GE Global Research

123457

Microcosm Study Report for Abiotic Degradation in the Gypsum-Rich Bedrock Unit at former Powerex Inc, Auburn, NY Site

Mark Harkness, Claire Susan Henderson, Nathan Mclean and Angela Fisher

2011GRC799, September 2011

Public (Class 1)

Technical Information Series

R2-0025128

GE Global Research

Technical Report Abstract Page

Title	Microcosm Study Report for Abiotic Degradation in the Gypsum-Rich Bedrock Unit at former Powerex Inc, Auburn, NY Site		
Author(s)	Mark Harkness Claire Henderson Nathan Mclean Angela Fisher	**Phone**	1 518-387-5949 1 518-387-7769 1 518-387-4887 1 518-387-7392
Component	Environmental Technology Laboratory, Niskayuna		
Report Number	2011GRC799	**Date**	September 2011
Number of Pages	54	**Class**	Public (Class 1)

Key Words: Trichloroethene, Microcosm Study, Bioremediation, Abiotic Degradation, Iron Sulfide

Abstract: A microcosm study was performed to assess the presence of abiotic degradation using black, fine-grained material (sediment) and groundwater obtained from a gypsum-rich bedrock unit at a former industrial site in Upstate New York. The site is highly biologically active, supporting extensive reductive dechlorination of high levels of trichloroethene (TCE).

Levels of TCE up to 500 milligrams per liter (mg/L) have been observed in groundwater in a gypsum-rich bedrock unit at an industrial site in Upstate New York. This bedrock unit has an average thickness of 6.2 feet and occurs more than 150 feet below grade. The site is biologically active and daughter products of reductive dechlorination (e.g., cis-1,2-dichloroethene [cDCE], vinyl chloride [VC], and ethene) are present. Groundwater concentrations in this unit decline substantially as measured in downgradient monitoring wells. The sulfate concentrations average more than 500 mg/L and sulfide is present, whereas ferrous iron is absent, indicating the gypsum-rich bedrock unit is sulfate rich and iron poor. Black iron sulfide material is present at the bottom of monitoring wells screened in this interval, suggesting that abiotic degradation may be an important attenuation process.

Samples of the black sediment were obtained from four on-site monitoring wells screened in the gypsiferous unit using methods carefully designed to protect the samples from oxidation. The samples were transported to the General Electric Company's (GE's) Global Research Center (GRC) in Niskayuna, New York and moved into an anaerobic chamber where all subsequent manipulations were performed. The samples were concentrated and dried, then submitted for a number of analyses used to characterize the mineral forms present, including x-ray fluorescence (XRF), x-ray diffraction (XRD), and determination of acid-volatile and chromium extractable sulfides (AVS and CES, respectively). The analyses confirmed the presence of both mackinowite and pyrite in the samples in varying ratios.

A laboratory microcosm study was subsequently performed using sediment and groundwater from all four wells, including treatments that were unamended, amended with lactate, amended with lactate and ferric citrate or ferrous chloride, and autoclaved and gamma-irradiated controls. The bottles were spiked with TCE to 20 mg/L and run in duplicate. The microcosm study was completed in 252 days. The study results reflect that both TCE and cDCE were degraded in autoclaved or gamma-irradiated controls, presumably by the iron-sulfide minerals shown to be present in the sediment. TCE losses ranged from 24 to 54 percent (%) with excellent reproducibility between duplicates, while losses in cDCE ranged from 9 to 33%. Fluid removal was tracked during sampling, so that losses due to sampling were estimable. When these losses were removed, net losses of TCE and cDCE were 24 to 48% and 4 to 24%, respectively. Compound-specific isotope analysis (CSIA) confirmed the losses were at least partially due to degradation and not sorption or other sampling loss. Biotic reductive dechlorination was also observed in some of the bottles, as evidenced by the production of daughter products. Reductive dechlorination was significantly enhanced by the addition of ferric or ferrous iron to the bottles, presumably due to the removal of inhibitory levels of hydrogen sulfide through reaction with the added iron. The results suggest that abiotic degradation contributes to the significant attenuation of TCE and its daughter products observed at the site.

Manuscript received September 04, 2011

Introduction

For more than two decades, anaerobic biodegradation has been the subject of intensive study and was believed to be the primary pathway by which most chlorinated solvents were degraded in the environment. The biological conversion of common chlorinated compounds like perchloroethene (PCE) and trichloroethene (TCE) to ethene or ethane by anaerobic reductive dechlorination was initially demonstrated more than 20 years ago both in the laboratory and in the field (Freedman & Gossett, 1989; Major, et al., 1991; de Bruin, et al., 1992) and has now become the backbone of the bioremediation industry. Reductive dechlorination involves the step-wise replacement of individual chlorine atoms with hydrogen atoms, such that

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{cDCE} \rightarrow \text{VC} \rightarrow \text{Ethene}$$

where cDCE and VC are cis-1,2-dichloroethene and vinyl chloride, respectively. This step-wise production of daughter products creates a hallmark signature of biotic reductive dechlorination. In these processes, the chlorinated compounds act as an electron acceptor, while an electron donor is required to provide energy (McCarty, 1994). Hydrogen is generally considered to be the direct electron donor for reductive dechlorination, but is typically produced from the anaerobic fermentation of other carbon substrates, such as sugars, organic acids, or alcohols (Maymo-Gatell, et al., 1995).

Reductive dechlorination of chlorinated compounds can occur under natural conditions. Complete dechlorination of chlorinated aliphatics to ethene has been demonstrated to occur at many sites, but does not occur at all sites (Ellis, 1997). In rare instances, no dechlorination is observed. More commonly, partial dechlorination is observed, where the process stops at an intermediate product like cDCE, rather than proceeding all the way to ethene. This typically occurs because of limitations in fermentable carbon substrates, which provide energy for the dechlorinating bacteria, or other important nutrients, such as nitrogen or phosphate, which bacteria require in order to grow. In some cases the proper dechlorinating microorganisms are not present. While dechlorinating bacteria are generally present in the environment, particularly those capable of dechlorinating TCE to cDCE, the bacteria responsible for dechlorinating cDCE and VC to ethene are more sensitive to environmental conditions and are not present at all sites.

Where natural systems are limited in one of these ways, reductive dechlorination can be enhanced through bioremediation, typically through the addition of simple and safe sources of carbon and nutrients to the subsurface in order to stimulate anaerobic bacteria capable of reductively dechlorinating chlorinated compounds. There are many carbon sources suitable for promoting reductive dechlorination of chlorinated aliphatics by anaerobic bacteria. Among these are sugars (e.g., molasses), organic acids (e.g., lactic acid or its sodium salt), and alcohols (e.g.,

methanol, ethanol), as well as carbon sources that biodegrade more slowly over time, including substances like lactic acid polymers, emulsified soybean oil, chitin, and wood chips. Basic nutrients are typically added in the form of nitrogen, phosphorus and/or vitamin B12. If needed, dechlorinating bacteria can be added via bioaugmentation and will grow and proliferate in the subsurface under favorable conditions (Harkness, et al., 1999; Ellis, et al., 2000).

