trichloroethylene (TCE) and tetrachloroethylene (PCE).

Previous Characterization Efforts

Previous work in the area included MetLab Phase I where seven groundwater monitoring wells were installed and one soil boring was completed near the MetLab HWMF. TCE and PCE sediment concentrations in the vadose zone ranged from below detection (<0.001 $\mu\text{g/g}$) to 0.068 and 0.025 $\mu\text{g/g}$ respectively (Van Pelt and Dunbar, 1995). MetLab Phase II included six CPT characterization and soil gas pushes and groundwater sample collection at three locations. TCE and PCE soil gas concentrations ranged from below detection to 15.1 and 7.2 ppmv respectively. The MetLab characterization was initiated to determine the vertical and lateral extent of contaminants in the vadose zone to aid in determining the source of ground water contamination in the area.

During MetLab Phase III, soil gas samples were collected at twenty-nine locations using a cone penetrometer testing (CPT) truck around the metallurgical manufacturing facility in M-Area at the Savannah River Site. This work expanded lateral vadose zone characterization north and east of the MetLab HWMF. The highest soil gas concentrations were found in an isolated area near building 717-A. Concentrations ranged from 88.4 ppmv TCE and 121.6 PCE ppmv near 717-A to non detect levels at the north end of the characterization area. Other contaminants (e.g. trichloroethane, Freon 113, degradation by-products) were also present in the soil gas samples at lower concentrations. The apparent source term is located on the south side of 717-A. The low contaminant concentrations measured at the CPT locations on the north and east side of building 717-A, in the soil gas (<15 ppmv) indicate that the soil gas plume has probably migrated from the apparent source on the south side of Building 717-A. If other source terms were present near the CPT pushes, much higher concentrations would be expected in the soil gas.

Geology

The Savannah River Site is underlain by a thick wedge (approximately 1000 ft) of unconsolidated Tertiary and Cretaceous sediments consisting primarily of sands, clayey sands, and sandy clays. Three fine grain layers in the vadose zone at the MetLab are located at approximately 0-15 ft, 60 ft and 80 ft below ground surface. The water table at the site is approximately 150 ft below the ground surface.

PSVE Well Installation

Nineteen vadose zone wells were installed at the MetLab using CPT during the Phase III characterization. The wells were installed by threading a steel push tip onto the PVC screen and pushing the tip with the steel CPT rods in the center of the PVC, effectively pulling the PVC well down with the push tip. The 6 inch long steel push tip remained in the ground.

The wells were installed so the formation was compressed against the outer surface of the casing and screen, leaving no annular space. This seal is verified by sustained gas pressure differences between the surface and subsurface. The wells were installed with continuous screens from 20 to 80 feet below surface. Concrete pads were installed around the wells at the surface.

Figure 1 - MetLab Vadose Zone Well Locations

Technology Description - Barometric Pumping

Natural atmospheric pressure fluctuations are transmitted through the unsaturated subsurface, however, these pressure waves are damped and delayed in phase to degrees dependent on the effective vertical permeability of the formation. As a result of the attenuation and delay of the transmitted pressure wave, at a given time the atmospheric pressure at the surface and the soil gas pressure in the subsurface will be different. If these two zones are directly connected (by a vadose zone well), the pressure differential will result in a flow either into or out of the well. If the subsurface contains VOCs in the gas phase, flow out of the well will result in removal of the contaminants from the subsurface without mechanical pumping. This phenomena has been observed for more than a century, (the first reference in the literature is an article in Science, 1897 by Fairbanks) but has only recently been proposed for environmental remediation. The technology is also known as barometric pumping. The duration of flow events (either flow into the well or flow out of the well) can be as long as three days continuously but, as expected by mass balance considerations, the average time of flow in is equal to the average time of flow out. The flow rates for a typical well are generally low (.1 to 10 scfm) but if the concentration of the contaminant in the gas phase is high, mass removal by this process can be significant. Rates as high as 1 to 2 kg/day/well have been observed near sources in the A/M Area of SRS. Mass removal can be enhanced using low cost or natural techniques. Enhancements to PSVE include the addition of wind powered turbine vacuum pumps, installation of one way mechanical valves to prevent dilution of the contaminated soil gas by clean air from the surface, and solar heat injection to raise vapor pressures and the partitioning of the VOCs from the liquid or aqueous phases to the gas phase.

The BaroBall is a device developed and patented by WSRC specifically for barometric pumping applications. It uses a lightweight ball in a conical seat to permit gas flow in one direction with a minimal pressure requirement (approximately 1 millibar) but effectively prevents gas flow in the reverse direction. Depending on the configuration, the BaroBall can be used to allow contaminated soil gas out of a well and prevent clean air from diluting the soil gas in the subsurface (standard mode of operation), to inject air and/or nutrients into the subsurface to enhance bioremediation, to control or confine the movement of a subsurface gas phase plume in the vadose zone, or to passively transfer solar heated, water-saturated air into the subsurface to enhance volatilization in the subsurface. The BaroBall device is attached directly to the top of the well casing at the surface.

Application of this technology is directed to any site where volatile substances (chlorinated solvents, petroleum products, etc.) have contaminated the vadose zone. Natural pressure fluctuations and their damped and delayed transmission through the subsurface occur in all environments but are particularly well-suited to sites with large vadose zones or substantial low permeability layers that increase the damping and delay of the atmospheric pressure signal.