More recently, interest has grown in studying alternate degradation pathways for chlorinated compounds, particularly those mediated by natural or biologically formed reduced minerals in the subsurface. These active minerals include iron sulfides (e.g., pyrite) and iron-oxides (e.g., magnetite, green rust) that possess the capability to facilitate the abiotic reduction of chlorinated solvents in much the same way as do zero-valent metals (e.g., iron) (Butler & Hayes, 1999; Butler & Hayes, 2001; Lee & Batchelor, 2002). A distinguishing characteristic of the reduction of chlorinated compounds carried out by these minerals is that daughter products are rarely produced. For example

$$\text{PCE or TCE} \rightarrow \text{acetylene} \rightarrow CO_2$$

where CO_2 is carbon dioxide. The acetylene formed in this process is labile and rapidly degraded to CO_2 in the environment. Because of the lack of readily identifiable daughter and end products, these mechanisms can be difficult to document in the environment.

The process is additionally complex because bacteria often play a role in the formation of these minerals and in their cycling between reduced and oxidized states. For example, iron sulfides are typically formed from the production of hydrogen sulfide from sulfate by sulfate-reducing bacteria and ferrous iron from ferric iron by iron-reducing bacteria. The sulfide and ferrous iron are both soluble and will react rapidly in the aqueous phase to produce an insoluble iron sulfide (FeS) mineral, known as mackinawite, which may reduce chlorinated compounds.

As is the case with biodegradation, the mineral facilitated abiotic degradation of chlorinated compounds may occur under natural conditions (Kennedy, et al., 2006a). Similarly, it may be enhanced by engineering, typically in combination with enhanced bioremediation by the addition of carbon substrate, nutrients, bacteria and/or a source of sulfate or iron if these are limiting (Kennedy, et al., 2006b).

The site of interest in this study is the former Powerex, Inc. (Powerex) facility in Auburn, New York. Previous studies have documented that extensive natural reductive dechlorination of TCE is occurring in the overburden and shallow bedrock underlying the site, where TCE is being completely dechlorinated through cDCE and VC to ethene (Beak Consultants Limited [BEAK],

1995; Major, et al., 1995). The dechlorinating bacteria are being supported by the presence of acetone and methanol in the groundwater.

The previous studies did not address reductive dechlorination in the so-called D3 interval, which is a gypsum-rich bedrock zone which lies about 150 feet below grade at the site. Chlorinated aliphatics found in D3 monitoring wells include TCE and cDCE with smaller amounts of VC and ethene. Bacteria capable of the complete reductive dechlorination of TCE have been documented to be present in the D3 strata and geochemical conditions are supportive of reductive dechlorination. Groundwater in the D3 interval is also very high in sulfate (e.g., sulfate concentrations typically exceed 500 milligrams per liter [mg/L]) due to sulfate dissolution from the gypsum-rich bedrock. Hydrogen sulfide is present and black iron-sulfide precipitates are readily apparent in the sediment that collects at the bottom of monitoring wells. However, ferrous iron levels are low, indicating that iron sulfide formation in the D3 interval is iron limited. Trace levels of acetylene have been measured in D3 groundwater, suggesting that abiotic degradation is contributing to the degradation of chlorinated solvents at the site.

The objectives of this study were to attempt to observe abiotic degradation of TCE in microcosm bottles containing D3 groundwater and fine-grained iron sulfide-rich material collected from the bottom of certain D3 monitoring wells and quantify its contribution to TCE degradation relative to parallel biotic reductive dechlorination. To meet this objective, TCE degradation in killed and unamended controls were compared to lactate amended bottles combined with two forms of iron (e.g., ferric and ferrous). The study was performed at the General Electric Company's (GE's) Global Research Center (GRC) in Niskayuna, New York, in accordance with standard practices developed in GE's partnership in the Remedial Technology Development Forum's (RTDF's) Bioremediation of Chlorinated Solvents Consortium. The microcosm study ran for 252 days.

Materials and Methods

Sample Collection and Processing

The fine-grained material used in this study was obtained from monitoring wells screened in the gypsum-rich D3 bedrock interval at locations B-31, B-32, B-33, and B-53 at the former Powerex facility. Great care was taken to limit exposure to oxygen during the collection of the material at each well because exposure to oxygen will cause oxidation and passivation of the active mineral surfaces. The fine-grain material was collected at each well by placing the pump intake at the bottom of the well and pumping the groundwater to the surface using inertial lift or low-flow sampling techniques. The groundwater was pumped into a 5½ gallon Nalgene® clear container which was simultaneously purged with nitrogen to exclude as much oxygen as

possible. The pump discharge tubing was placed at the base of the container and the container was allowed to fill with groundwater. The container was filled to the brim and immediately capped and sealed with electrical tape.

The sealed containers were submerged in a water bath to minimize oxygen diffusion through the container walls and the fine-grained material was allowed to settle. After settling, the fine-grained material was transferred to glass containers by siphoning the material from the base of the 5½ gallon container while simultaneously purging the glass container with nitrogen to exclude as much oxygen as possible. The siphon discharge tubing was placed at the base of each sample container and the container was allowed to fill up. Each sample container was filled to the brim with groundwater and capped. The threads on the cap were wrapped with Teflon tape. The cap was subsequently sealed with electrical tape.

The sample containers were delivered to GRC under chain-of-custody and stored in an anaerobic chamber containing an atmosphere of approximately 0.8 percent (%) hydrogen in nitrogen. All subsequent sample manipulation prior to analysis occurred in the anaerobic chamber. The groundwater was decanted from each sample container and transferred into clean, small necked, one-gallon glass bottles. The fine-grain material was transferred in wide-mouthed glass jars with Teflon-lined screw-cap lids. Resazurin, a redox-sensitive color indicator for anaerobic conditions, was added to the groundwater bottles at a final concentration of 0.5 mg/L. The Resazrin turned from blue to clear within 30 minutes in all the bottles, indicating the groundwater was still highly reduced. The groundwater in the bottles was subsequently analyzed for volatile organic compounds (VOCs) and sulfate. After sitting for a weekend, any additional standing water was removed from above the fine-grained material.

Samples of the consolidated sediment were submitted to commercial laboratories for a number of analyses used to characterize the composition of the sediment and the amount and form of the iron sulfide present, including x-ray fluorescence (XRF), x-ray diffraction (XRD), and determination of acid-volatile and chromium extractable sulfides (AVS and CES, respectively). The latter is also known as Aqueous and Mineral Intrinsic Biodegradation Assessment (AMIBA). The XRF and XRD analyses were performed by Adirondack Environmental Laboratories (Albany, New York), while the AVS and CES were performed by Microseeps (Pittsburgh, Pennsylvania).

After analysis for VOCs, the groundwater from each location was gently sparged with nitrogen for 10 to 15 minutes to reduce the concentrations of any residual TCE, cDCE and VC initially present in the groundwater. This could not be done in the glovebox, so it was done in a fume hood under an ambient air environment and the color in the Resazurin in the bottles was closely monitored to ensure the groundwater remained anaerobic. The wet fine-grained material

and sparged groundwater were subsequently transferred into the microcosm bottles in the anaerobic chamber.

Microcosm Set-Up

The study was designed to test for abiotic degradation due to reduction of TCE by iron sulfides. Five separate conditions were tested using the fine-grained material and groundwater from each of four locations, for a total of 20 combinations. The five treatments included a killed control, unamended control, biotic treatment, and two treatments that combine biotic treatment with the presence of various forms of iron to produce fresh iron sulfide minerals (see Table 1). The killed controls were autoclaved to kill any bacteria and inhibit any biotic activity in the bottles. The unamended controls were run without any additional amendments. There may be some biological activity in these bottles, because the bacteria will remain alive and some residual substrates may be present. Sodium lactate and nutrients were added to the biotic treatments and to the two combined treatments. The biotic treatments were run to create a comparison for the two combined treatments. For each location, the first combined treatment received ferric citrate, which is a source of iron easily utilizable by iron-reducing bacteria. Iron reduction will create ferrous iron, which will react with hydrogen sulfide produced by the reduction of sulfate to produce fresh iron sulfide minerals. The second combined treatment for each location received ferrous chloride. In this case the iron reduction step is eliminated by directly adding the ferrous iron. Once again, it is expected that the ferrous iron will react with the hydrogen sulfide produced by the sulfate-reducing bacteria to produce fresh iron sulfide minerals.

The microcosm study was performed in sterile 120 milliliter (mL) serum bottles. Ten (10) grams (g) of fine-grained material were weighed out and dispensed into each bottle in an anaerobic glove box. The moisture content of the fine-grained material varied from 33 to 38% water. Each serum bottle was then filled with 100 mL of non-sterile site groundwater.

With one exception, microcosm treatments and controls were set up in duplicate, so that the experiment included a total of 45 bottles. The bottles were sealed with Teflon-coated septa and incubated in the dark either upside-down or sideways to exclude any headspace in the bottle from coming into contact with the septa and crimp seal. The incubation temperature was controlled to 20 to 22 degrees Centigrade (^{o}C) and monitored during the experiment.

Table 1: Experimental Design

Treatment	Well ID	Treatment	Donor	Iron	Nutrients
1	B-31D3	Autoclaved	-	-	-
2	B-31D3	Unamended	-	-	-
3	B-31D3	Biotic	+	-	+
4	B-31D3	Combined 1	+	Ferric	+
5	B-31D3	Combined 2	+	Ferrous	+
6	B-32D3	Autoclaved	-	-	-
7	B-32D3	Unamended	-	-	-
8	B-32D3	Biotic	+	-	+
9	B-32D3	Combined 1	+	Ferric	+
10	B-32D3	Combined 2	+	Ferrous	+
11	B-33D3	Autoclaved	-	-	-
12	B-33D3	Unamended	-	-	-
13	B-33D3	Biotic	+	-	+
14	B-33D3	Combined 1	+	Ferric	+
15	B-33D3	Combined 2	+	Ferrous	+
16	B-53D3	Killed	-	-	-
17	B-53D3	Unamended	-	-	-
18	B-53D3	Autoclaved	+	-	+
19	B-53D3	Combined 1	+	Ferric	+
20	B-53D3	Combined 2	+	Ferrous	+

Supplemental

21A&B	B-31D3	Gamma	-	-	-
21C	B-32D3	Gamma	-	-	-
21D&E	B-33D3	Gamma	-	-	-

The sodium lactate used was Wilclear™ bioremediation grade lactate from JRW Bioremediation (Lenexa, Kansas). Wilclear™ contains a 60% solution of the L-form of the lactate. The amount of sodium lactate added to each bottle was calculated based upon the stoichiometric demand of the primary contaminant and the background demand imposed by competitive electron acceptor processes such as nitrate reduction, iron reduction, sulfate reduction, and methanogenesis. A total donor demand of 1000 mg/L sodium lactate was calculated assuming a TCE concentration of 20 mg/L and average nitrate and sulfate groundwater concentrations of 0 mg/L and 600 mg/L, respectively. These assumed concentrations are reasonable based on the sampling results for wells B-31D3, B-32D3, B-33D3, and B-53D3. Sulfate was the major electron donor sink in this calculation. An engineering safety factor of 2X was used to account for competitive processes that could not be easily quantified.

The sodium lactate was added at two-week intervals throughout the study from a 1 molar (M) solution using a gas-tight syringe. Amendment amounts are shown in Table 2.

Table 2 – Microcosm Amendment Table

Material	Number of Additions	Stock Solution	Amount
Sodium Lactate	10	1.0 M	0.1 mL
Ammonium Phosphate	1	1.0 M	0.1 mL
Yeast Extract	1	30 g/L	0.1 mL
Ferric Citrate	1	1.0 M	0.625 mL
Ferrous Chloride Tetrahydrate	5	1.0 M	0.125 mL
TCE	1	Saturated Sol'n	As needed

Supplemental nutrient levels were calculated by assuming the optimal carbon:nitrogen:phosphorous (C:N:P) ratio for bacterial growth is 100:10:1. Reagent grade diammonium phosphate and yeast extract (YE) were added once to designated bottles at the beginning of the study. Reagent grade diammonium phosphate was purchased from EM Science (Gardena California) and added as a 1.0 M solution in water. Difco technical grade YE was purchased from Sigma Aldrich (St Louis, Missouri) and added as a concentrated solution of 30 grams per liter (g/L) YE. The nutrient solutions were autoclaved or filter sterilized prior to use. Amendment amounts are shown in Table 2.

Ferric citrate and ferrous chloride were added in equivalent molar concentrations to the sulfate in solution (e.g., 600 mg/L is equivalent to 6.25 millimolar [mM]). Reagent grade ferric citrate was purchased from MP Biomedicals (Solon, Ohio) and initially added at the beginning of the study as a 1.0 M solution in water, then again as necessary to remove any additional hydrogen sulfide from solution in the bottles. Reagent grade ferrous chloride 6-hydrate was purchased from Sigma Aldrich and added nine times throughout the study as a 1.0 M solution in water. The ferrous chloride solution was prepared in the anaerobic glovebox using anaerobic deionized (DI) water. Amendment amounts are shown in Table 2.

The autoclaved controls were autoclaved on three consecutive days to eliminate biological activity in these bottles. A more limited set of bottles was treated with 30 to 40 kilogray (kGy) of gamma radiation to provide an alternate set of killed controls without the high temperatures associated with autoclaving. These bottles were set up 79 days later than the others

in the study. With the exception of one of the gamma-irradiated controls, all the microcosm treatments were run in duplicate. The unamended controls did not receive any electron donor or nutrient amendments. Resazurin, a redox-sensitive color indicator for anaerobic conditions, was added to all the bottles prior to sparging at a final concentration of 0.5 mg/L in the bottles. No reducing agents were used in this experiment.

Table 3 – Average Starting VOC Concentrations and TCE Spike Volumes in Microcosm Bottles

Source	TCE	cDCE	VC	TCE Stock	TCE Added
B-31D3	19.8 (100)	4.3 (6)	ND (NA)	Saturated	0 mL
B-32D3	9.4 (42)	20.7 (29)	2.5 (NA)	Saturated	0.96 mL
B-33D3	0.7 (6)	8.3 (18)	ND (NA)	Saturated	1.75 mL
B-53D3	7.9 (32)	16.1 (29)	ND (NA)	Saturated	1.10 mL
Gamma Bottles	ND	ND	ND	Saturated	1.75 mL

All concentrations in mg/L
Pre-sparging VOC concentrations in parentheses.
Stock solution assumed to contain 1100 mg/L TCE.

TCE was spiked into the microcosms at the beginning of the study using a gas-tight syringe. TCE was added from saturated stock solutions in water (e.g., 1100 mg/L) to target concentrations of 20 mg/L. The VOC concentration in select microcosm bottles was measured prior to spiking to test for residual levels of TCE in the sediment and groundwater. Spiked amounts of TCE were adjusted accordingly to approximate the target concentration, as shown in Table 3. The water used in the gamma controls did not contain any VOCs, so all of the TCE in these bottles came from spiked material.