Field scale studies have been ongoing at SRS, the Hanford site and the Idaho National Engineering Lab for approximately six years, and a field scale implementation of the technology for control of subsurface methane migration using a combination of passive injection and extraction was installed at a landfill in Richmond County, Georgia. In addition several other contaminated sites, both public and private, have implemented barometric pumping remediation programs with the BaroBall. The 1996 start of PSVE at the SRS Miscellaneous Chemical Basin was the first implementation to directly target the removal of the vadose zone source term.

Methods

Well Vapor Sampling and Analysis Methods

Concentration measurements were made on the vadose zone wells during barometric pumping outflow events. Well vapor was sampled and analyzed using a Bruel and Kjaer Model 1302 photo acoustic infrared gas analyzer. The instrument was calibrated to measure TCE, PCE, and CO₂. The B&K data is inadequate at this site due to interference from the Freon-113. Freon-113 interferes with the PCE and TCE measurements due to similar infrared spectra and the strong sensitivity of the instrument to the Freon. When the interference was discovered, samples were also obtained in Tedlar sample bags and analyzed on an HP 5890 series gas chromatograph (GC). Due to the cost and time involved for the GC analysis, the number of sampling events was limited.

Results and Discussion

Well Flow Rates and Vapor Concentration

Well vapor concentration measurements show mass removal and a concentration decrease in the vadose zone at the MetLab. Well head measurements were made during outflow events with a Bruel and Kjaer infrared photo-acoustic analyzer calibrated for PCE, TCE, and CO₂. When interference on the B&K from Freon-113 was discovered, samples were also obtained in Tedlar sample bags and analyzed on an HP 5890 series gas chromatograph (GC). The contaminant concentrations were normalized with the CO₂ concentrations to the average soil gas CO₂ levels of each well. This normalization provides a more realistic representation of soil gas concentration in the subsurface by correcting for surface air dilution. The Baroballs leak slightly during inflow periods which dilutes the soil gas and produces low readings during the beginning of outflow events. Monitoring of sealed vadose zone wells have shown CO₂ concentrations are fairly constant in the subsurface. However, varying concentrations of CO₂ have been observed to correlate to the TCE and PCE concentrations in individual wells at the Miscellaneous Chemical Basin after three years of monitoring. This is attributed to infiltrating surface air

diluting the soil gas concentration of both CO₂ and the contaminants in a particular well. The normalized concentration values are provided in Appendix A. Both the B&K and the GC values are provided but only the GC values were used for calculations.

Soil gas concentrations measured over this 18 month time period show an exponentially declining concentration as is expected based on a conceptual model of mass transfer from the liquid or aqueous phase in the fine grain zones to the gas phase in the coarse grain sediments. The data from the GC analysis was limited and most data points used for the exponential fits do not cover the entire 18 month period. The date range and number of data points used for each fit is provided in Table 1 and the data is provided in Appendix A. Note the data were limited and some of the correlation coefficients (quality of fit) were low but most of the wells show a decreasing trend. The concentrations were projected back to the start of the PSVE (May 1998) to estimate size and concentration of the soil gas plume and mass removal. An average concentration was used for some of the lower concentration wells. The parameters for the exponential concentration decline equations are provided in Table 2 and 3. Concentration trends along with the correlation coefficient (quality of fit) from several wells are shown in Figure 2 and 3.

The concentration values from the exponential fits to the field data should be taken as the general trend or order of magnitude of concentration until longer-term data is collected. These trends are showing the same characteristics as the concentration trends at the SRS Miscellaneous Chemical Basin after three years of PSVE (Riha et. al., 1999).

A contour plot of the average CO₂ well vapor concentrations is shown in Figure 4. CO₂ levels increase from west to east. The differences in CO₂ levels may be attributed to higher biological activity on the east side and/or greater surface air inflow on the west side of the site. The average Freon-113 concentrations are shown on the contour plot in Figure 5. The concentrations are low and do not correspond with the higher TCE and PCE concentrations. This difference in plume locations may be attributed to the higher volatility of Freon 113 or it may indicate the Freon-113 is migrating from a different source to the south. In either case, the Freon-113 concentrations are low.

Table 1 – Trend Data Information and Average CO₂ and Freon-113 Concentrations

Well ID	Number of Data Points used for trends or Average Values Used	Date Range	Average CO ₂ ppmv	Average Freon 113, ppmv
MLBB-001	6	10/14/97-9/21/99	5,475	0.41
MLBB-002	3	12/29/98-9/21/99	6,091	0.99
MLBB-003	3.56 PCE, 3.01 TCE	12/29/98-8/27/99	9,324	0.13
MLBB-004	5	12/29/98-9/21/99	10,933	0.90
MLBB-006	3	11/24/98-9/21/99	4,138	0.52
MLBB-007	3	12/29/98-9/21/99	4,146	3.33
MLBB-008	8	5/8/98-8/26/99	9,252	0.94
MLBB-009	5	12/29/98-8/26/99	15,579	3.78
MLBB-010	6	11/24/98-9/21/99	8,735	1.23
MLBB-011	5	12/29/98-8/26/99	15,093	3.83
MLBB-012	5	12/16/98-8/26/99	12,907	0.76
MLBB-013	0.70 PCE, 0.54 TCE	12/29/98-8/27/99	15,000	0.63
MLBB-014	5	12/29/98-8/27/99	16,023	0.47
MLBB-015	6	12/16/98-8/27/99	13,825	1.71
MLBB-016	5	12/29/98-8/26/99	15,677	4.71
MLBB-017	1.79 PCE, 2.01 TCE	12/29/98-8/26/99	13,565	4.60
MLBB-018	5	12/29/98-8/26/99	12,429	4.67
MLBB-019	3.25 PCE, 1.84 TCE	3/25/99-8/27/99	10,046	1.04
MLBB-020	0.64 PCE, 0.38 TCE	5/24/99-8/27/99	13,998	0.67