VOC Analysis

VOC samples were obtained by removing small aliquots of liquid from the bottles using glass, gas-tight syringes. The microcosms were sampled at the start and at two- to four-week intervals throughout the study. The first sampling occurred one day after all the amendments and contaminants are added to the bottles. This one-day interval was designed to allow the TCE in the bottle to partition between the soil, groundwater, and headspace in the bottles and reach equilibrium. The subsequent sampling intervals are specified in Table 4. TCE, cDCE, VC and ethene/ethane were measured using a purge and trap autosampler and a gas chromatograph (GC) equipped with a flame ionization detector (FID). Chlorinated aliphatics and ethene/ethane were

quantified by comparing peak areas to standard calibration curves generated using water dilutions of a standard mixture containing TCE, cDCE, and VC or by direct injection of known amounts of a standard gas mixture containing ethene.

Table 4: Example Microcosm Sampling Schedule

1 Day
14 Days
28 Days
42 Days
Subsequent sampling intervals to be determined based upon results observed in the bottles

There are three compartments in each microcosm bottle (e.g., aqueous phase, sediment, and headspace) and chlorinated ethenes will distribute into these compartments based on their individual partitioning characteristics. Sampling was performed only in the aqueous phase, and thus does not represent the total VOC content in each bottle. To address this issue, the concentration of chlorinated compound in each phase was determined using the measured aqueous phase concentration, the equilibrium partitioning coefficient for the sediment using the measured sediment total organic content, and the Henry's Law coefficient at 20^{o}C for the headspace. The compound mass in each phase was summed and converted to moles so that molar balances could be constructed. Changes in the volume of the aqueous phase and headspace due to sampling were included in these computations.

Acetylene is a known endproduct of abiotic degradation catalyzed by iron and iron sulfides, but is itself easily degraded and likely co-elutes with ethane or ethane in our GC analysis. Therefore no attempt was made to measure acetylene in this study.

Other Biological Indicators

In addition to VOC analysis, other indicators of biological activity were monitored during the study. Resazurin is a redox-sensitive color indicator for anaerobic conditions. Resazurin is blue under oxidizing conditions, pink under mildly reduced conditions, and clear under more strongly reduced (ca. –100 millivolts [mV]) conditions. Therefore, the color of the water in the bottles was monitored, especially early in the experiment.

Sulfate, dissolve ferrous iron, and sulfide were monitored in the bottles during the experiment. Sulfate was quantified by ion chromatography. Sulfide was measured using

CHEMetrics (Calverton, Virginia) test kits. Soluble iron was measured colorimetrically using ferrozine.

Supplemental Chemical Analyses

The pH in the bottles was monitored over the course of the study to monitor acid production due to biotic or abiotic reactions. TCE and cDCE samples from selected bottles were measured for C^{13}/C^{12} by CSIA to distinguish between degradative and non-degradative loss mechanisms. This analysis was performed by Microseeps (Pittsburgh, Pennsylvania).

Results and Discussion

Mineral Phase Analyses

XRF and XRD are complementary analyses that provide information on the elemental composition and crystal structure of solid phases. The results of the XRF analyses are shown in Tables A1a and A1b in Appendix 1. The analyses indicated that sulfur and iron are present at comparable levels in the gypsum rock (e.g., 7.8% and 9.0% by weight). Note that XRF does not measure carbon and oxygen. High levels of limestone are present in most of the bedrock units at the site and provide significant buffering against biologically induced pH excursions (Table A1a). The sediment was lower in sulfur (2.7 versus 5.3%) and higher in iron (12.7 versus 14.6%) than the D3 bedrock as measured by XRF, consistent with the sediment being richer than the background material in iron sulfide (Table A1b).

The results of the XRD analysis are shown in Table A2 in Appendix 1. This analysis was used to identify the major forms of crystalline materials in the D3 bedrock and sediment. The analysis indicates that celestine, a strontium sulfate mineral, may also be present in the D3 zone. The strontium might also be from strontianite, a strontium carbonate. Calcite and silica were also identified in all the samples. The detection limits of the XRD are generally not sufficient to quantify pyrite, although it was detected in one of the sediment samples. Mackinawite is poorly crystaline and therefore is not detected by XRD.

The results of the AMIBA, including a summary of the AVS and CES analyses performed on the sediment samples, are shown in Table A3 in Appendix 1. The AVS is generally assumed to measure mackinawite or more recently produced iron sulfide, while the CES measures pyrite or aged iron sulfide. The analyses indicated these are present at tenths of a percent in the sediment samples. The ratio of AVS to CES is also shown in Table 7. Sediments from wells B-32D3 and B-33D3 had the highest AVS/CES ratios and were also the most biologically active in reducing TCE in the microcosm study, suggesting a correlation. In this case, the high AVS/CES ratio may indicate that precursor biological activity to iron sulfide formation (e.g., sulfate and

iron reduction) is more robust in these wells. Supplemental analyses performed concurrently with the AVS and CES suggest that most of the iron in the sediment from B-31D3 and B-32D3 has been reduced to the ferrous state, whereas the sediment from B-33D3 and B-53D3 still contains some non-reduced ferric iron (Table A3).

Microcosm Study Results

The specialized sampling procedures employed in the field appeared to be effective in preventing the samples from being significantly oxidized during sample collection and transport. When Resazurin was added to the groundwater in the anaerobic chamber, all the groundwater samples cleared, indicating the water was still in a reduced state. Water from wells B-32D3 and B-33D3 cleared most rapidly, consistent with the observation that these samples were the most biologically active. However, all the samples were clear within 30 minutes of adding the Resazurin.

The data for total TCE, cDCE, VC, and ethene measured in the bottles during the study are shown in Appendix 2. Plots showing changes over time of these VOCs in individual bottles are shown in Appendix 3 (Figures A2 through A26). Sulfate, sulfide, iron, and pH data are found in Appendix 4, along with accompanying figures. Bottles from the main experiment ran for 252 days, whereas the gamma controls ran for 173 days. Both biotic and abiotic degradation were observed in the microcosm study. Biotic degradation followed the classic reductive dechlorination pattern, producing daughter products cDCE, VC and ultimately ethene. In contrast, abiotic degradation was characterized by losses of both TCE and cDCE without the production of daughter products. As expected, abiotic degradation was observed primarily in killed controls and some of the unamended bottles.

Abiotic Degradation

Abiotic losses from the bottles are summarized in Table 5. No daughter products were observed in these bottles, although production of small amounts of cDCE in the main experiment may have been masked by starting cDCE concentrations. These bottles include the autoclaved and gamma-irradiated controls and other bottles if they did not exhibit significant daughter product production, such as the unamended bottles from B-31D3 and B-53D3 and lactate amended bottles from B-53D3. Figure 1 is a representative example of abiotic losses of TCE and cDCE observed throughout the study.

The pH of the autoclaved and gamma-irradiated controls and unamended bottles generally ranged from 7.4 to 8.1 (Table A7 in Appendix 4), consistent with the strong pH buffering provided by the carbonate minerals. Significant sulfate reduction or sulfide production

was not observed in the autoclaved bottles (Tables A5 and A6 in Appendix 4). Sulfide production ranging from 50 to 125 mg/L was noted in the B-33D3 and B-53D3 unamended bottles. Sulfide may have also been produced in the other unamended bottles as well, but reacted with the ferrous iron in the sediment to form iron sulfides (Table A3). As previously noted, sediments from B-31D3 and B-32D3 contained higher levels of ferrous iron than did sediments from the other locations.