Figure 2 – PCE Well Vapor Concentration Trends

Figure 3 – TCE Well Vapor Concentration Trends

Figure 4 – Average CO₂ Well Vapor Concentration Contour (ppmv)

Figure 5 – Average Freon-113 Well Vapor Concentration Contour (ppmv)

Concentration contour plots of TCE and PCE well concentrations at 5/98, 10/98, 5/99 and 10/99 are provided in Figures 6 through 9. The wells have long screens (60 ft) so these plots show a general representation of the soil gas plume at the unit. Over the 18 months of PSVE with Baroball flow enhancement, the soil gas plume has decreased in concentration and size. Note these plots are based on the limited data as discussed above and will change, but the general decreasing trend is expected to continue.

Figure 6 – TCE Soil Gas Plume Contours, ppmv

Figure 7 – TCE Soil Gas Plume Contours, ppmv

Figure 8 – PCE Soil Gas Plume Contours, ppmv

Figure 9 – PCE Soil Gas Plume Contours, ppmv

Flow Control Enhancement of Mass Removal

Flow control enhancement has been proven to increase mass removal by at least a factor of 2 (May et al., 1994 and Rössabi, 1999). Theoretically, without any engineering controls, the volume of soil gas outflow is approximately equal to the volume inflow in an open vadose zone well. Under these conditions, air entering the vadose zone will dilute the soil gas and force the soil gas plume away from the well. The soil gas removed after an inflow event will thus be a mixture of surface air and soil gas, effectively reducing the mass of contaminants removed.

With flow control which only allows outflow, the soil gas is not diluted and a step process is created which brings contaminants from further distances from the well screen with each successive outflow event. Also, when wells are not flowing out (checked inflow event), contaminants will move into the coarse grained sediments by mass transfer and will be removed during the next outflow event(s). The Baroball check valve does leak slightly during inflow events and will produce some subsurface dilution dependent on the length of the inflow event.

Mass Removal Estimation

Based on the concentration curves for 19 wells installed at MetLab, the mass of contaminants removed can be estimated. The assumptions include a uniform average flow rate of 1 cfm out of all of the wells based on measured flow from other PSVE wells, initial concentrations estimated from the concentration trends on 5/1/98 and final concentration projected using the rate constants from approximately 18 months of monitoring. Physically observed vapor flow and concentration measurements indicate mass removal from the vadose zone at the MetLab.

Well flow rates have not been measured at the MetLab so PSVE flow rates from nearby wells are used for estimating the mass removal. The average flow measured from 2 inch diameter PSVE wells at the Miscellaneous Chemical Basin and near the M-Area Basin is approximately 2 cfm during outflow events. Since soil gas is removed 50% of the time with barometric pumping, the continuous average flow out of the wells is 1 cfm. The area under the removal curves is calculated and multiplied by the flow rate to obtain the mass of contaminant removed. The total mass removed at the MetLab for a given time period is the sum of the mass removed from the individual wells. The calculated mass removal is presented in Tables 2 and 3.

After 18 months of PSVE more than 200 lbs of chlorinated organic contaminants have been removed by the natural barometric pumping of wells fitted with BaroBall valves. The mass removal estimates are approximate since the flow rates are estimated, the concentration data is based on exponential fits of a limited data set, and the concentration data is normalized to the average CO₂ concentrations.

Figure 10 – Cumulative Mass Removed

Table 2 – Fitted PCE Concentration Data and Estimated Mass Removed by Well

Well ID	Decay Constant B	Well Vapor PCE Concentration, ppmv				Cumulative PCE Mass Removed, lbs		
		0-Year	1-Year		2-Year	1-Year		2-Year
		May-98	May-99	Oct-99	May-00	May-99	Oct-99	May-00
MLBB-001	-8.8605E-04	47.82	34.61	30.22	25.02	8.99	11.96	15.50
MLBB-002	-3.2217E-03	39.04	12.04	7.36	3.70	4.86	5.71	6.36
MLBB-003	Average used	3.56	3.56	3.56	3.56	0.79	1.13	1.59
MLBB-004	-9.3625E-04	12.35	8.77	7.60	6.23	2.30	3.05	3.93
MLBB-006	-1.2655E-03	97.57	61.48	50.66	38.69	17.09	22.19	27.86
MLBB-007	-3.2382E-03	68.49	21.01	12.80	6.42	8.51	9.98	11.12
MLBB-008	-1.6731E-03	101.30	55.00	42.58	29.82	16.47	20.87	25.41
MLBB-009	-2.5705E-03	50.90	19.92	13.44	7.77	7.07	8.54	9.84
MLBB-010	-1.7055E-03	106.33	57.06	43.95	30.56	17.19	21.74	26.41
MLBB-011	-1.7274E-03	11.01	5.86	4.50	3.11	1.77	2.24	2.72
MLBB-012	-1.7681E-03	63.17	33.13	25.28	17.35	10.10	12.73	15.39
MLBB-013	Average used	0.70	0.70	0.70	0.70	0.16	0.22	0.31
MLBB-014	-1.6630E-03	3.08	1.68	1.30	0.91	0.50	0.64	0.77
MLBB-015	-3.2711E-03	34.76	10.53	6.39	3.18	4.30	5.03	5.60
MLBB-016	-1.5716E-03	3.22	1.81	1.43	1.02	0.53	0.68	0.83
MLBB-017	Average used	1.79	1.79	1.79	1.79	0.40	0.57	0.80
MLBB-018	-6.8063E-03	6.24	0.52	0.18	0.04	0.46	0.49	0.50
MLBB-019	Average used	3.25	3.25	3.25	3.25	0.73	1.03	1.45
MLBB-020	Average used	0.60	0.60	0.60	0.60	0.13	0.19	0.27
Total PCE Removed, lbs						102.36	128.96	156.67

Concentration (ppmv) = $Ae^{(Bt)}$ where A is 0-Year concentration and t is time in days

Table 3 – Fitted TCE Concentration Data and Estimated Mass Removed by Well

Well ID	Decay Constant B	Well Vapor TCE Concentration, ppmv				Cumulative TCE Mass Removed, lbs		
		0-Year	1-Year		2-Year	1-Year		2-Year
		5/1/98	5/1/99	10/1/99	5/1/00	5/1/99	10/1/99	5/1/00
MLBB-001	-6.70E-04	33.21	26.01	23.47	20.35	6.51	8.78	11.60
MLBB-002	-2.06E-03	19.30	9.08	6.62	4.27	2.93	3.63	4.30
MLBB-003	Average used	3.01	3.01	3.01	3.01	0.67	0.95	1.34
MLBB-004	-2.51E-03	6.24	2.50	1.70	1.00	0.88	1.06	1.23
MLBB-006	-4.18E-04	55.13	47.33	44.40	40.62	11.34	15.57	21.07
MLBB-007	-3.34E-03	55.90	16.52	9.91	4.86	6.83	7.97	8.85
MLBB-008	-1.29E-03	78.38	48.94	40.18	30.52	13.67	17.72	22.20
MLBB-009	-2.53E-03	50.28	19.95	13.54	7.90	7.03	8.51	9.82
MLBB-010	-1.77E-03	87.86	46.13	35.21	24.18	14.05	17.71	21.43
MLBB-011	-1.51E-03	7.96	4.58	3.63	2.63	1.33	1.70	2.10
MLBB-012	-2.37E-03	48.27	20.30	14.12	8.52	6.94	8.46	9.85
MLBB-013	Average used	0.54	0.54	0.54	0.54	0.12	0.17	0.24
MLBB-014	-7.64E-04	1.26	0.95	0.85	0.72	0.24	0.32	0.43
MLBB-015	-2.91E-03	16.32	5.64	3.61	1.94	2.14	2.54	2.88
MLBB-016	-1.07E-03	2.95	1.99	1.69	1.35	0.54	0.70	0.90
MLBB-017	Average used	2.01	2.01	2.01	2.01	0.45	0.64	0.90
MLBB-018	-5.79E-03	9.44	1.14	0.47	0.14	0.80	0.86	0.90
MLBB-019	Average used	1.84	1.84	1.84	1.84	0.41	0.58	0.82
MLBB-020	Average used	0.4	0.40	0.40	0.40	0.09	0.13	0.18
Total TCE Removed, lbs						76.96	98.03	121.03

Concentration (ppmv) = $Ae^{(Bt)}$ where A is 0-Year concentration and t is time in days

Conclusions

The results to date on the treatability study of the PSVE system at the MetLab of the Savannah River Site indicate the technology is performing well. Well concentrations are decreasing and contour maps of the vadose zone soil gas plume show a decrease in the extent of the plume. In the 18 months of operation approximately 200 pounds of chlorinated organic contaminants have been removed by natural barometric pumping of wells fitted with BaroBall valves (low pressure check valves). The mass removal estimates are approximate since the flow rates are estimated, the concentration data is based on exponential fits of a limited data set, and the concentration data is normalized to the average CO₂ concentrations.

The concentration values presented in this report should be taken as the general trend or order of magnitude of concentration until longer-term data is collected. These trends are of exponentially decreasing concentration showing the same characteristics as the concentration trends at the SRS Miscellaneous Chemical Basin after three years of PSVE (Riha et. al., 1999).

Mass removal during this time frame is primarily attributed to residual contamination in the coarse grained material and some contaminant mass transfer from the finer grained zones to coarse zones where the majority of the PSVE flow is achieved. Removal from the fine grained sediments will be limited by the mass transfer from these zones to the coarse grained zones.

The PSVE system has required minimal operating and maintenance costs and can be expected to operate continuously for at least 10 years with no intervention. All of the vadose zone extraction wells installed can also be used with an active vapor extraction system.