Total TCE losses in the main experiment are shown in Table 5 and ranged from 34 to 54%, whereas total cDCE losses ranged from 9 to 33%. There was excellent reproducibility between duplicates. Roughly 10 to 15% of the absolute loss in the main experiment bottles is attributable to liquid removal due to sampling over the course of the study. This removal was measured during the study. If these sampling losses are removed, TCE and cDCE losses potentially due to abiotic degradation are conservatively reduced by 25 to 48% and 4 to 24%, respectively, so that the loss of TCE is approximately twice that for cDCE.

Table 5: Absolute Losses in Abiotic Bottles (quantities expressed as average micromoles [μmoles] present in each bottle)

Treatment/Well ID	TCE Start	TCE End	Change	cDCE Start	cDCE End	Change
	μmoles	μmoles		μmoles	μmoles	
Autoclaved Controls						
B-31D3	21.01	13.27	- 36.9 %	4.98	3.35	- 32.7 %
B-32D3	17.43	8.96	- 48.6 %	24.11	16.01	- 33.6 %
B-33D3	15.80	7.18	- 54.5 %	8.82	6.20	- 29.7 %
B-53D3	15.06	7.15	- 52.5 %	16.64	11.66	- 29.9 %
Unamended						
B-31D3	19.79	12.83	- 35.2 %	5.37	4.88	- 9.1 %
B-53D3	16.38	10.68	- 34.7 %	18.03	13.48	- 25.2 %
Lactate Amended						
B-53D3	15.72	8.28	- 47.3 %	17.62	12.68	- 28.1 %
Gamma Controls						
B-31D3	8.62	6.50	- 24.6 %	0.00	0.00	---
B-32D3 *	12.40	7.97	- 35.7 %	0.00	0.34	---
B-33D3	13.03	9.72	- 25.4 %	0.00	0.56	---

* Only data in sample set that represent results from a single bottle. All other data are average from duplicate bottles.

Representative losses of TCE from the gamma-irradiated controls are also summarized in Table 5, while the progression of loss over time is shown in Figure 2. Total TCE losses ranged from 24 to 35%. There was no cDCE in these bottles at set-up. Sampling losses for the gamma controls are significantly less than for bottles in the main study, amounting to only 3 to 4%, so that losses of TCE in the gamma controls with sampling losses removed are comparable to those for the main experiment despite the shorter incubation period for the gamma controls. Low levels of cDCE were produced in the B-32D3 and B-33D3 gamma-irradiated controls, amounting to 3 to 4% of the starting TCE on a molar basis. It is possible the gamma radiation did not completely kill the dechlorinating bacteria in these bottles, so that the generation of cDCE indicates low-level biotic transformation. However, abiotic degradation of TCE is also known to produce small amounts of cDCE (Butler & Hayes, 1999; Butler & Hayes, 2001). Therefore the production of cDCE may also be the result of abiotic activity.

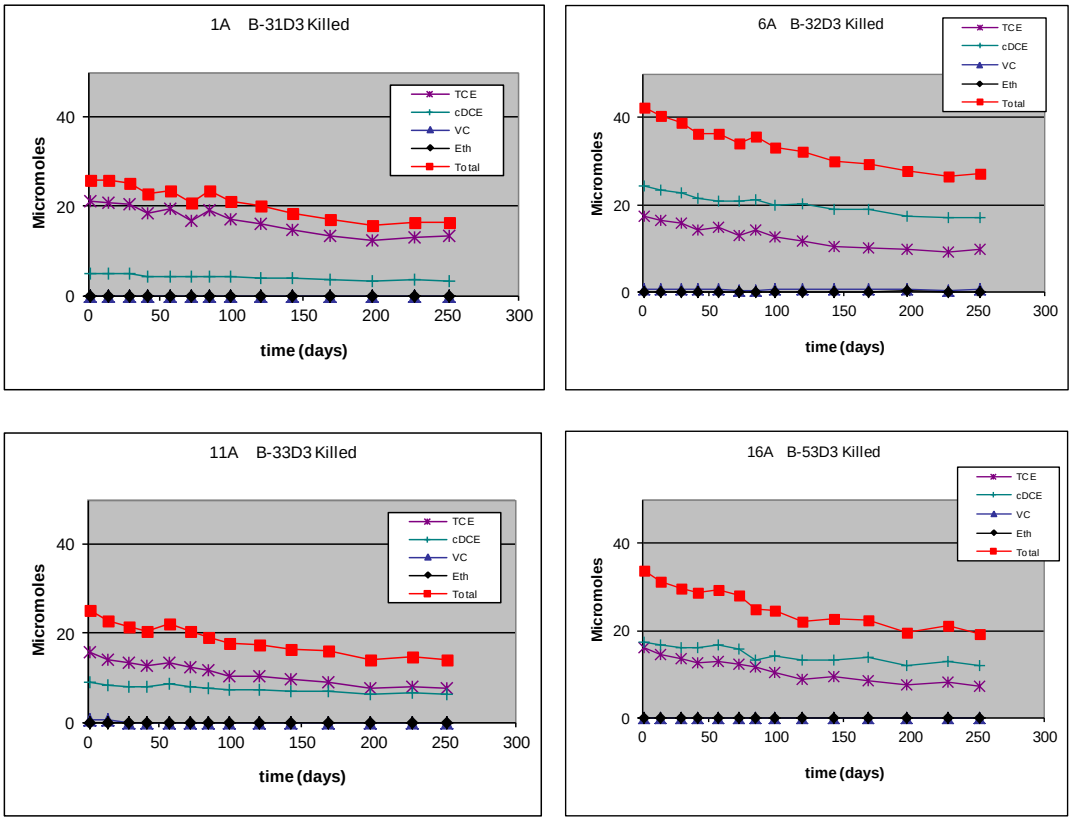

Figure 1 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in autoclaved controls. Only one bottle from each treatment set is shown. Plots for all bottles are available in Appendix 3.

CSIA was used to distinguish losses due to abiotic degradation from non-degradative losses, such as sorption of the TCE and cDCE into the septa. The former will produce a distinctive shift in the C^{13}/C^{12} ratio, while the latter will not. Selected bottles were submitted for CSIA at the end of the study. These included bottles that received the majority of their starting TCE by spiking from a stock solution, so that the TCE CSIA signature at the end of the study could be compared directly to the signature of the TCE in the spike solution. In the case of cDCE, the CSIA signature was measured at the end of the study as well as in the initial groundwater, which had been stored in a cold room at 4°C.