Recommendations

The PSVE system is performing well in a cost-effective manner. The following recommendations are intended to refine the concentration data and estimates of contaminant removal.

- Continue monthly well vapor sampling and gas chromatograph analysis to refine the exponential concentration trends and verify the anticipated contaminant removal.
- Install a flow measurement system on several wells to provide a better estimate of PSVE flow rates and contaminant removal at the MetLab.
- Install additional wells between buildings 722-A and 722-4A and to the east of building 722-A to bound the soil gas plume.
- Continue to evaluate the low concentration Freon-113 plume to determine if an additional contaminant source is indicated.
- Collect soil samples near wells MLBB-006 and MLBB-008 to determine the maximum concentration intervals and to evaluate the remediation progress.

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APPENDIX A - Well Vapor Concentrations

	MLBB-001 GC						MLBB-002 GC						MLBB-003 GC					
Date	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113
10/14/97	66.08	35.29	7300	57.69	38.94	0.39	34.10	19.78	8130	nm	nm	nm	4.58	3.01	3750	nm	nm	nm
5/8/98	50.52	32.34	5590	51.12	40.19	0.23	38.06	26.45	7850	nm	nm	nm	6.39	4.13	7850	nm	nm	nm
6/30/98	20.64	11.86	3790	nm	nm	nm	9.37	4.51	2600	nm	nm	nm	3.33	2.51	5980	nm	nm	nm
8/10/98	25.64	13.78	3900	nm	nm	nm	11.17	6.02	3310	nm	nm	nm	3.38	2.60	6280	nm	nm	nm
9/8/98	48.63	26.93	6120	nm	nm	nm	25.25	14.15	4410	nm	nm	nm	3.49	2.37	12600	nm	nm	nm
11/24/98	34.43	17.38	3880	31.20	16.97	0.16	19.32	11.23	4970	nm	nm	nm	2.97	0.42	11800	nm	nm	nm
12/8/98	10.22	5.79	4390	nm	nm	nm	nm	nm	nm	nm	nm	nm	2.80	0.60	9010	nm	nm	nm
12/16/98	18.92	9.51	3120	7.77	6.10	nd	10.05	3.18	4070	nm	nm	nm	3.67	0.13	9490	nm	nm	nm
12/29/98	53.60	26.50	7880	43.22	32.65	0.25	22.34	9.69	9830	17.77	11.76	0.78	3.35	0.17	13500	2.11	2.07	0.04
2/2/99	58.17	28.92	7330	nm	nm	nm	20.93	9.11	9230	nm	nm	nm	3.93	0.45	11200	nm	nm	nm
3/9/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
3/25/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
5/24/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	2.88	1.58	10500	2.87	2.34	0.11
6/14/99	4.07	5.37	1330	5.95	5.11	nd	0.14	3.86	1360	9.44	7.50	nd	nm	nm	nm	nm	nm	nm
6/15/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/16/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/17/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	0.30	1.10	6670	0.67	0.97	nd
7/7/99	40.14	30.04	8550	32.15	26.75	0.96	14.02	9.53	10100	9.93	7.85	1.24	nm	nm	nm	nm	nm	nm
7/19/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	6.98	5.63	11100	6.76	5.07	0.29
8/26/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
8/27/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	5.16	4.98	10800	5.42	4.60	0.06
9/21/99	41.85	29.94	7990	32.41	25.94	0.48	12.18	7.78	7230	7.47	6.81	0.95	nm	nm	nm	nm	nm	nm

All concentrations in ppmv and normalized by CO2 levels.

Shaded values are from the B&K. Non-shaded values are from gas chromatography analysis

nm = not measured

nd = not detected

italicized values were not used – low CO2 indicates non-representative sample

	MLBB-004 GC						MLBB-006 GC						MLBB-007 GC					
Date	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113
10/14/97	18.43	10.64	8140	nm	nm	nm	85.96	57.42	3490	nm	nm	nm	29.03	22.49	2220	nm	nm	nm
5/8/98	17.45	8.88	8390	nm	nm	nm	108.99	67.83	4140	nm	nm	nm	66.38	45.12	5080	nm	nm	nm
6/30/98	11.36	5.81	11300	nm	nm	nm	60.67	36.07	3560	nm	nm	nm	20.34	15.81	1670	nm	nm	nm
8/10/98	10.17	4.91	10700	nm	nm	nm	61.76	36.47	3070	nm	nm	nm	21.85	10.68	1450	nm	nm	nm
9/8/98	10.91	4.88	12100	nm	nm	nm	76.45	47.18	4960	nm	nm	nm	32.58	19.51	3020	nm	nm	nm
11/24/98	15.61	3.01	11300	nm	nm	nm	82.01	44.02	3980	63.14	42.51	0.33	20.49	13.89	2800	nm	nm	nm
12/8/98	12.40	2.94	11900	nm	nm	nm	40.44	22.58	2620	88.76	60.27	0.46	10.78	6.70	1770	nm	nm	nm
12/16/98	12.00	2.00	10900	nm	nm	nm	71.35	37.95	3700	nm	nm	nm	18.08	9.20	2230	nm	nm	nm
12/29/98	13.23	2.66	12700	10.05	3.55	1.20	115.55	61.15	7280	nm	nm	nm	43.46	24.07	6930	31.71	25.54	3.97
2/2/99	12.49	2.08	12300	nm	nm	nm	108.42	57.90	6010	nm	nm	nm	40.37	21.30	6480	nm	nm	nm
3/9/99	nm	nm	nm	nm	nm	nm	76.78	38.16	2110	nm	nm	nm	nm	nm	nm	nm	nm	nm
3/25/99	nm	nm	nm	nm	nm	nm	26.95	14.63	1870	10.20	13.09	nd	nm	nm	nm	nm	nm	nm
5/24/99	10.63	2.59	13100	8.63	2.12	1.30	nm	nm	nm	nm	nm	nm	25.29	16.22	8210	18.87	14.48	3.87
6/14/99	nm	nm	nm	nm	nm	nm	7.79	12.38	1880	15.13	13.02	nd	8.19	7.41	1700	5.29	4.31	nd
6/15/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/16/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/17/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
7/7/99	nm	nm	nm	nm	nm	nm	74.42	53.64	7740	nm	nm	nm	28.27	15.83	8490	nm	nm	nm
7/19/99	11.01	3.56	12100	7.58	2.18	0.93	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
8/26/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
8/27/99	9.36	1.84	6130	7.38	1.66	0.14	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
9/21/99	11.80	3.15	12000	8.56	1.95	0.95	62.33	48.34	5660	50.95	44.20	0.76	23.60	12.38	6000	13.44	10.56	2.16