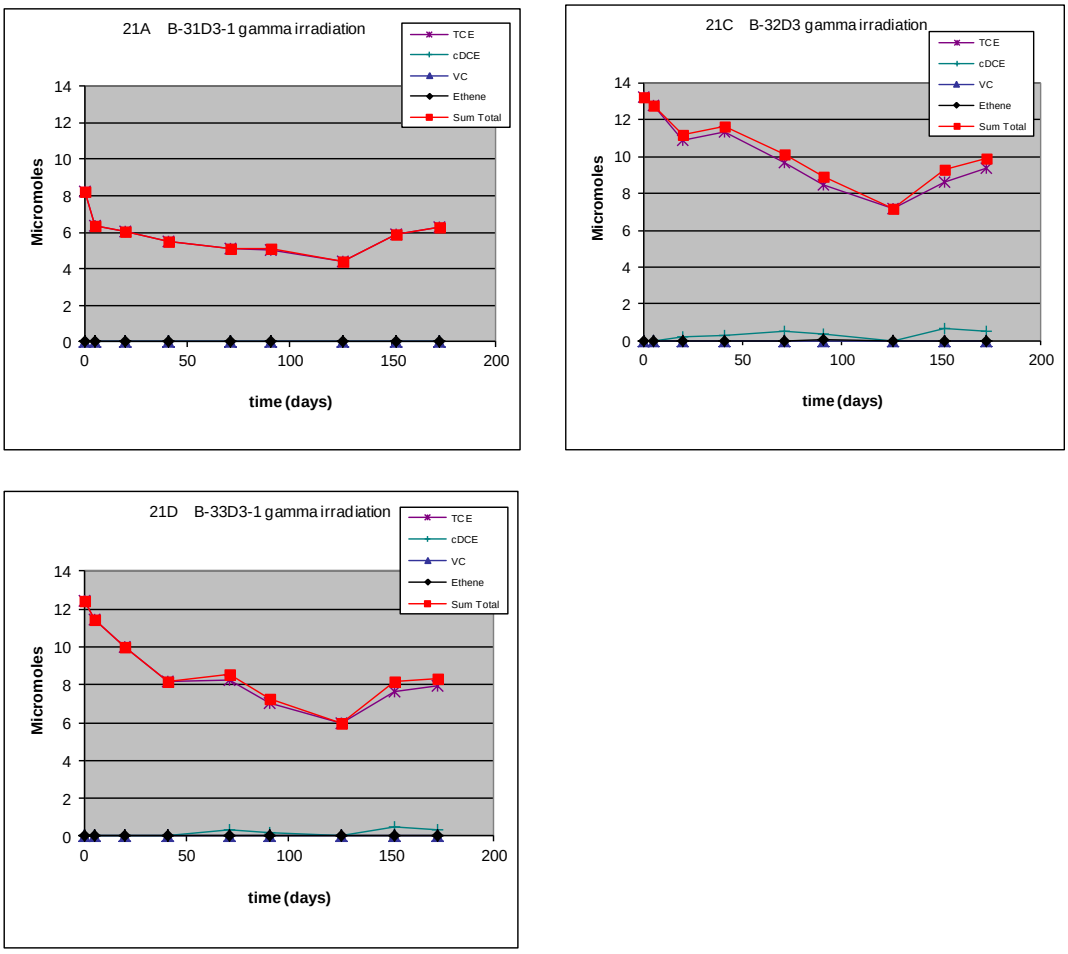

Figure 2 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in gamma-irradiated controls. Only one bottle from each treatment set is shown. Plots for all bottles are available in Appendix 3.

Results of the CSIA are summarized in Table 6. Duplicates and blind replicates of the TCE spike solution are in good agreement and give an indication of the reproducibility of the method. Shifts in the TCE CSIA signature are evident in all the control bottles, indicating a substantial portion of the losses observed are due to abiotic transformation and not due to sorption or sampling loss. A smaller shift is observed in the CSIA signature for cDCE, indicating some of this loss is also due to abiotic degradation. Enrichment factors (ε_c) were calculated combining the results of Tables 3 and 4 and produced ε_c values of –4.3 and –3.8 in the B-33D3 autoclaved control for TCE and cDCE, respectively, and –11.7 to –16.9 for TCE in the gamma controls. These values are within the large range of –2.5 to –23 for ε_c values for biotic reductive dechlorination of TCE and cDCE found in the literature (Hunkeler, et al., 2008), but lower than the single reported value for abiotic degradation of TCE by iron sulfide of –33.4 (Liang, et al., 2007). At this time it is not known whether there is also a range of ε_c values for abiotic degradation or whether the values reported in this study represent a combination of degradative and non-degradative loss mechanisms. For example, if half of the loss observed in this study were due to sorption into the septa, then the enrichment values calculated above would approximately double, putting those factors for the gamma controls into relatively close agreement with the single literature value. Regardless, it is clear that abiotic degradation is occurring in the microcosm bottles of this study.

Table 6: Results of CSIA of TCE and cDCE in Selected Bottles

Sample	Compound	del ($^o/_{oo}$)
TCE Spike Sol'n	TCE	-30.32
TCE Spike Sol'n (Blind Duplicate)	TCE	-30.67
TCE Spike Sol'n (Lab Duplicate)	TCE	-30.47
B-33D3 Autoclaved Control	TCE	-27.91
B-31D3 Gamma Control	TCE	-26.40
B-32D3 Gamma Control	TCE	-25.19
B-33D3 Gamma Control	TCE	-27.54
B-33D3 Water	cDCE	-27.05
B-33D3 Autoclaved Control	cDCE	-26.24

The TCE and cDCE data in the abiotic bottles was fitted using first-order kinetics and an average rate constant was calculated in each case, as shown in Table 7. These rate constants were normalized to the molar sum of FeS and FeS_2 in the bottles, measured on a dry weight basis so that they could be compared to similar rate constants derived from other literature studies

performed over a similar pH range. The calculated rate constants are quite comparable to other literature derived values. This would remain true even if a portion of the losses observed in this study were due to non-degradative mechanisms like sorption into the septa. It is also interesting to note that the ratio of the degradation rate of TCE to cDCE derived in this study is also quite similar to that derived by Batchelor and Lee (2002). Coupled with the CSIA data, these calculations provide further support that the changes observed in the study are consistent with abiotic degradation mediated by iron sulfide minerals.

Table 7: Calculation of First-order Rate Constants and Comparison to Literature Values

Source	Iron Phase	Compound	pH	Rate Constant ($d^{-1}*M^{-1}$)
Autoclaved Control	FeS + FeS_2	TCE	7.4 – 8.1	1.64
Autoclaved Control	FeS + FeS_2	cDCE	7.4 – 8.1	0.77
Gamma Control	FeS + FeS_2	TCE	7.4 - 7.9	1.14
He, et al. (2010)	FeS	TCE	7.2	0.43 – 0.75
Lee & Batchelor (2002)	FeS_2	TCE	8.0	2.28
Lee & Batchelor (2002)	FeS_2	cDCE	8.0	1.40
Jeong & Hayes (2007)	FeS	TCE	8.3	0.49

Biotic Degradation

Biotic reductive dechlorination was observed in all the bottles of the study not listed in Table 5. Many of the bottles amended with lactate and either form of iron supported complete dechlorination of TCE to ethene by the end of the study. Representative examples are shown in Figures 3 and 4. Molar balances were reasonable in these bottles until significant ethene production was observed. At this point the molar balance typically deteriorated. This may be the result of biological degradation of the ethene to carbon dioxide or difficulties with the purge and trap completely capturing the ethene prior to GC analysis.

The pH in the amended bottles was highest where lactate and nutrients were added alone. Here the pH generally ranged from 7.5 to 8.5. The initial pH was lower in the combined treatments because the ferric citrate and ferrous iron solutions are acidic. However, the pH in these bottles returned to between 7.5 and 8.0 over time, probably due to the pH buffering provided by the carbonate minerals.