All concentrations in ppmv and normalized by CO2 levels.

Shaded values are from the B&K. Non-shaded values are from gas chromatography analysis

nm = not measured

nd = not detected

italicized values were not used – low CO2 indicates non-representative sample

	MLBB-008 GC						MLBB-009 GC						MLBB-010 GC					
Date	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113
10/14/97	83.06	60.10	5750	nm	nm	nm	105.81	78.58	12400	nm	nm	nm	82.18	54.42	4410	nm	nm	nm
5/8/98	98.40	66.80	6000	78.30	61.58	0.94	75.73	61.07	12000	nm	nm	nm	81.91	56.35	6900	nm	nm	nm
6/30/98	93.01	58.09	8180	nm	nm	nm	55.43	41.81	15500	nm	nm	nm	83.74	54.31	8440	nm	nm	nm
8/10/98	90.00	59.26	8080	nm	nm	nm	53.86	42.04	16100	nm	nm	nm	78.52	53.67	7580	nm	nm	nm
9/8/98	91.76	57.93	7520	nm	nm	nm	46.99	35.92	15900	nm	nm	nm	68.14	46.72	9580	nm	nm	nm
11/24/98	116.34	71.29	9190	85.23	75.79	1.08	49.01	30.44	17400	nm	nm	nm	107.00	70.24	9140	45.60	37.30	2.26
12/8/98	105.07	60.93	9000	69.07	60.65	0.85	48.00	31.30	16000	nm	nm	nm	117.80	68.51	8180	nm	nm	nm
12/16/98	102.15	61.53	9010	79.50	69.64	1.00	43.64	28.40	16900	nm	nm	nm	109.31	68.50	9320	90.95	78.68	1.27
12/29/98	109.76	65.61	10900	nm	nm	nm	42.20	26.50	16000	28.86	29.26	4.89	73.95	46.44	12300	nm	nm	nm
2/2/99	95.12	58.13	10900	nm	nm	nm	38.76	24.45	16100	nm	nm	nm	71.25	43.18	11200	nm	nm	nm
3/9/99	96.33	57.24	9119	101.33	59.48	1.32	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
3/25/99	57.24	38.79	9560	41.79	40.97	0.88	nm	nm	nm	nm	nm	nm	87.49	49.63	6940	71.01	52.18	0.12
5/24/99	72.20	48.39	12300	nm	nm	nm	27.50	19.54	16700	18.37	18.16	4.27	nm	nm	nm	nm	nm	nm
6/14/99	52.29	46.93	8720	52.33	51.36	0.70	39.94	18.80	14300	17.20	16.17	4.71	95.58	65.87	6340	92.18	75.35	0.79
6/15/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/16/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/17/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
7/7/99	62.54	47.19	11800	nm	nm	nm	38.52	18.85	15700	13.94	14.56	3.06	42.72	27.55	12500	nm	nm	nm
7/19/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
8/26/99	nm	nm	12000	35.01	34.12	0.74	28.07	21.61	17100	17.63	18.13	1.99	63.05	44.59	6890	47.63	37.50	0.77
8/27/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
9/21/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	44.39	27.82	11300	27.98	23.48	2.17

All concentrations in ppmv and normalized by CO2 levels.