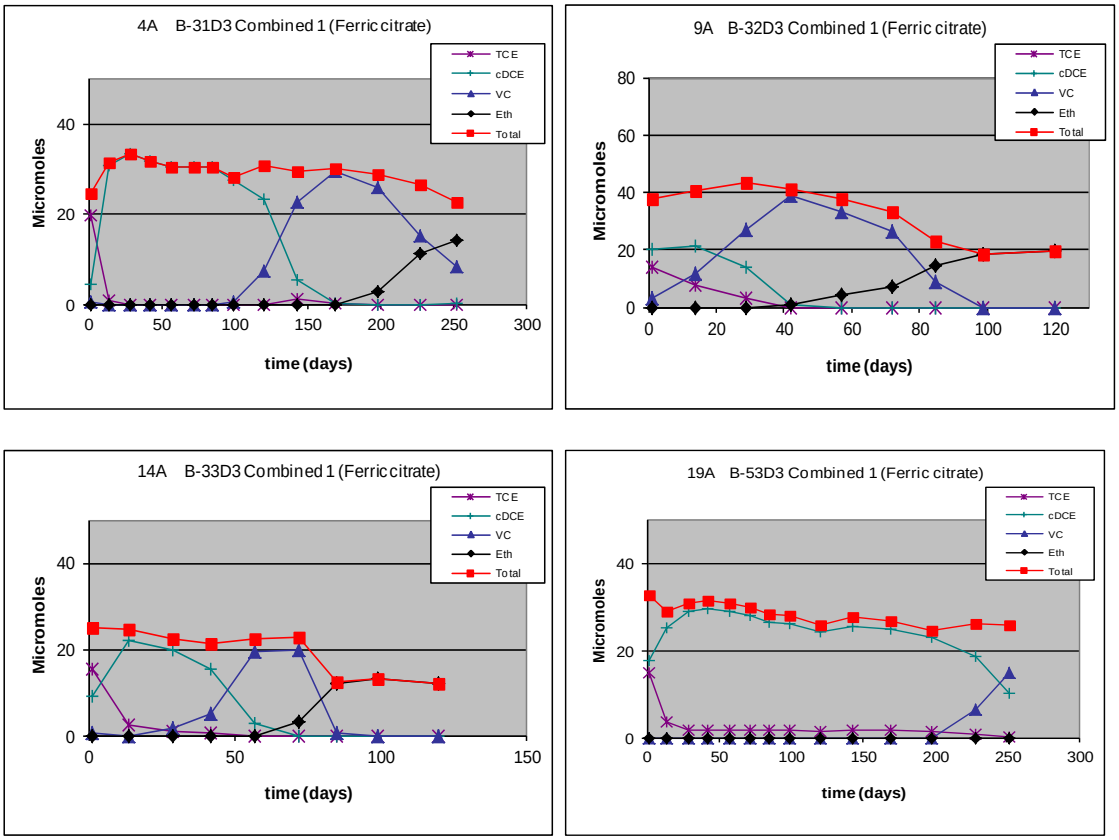

Figure 3 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in lactate + ferric citrate amended bottles. Only one bottle from each treatment set is shown. Plots for all bottles are available in Appendix 3.

The B-32D3 and B-33D3 bottles were the most biologically active. Complete dechlorination of TCE to ethene was achieved in the combined treatments in these bottles in as little as 100 days (Figures 3 and 4). Complete dechlorination required 200 to 250 days in the B-31D3 bottles and was not observed in the B-53D3 bottles, although it appeared it would have occurred if the study was run longer than 252 days. Dechlorination of TCE to VC and ethene was observed in the B-32D3 unamended control, while cDCE was produced in the unamended B-33D3 bottles. Acetone is found in the site groundwater and is likely the primary electron donor supporting this activity. There appeared to be very limited reductive dechlorination of TCE to cDCE in the unamended B-31D3 bottles, while this activity was absent in the unamended B-53D3 bottles. The reason for the differences in biological activity between the bottles was not determined.

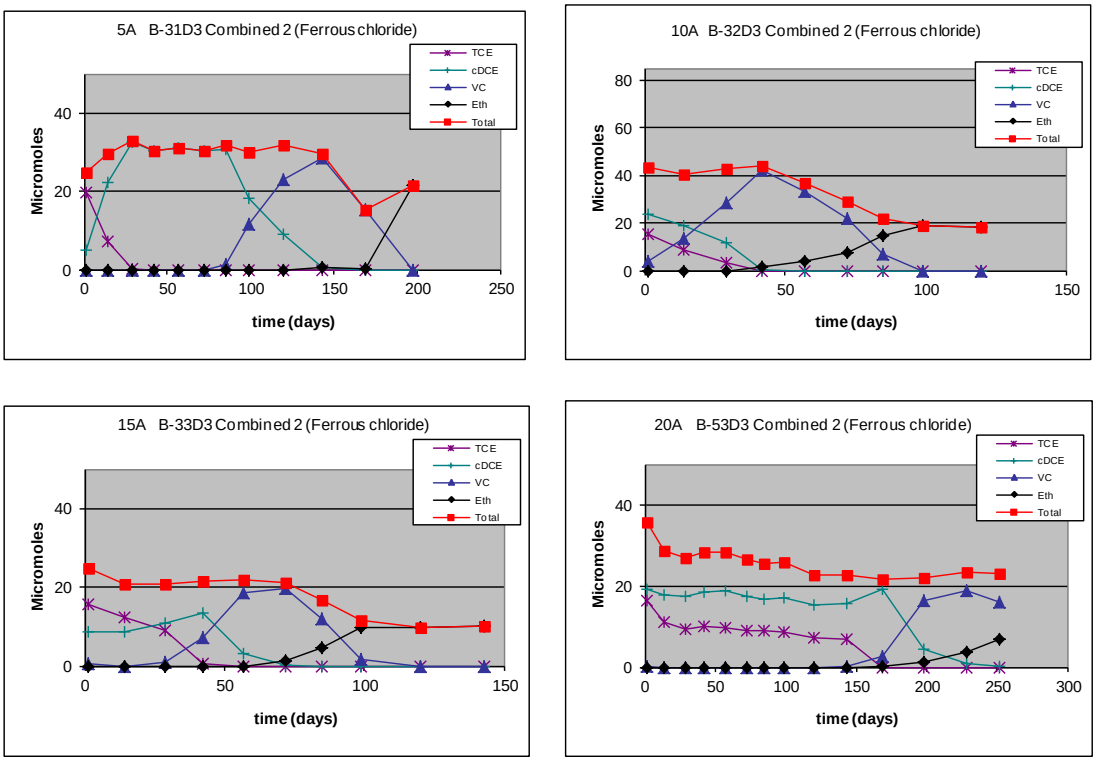

Figure 4 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in lactate + ferrous chloride amended bottles. Only one bottle from each treatment set is shown. Plots for all bottles are available in Appendix 3.

Reductive dechlorination of TCE to daughter products was also observed in most of the lactate amended bottles, but this activity stopped prior to reaching full dechlorination to ethene (Figure 5). VC and ethene were produced in the B-32D3 and B-33D3 bottles, while only cDCE was produced in the B-31D3 bottles. As previously noted, the B-53D3 lactate amended bottles did not produce daughter products. Sulfate reduction was stimulated in all the lactate-amended bottles and to a lesser extent in some of the unamended controls. The stalling observed in the lactate amended bottles was likely due to this sulfate reduction and consequent hydrogen sulfide production. Ferrous iron levels in these bottles were consistently non-detect, so that hydrogen sulfide was not removed from solution and built up in the bottles. Sulfide levels reached 100 mg/L in the B-53D3 bottles in as little as 29 days, and exceeded that level by 50 to 120 days in the other bottles (Table A5). Maximum concentrations of sulfide reached 300 mg/L in some of the bottles.

High levels of hydrogen sulfide are inhibitory to many bacteria, include fermenters, acetogens, sulfate reducing bacteria, and methanogens (Maillacheruvu & Parkin, 1996). We are not aware of a literature study where the sulfide toxicity level for dechlorinating bacteria has

been measured. In this study, it appears that this toxicity level may be around 200 mg/L. Dechlorination of cDCE to VC was observed under sulfide concentrations at this level in the lactate amended B-33D3 bottles, although little ethene was produced thereafter (Figure 5). Dechlorination of TCE to VC occurred before sulfide levels reached 100 mg/L in the lactate amended B-32D3 bottles, while ethene production was slow thereafter. After depletion of sulfate, rebound in sulfate concentrations was observed in all the lactate amended bottles (Table A4, Figure A27). This suggests both that additional sulfate was dissolving into solution from sulfur containing minerals in the sediment and that the sulfate reducing bacteria may also have been inhibited once hydrogen sulfide levels reached 150 to 200 mg/L.