Shaded values are from the B&K. Non-shaded values are from gas chromatography analysis

nm = not measured

nd = not detected

italicized values were not used – low CO2 indicates non-representative sample

	MLBB-011 GC						MLBB-012 GC						MLBB-013 GC					
Date	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113
10/14/97	29.78	21.60	11000	nm	nm	nm	81.44	51.79	11700	nm	nm	nm	5.42	2.58	10000	nm	nm	nm
5/8/98	19.12	14.44	12300	nm	nm	nm	63.41	38.64	10900	nm	nm	nm	3.63	2.11	13300	nm	nm	nm
6/30/98	16.36	11.45	15400	nm	nm	nm	46.51	27.16	12900	nm	nm	nm	3.12	2.04	16900	nm	nm	nm
8/10/98	16.38	11.62	15900	nm	nm	nm	43.73	25.73	13200	nm	nm	nm	3.02	1.62	15900	nm	nm	nm
9/8/98	14.83	10.14	16100	nm	nm	nm	44.78	25.16	13400	nm	nm	nm	2.78	1.49	18000	nm	nm	nm
11/24/98	21.78	10.01	15700	nm	nm	nm	50.03	22.15	13000	nm	nm	nm	1.49	0.84	10700	nm	nm	nm
12/8/98	18.35	9.14	15500	nm	nm	nm	50.64	24.91	13200	nm	nm	nm	2.78	nm	15900	nm	nm	nm
12/16/98	18.69	8.77	15600	nm	nm	nm	49.09	23.18	13200	40.05	26.71	0.58	2.33	nm	13900	nm	nm	nm
12/29/98	18.35	7.90	15500	7.70	5.74	4.85	52.18	23.27	13200	nm	nm	nm	2.78	nm	16700	0.78	0.63	0.82
2/2/99	15.85	7.08	15600	nm	nm	nm	47.82	21.13	13400	nm	nm	nm	2.64	nm	17200	0.90	0.66	0.78
3/9/99	15.58	6.57	15400	6.69	5.28	4.64	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
3/25/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
5/24/99	nm	nm	nm	nm	nm	nm	40.20	18.22	13700	35.07	21.91	0.83	nm	nm	nm	nm	nm	nm
6/14/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/15/99	21.49	6.45	15300	4.56	3.54	4.06	36.65	20.12	13000	28.86	17.01	0.78	nm	nm	nm	nm	nm	nm
6/16/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	2.57	2.28	16300	0.64	0.66	0.60
6/17/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
7/7/99	24.00	6.59	15800	4.31	3.64	2.73	36.82	20.09	13200	34.88	19.10	0.90	nm	nm	nm	nm	nm	nm
7/19/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	3.12	1.68	17100	0.52	0.51	0.55
8/26/99	19.56	7.27	16200	6.19	4.77	2.86	30.71	16.25	12700	23.15	13.76	0.72	nm	nm	nm	nm	nm	nm
8/27/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	2.13	0.59	13100	0.64	0.24	0.42
9/21/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm

All concentrations in ppmv and normalized by CO2 levels.

Shaded values are from the B&K. Non-shaded values are from gas chromatography analysis

nm = not measured

nd = not detected

italicized values were not used – low CO2 indicates non-representative sample

Date	MLBB-014 GC						MLBB-015 GC						MLBB-016 GC					
	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113
10/14/97	11.49	5.76	11800	nm	nm	nm	nm	nm	nm	nm	nm	nm	17.42	12.58	10400	nm	nm	nm
5/8/98	5.88	3.22	13000	nm	nm	nm	nm	nm	nm	nm	nm	nm	13.88	10.50	12800	nm	nm	nm
6/30/98	4.62	2.51	16700	nm	nm	nm	15.38	9.39	10300	nm	nm	nm	11.71	8.46	16600	nm	nm	nm
8/10/98	3.92	2.22	16700	nm	nm	nm	nm	nm	nm	nm	nm	nm	11.49	8.24	16600	nm	nm	nm
9/8/98	3.95	1.94	17400	nm	nm	nm	15.61	9.15	14300	nm	nm	nm	11.16	7.72	17100	nm	nm	nm
11/24/98	4.82	0.19	15700	nm	nm	nm	24.37	8.95	12900	nm	nm	nm	13.63	5.37	16200	nm	nm	nm
12/8/98	4.04	nm	16500	nm	nm	nm	18.26	7.70	13800	nm	nm	nm	14.00	5.89	16200	nm	nm	nm
12/16/98	4.35	nm	16400	nm	nm	nm	19.45	7.50	13700	17.25	9.02	1.59	13.40	5.07	16300	nm	nm	nm
12/29/98	3.97	nm	16500	2.21	1.14	0.62	17.78	6.58	13900	nm	nm	nm	13.94	5.38	16100	2.18	2.26	5.68
2/2/99	3.42	nm	16900	1.80	0.96	0.51	15.63	5.72	14200	nm	nm	nm	12.80	4.78	16400	2.27	2.20	5.09
3/9/99	nm	nm	nm	nm	nm	nm	16.03	5.34	13700	15.62	7.12	1.80	nm	nm	nm	nm	nm	nm
3/25/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
5/24/99	nm	nm	nm	nm	nm	nm	10.90	5.54	15300	7.76	4.53	1.65	nm	nm	nm	nm	nm	nm
6/14/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/15/99	nm	nm	nm	nm	nm	nm	16.38	6.30	14800	6.88	4.22	2.09	23.54	5.15	15700	1.26	1.86	4.64
6/16/99	3.52	1.82	17100	1.54	0.81	0.49	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/17/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
7/7/99	nm	nm	nm	nm	nm	nm	14.61	5.50	15200	7.29	4.09	1.87	nm	nm	nm	nm	nm	nm
7/19/99	3.39	1.63	17200	1.44	0.91	0.42	nm	nm	nm	nm	nm	nm	25.30	5.24	16600	1.85	2.00	4.78
8/26/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	19.36	4.29	16800	1.61	1.66	3.35
8/27/99	2.81	1.49	16400	1.43	0.95	0.39	13.83	6.65	13800	10.57	5.30	1.25	nm	nm	nm	nm	nm	nm
9/21/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm

All concentrations in ppmv and normalized by CO2 levels.

Shaded values are from the B&K. Non-shaded values are from gas chromatography analysis

nm = not measured

nd = not detected

italicized values were not used – low CO2 indicates non-representative sample

Date	MLBB-017						MLBB-018						MLBB-019					
	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113	PCE	TCE	CO2	PCE	TCE	FR113
10/14/97	24.81	17.77	10400	nm	nm	nm	21.29	15.53	10200	nm	nm	nm	9.95	2.81	1025	nm	nm	nm
5/8/98	18.09	12.74	13000	nm	nm	nm	20.73	14.28	12100	nm	nm	nm	12.20	6.58	12100	nm	nm	nm
6/30/98	13.90	9.65	15800	nm	nm	nm	15.70	10.71	14900	nm	nm	nm	6.80	4.55	11100	nm	nm	nm
8/10/98	12.25	8.67	14400	nm	nm	nm	12.56	8.57	12800	nm	nm	nm	4.91	3.49	6080	nm	nm	nm
9/8/98	12.15	8.42	16100	nm	nm	nm	13.20	8.89	17000	nm	nm	nm	6.45	3.31	5690	nm	nm	nm
11/24/98	9.17	3.10	8740	nm	nm	nm	6.97	1.75	10100	nm	nm	nm	4.91	2.22	4860	nm	nm	nm
12/8/98	13.70	5.95	14100	nm	nm	nm	12.43	5.16	14000	nm	nm	nm	3.02	2.22	2540	nm	nm	nm
12/16/98	11.11	4.08	12100	nm	nm	nm	7.65	1.95	10400	nm	nm	nm	6.17	0.84	10800	nm	nm	nm
12/29/98	14.58	5.92	15800	1.81	2.08	6.58	16.58	6.73	16500	1.00	1.77	8.44	6.58	1.04	13200	nm	nm	nm
2/2/99	13.54	5.46	15600	1.79	2.22	5.95	16.10	6.82	16700	nm	nm	nm	5.43	0.48	12000	nm	nm	nm
3/9/99	nm	nm	nm	nm	nm	nm	10.84	3.67	12400	nd	1.95	5.55	nm	nm	nm	nm	nm	nm
3/25/99	nm	nm	nm	nm	nm	nm	10.08	3.53	12500	0.61	1.50	5.05	4.53	0.15	12400	1.87	1.51	0.76
5/24/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	4.57	2.21	14700	3.08	1.87	0.97
6/14/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/15/99	22.25	5.32	15100	1.80	2.42	4.36	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/16/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6/17/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
7/7/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	7.51	3.05	14500	2.89	1.93	1.00
7/19/99	20.73	4.75	14300	1.19	1.93	3.78	15.09	3.41	9860	0.38	1.11	2.91	7.98	2.76	14400	2.34	1.84	1.11
8/26/99	14.75	3.39	10900	2.37	1.39	2.31	6.93	0.85	4540	0.19	0.37	1.40	nm	nm	nm	nm	nm	nm
8/27/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	8.71	2.96	15300	6.07	2.05	1.36
9/21/99	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm

All concentrations in ppmv and normalized by CO2 levels.

Shaded values are from the B&K. Non-shaded values are from gas chromatography analysis

nm = not measured

nd = not detected

italicized values were not used – low CO2 indicates non-representative sample

Date	MLBB-020			GC		
	PCE	TCE	CO2	PCE	TCE	FR113
10/14/97	4.02	3.68	1075	nm	nm	nm
5/8/98	3.66	1.19	14100	nm	nm	nm
6/30/98	2.28	1.05	15500	nm	nm	nm
8/10/98	1.95	0.96	14200	nm	nm	nm
9/8/98	2.37	0.86	14900	nm	nm	nm
11/24/98	1.30	nm	11700	nm	nm	nm
12/8/98	0.73	1.67	2300	nm	nm	nm
12/16/98	1.64	nm	10900	nm	nm	nm
12/29/98	1.72	nm	15100	nm	nm	nm
2/2/99	1.58	nm	13800	nm	nm	nm
3/9/99	nm	nm	nm	nm	nm	nm
3/25/99	nm	nm	nm	nm	nm	nm
5/24/99	1.77	0.72	21700	0.62	0.38	0.69
6/14/99	nm	nm	nm	nm	nm	nm
6/15/99	nm	nm	nm	nm	nm	nm
6/16/99	nm	nm	nm	nm	nm	nm
6/17/99	3.93	1.19	20200	0.64	0.36	0.59
7/7/99	nm	nm	nm	nm	nm	nm
7/19/99	3.84	1.16	20700	0.66	0.40	0.72
8/26/99	nm	nm	nm	nm	nm	nm
8/27/99	3.50	1.03	19800	0.62	nd	nd
9/21/99	nm	nm	nm	nm	nm	nm

All concentrations in ppmv and normalized by CO2 levels.

Shaded values are from the B&K. Non-shaded values are from gas chromatography analysis

nm = not measured

nd = not detected

italicized values were not used – low CO2 indicates non-representative sample