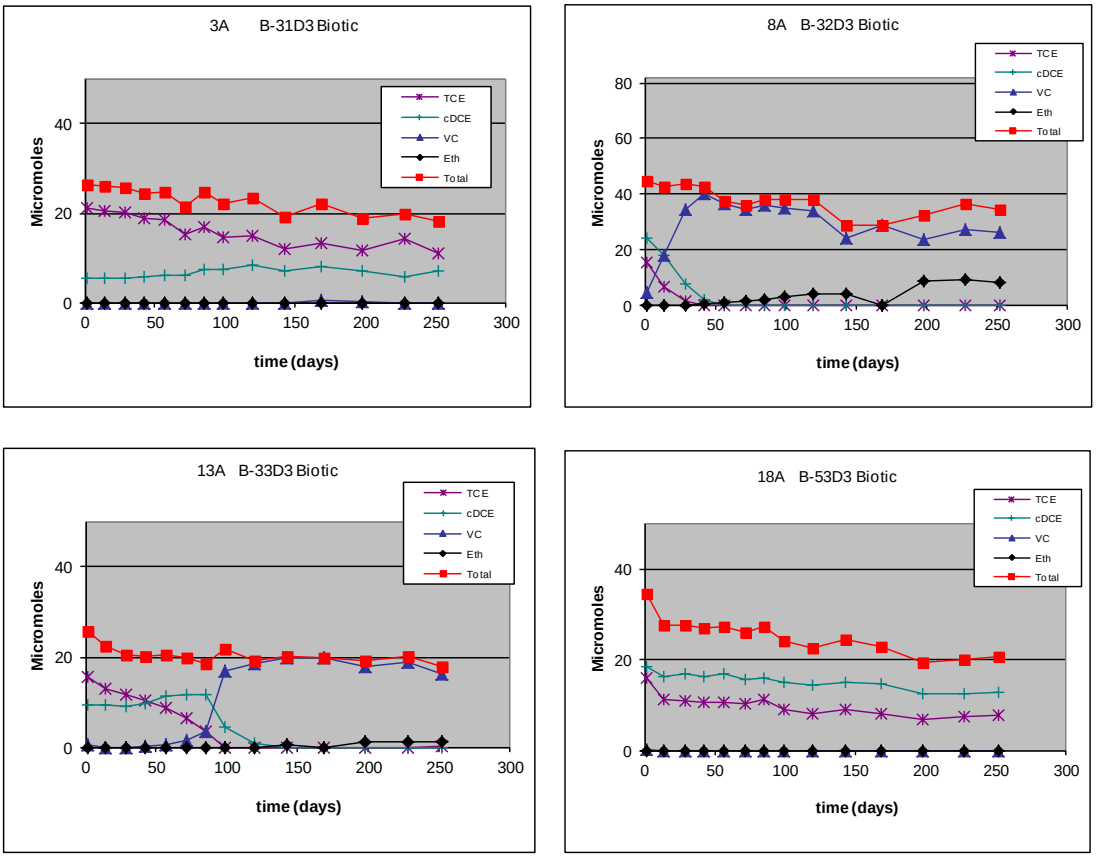

Figure 5 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in lactate amended bottles. Only one bottle from each treatment set is shown. Plots for all bottles are available in Appendix 3.

It is interesting to note that whereas the iron was added in an attempt to promote abiotic degradation, it actually facilitated biotic dechlorination. In the combined treatments where iron was added, ferrous iron was either added or, in the case of ferric citrate, rapidly formed, so that it reacted with the hydrogen sulfide and removed the sulfide from solution. In contrast to the

lactate amended bottles, the sulfide inhibition was eliminated, allowing the biological reductive dechlorination process to proceed. In the case of ferric citrate addition, it is also possible the ferric citrate stimulated an iron-reducing population that was also capable of reducing TCE to cDCE (Sung, et al., 2006).

Biotic degradation rates were higher than abiotic degradation rates in most of the bottles under lactate and iron amended conditions and in the unamended B-32D3 and B-33D3 bottles. It is probable that abiotic degradation was also occurring in these bottles, but at a rate that could not be quantified given the larger biotic changes that were occurring. In some circumstances, such as in the unamended B-32D3 or B-53D3 bottles, the abiotic degradation rates appear to be of similar order or even larger than the biotic rates. The microcosm study results suggest that abiotic degradation is contributing to the natural, on-going attenuation of TCE and its daughter products observed in the field. It appears it is acting in concert with the ongoing intrinsic reductive dechlorination of TCE observed in the site groundwater.

References

BEAK, "Biodegradation Study Report; Former Powerex, Inc. Facility", Submitted to the General Electric Company on April 12, 1995.

de Bruin, W.P., M.J.J. Kotterman, M.A. Posthumus, G. Schraa, A.J.B. Zehnder, "Complete Biological Reductive Dechlorination of Tetrachloroethene to Ethane", *Appl. Environ. Microbiol.*, 1992, 58:1996-2000.

Butler, E.C. and K.F. Hayes, Kinetics of the Transformation of Trichloroethylene and Tetrachloroethylene by Iron Sulfide, *Environ. Sci. Technol.*, 1999, 33, 2021-2027.

Bulter, E.C. and K.F. Hayes, Factors Influencing the Rates and Products in the Tranasformation of Trichlorethylene by Iron Sulfide and Iron Metal, *Environ. Sci. Technol.*, 2001, 35, 3884-3891.

Ellis, D.E., "Intrinsic Remediation in the Industrial Marketplace", in Proceedings of the Symposium on Natural Attenuation of Chlorinated Organics in Ground Water, EPA/540/R-97/504, United States Environmental Protection Agency, Washington, DC, 1997, pp. 129-132.

Ellis, D.E., E.J. Lutz, J.M. Odom, R.J. Buchanan Jr., M.D. Lee, C.L. Bartlett, M.R. Harkness, K.A. Deweerd, "Bioaugmentation for Accelerated In Situ Anaerobic Bioremediation," *Environ. Sci. Technol.*, 2000, 34:2254-2260.

Freedman, D.L. and J.M. Gossett, "Biological Deductive Dechlorination of Tetrachloroethylene and Trichloroethylene to Ethylene under Methanogenic Conditions" *Appl. Environ. Microbiol.*, 1989, 55:2144-2151.

Harkness, M.R., A.A. Bracco, M.J. Brennan Jr., K.A. DeWeerd, J.L Spivack., "Use of Bioaugmentation to Stimulate Complete Reductive Dechlorination of Trichloroethene in Dover Soil Columns", *Environ. Sci. Technol.*, 1999, 33:1100-1109.

He, Y., J.T. Wilson, R.T. Wilkins, "Impact of Iron Sulfide Transformation on Trichloroethylene Degradation", *Geochimica et Cosmochimica Acta*, 2010, 74:2025-2039.

He, Y., C. Su, J.T. Wilson, R. Wilkin, C. Adair, T. Lee, P. Bradley, M. Ferrey, "Identification and Characterization Methods for Reactive Minerals Responsible for Natural Attenuation of chlorinated Organic Compounds in Ground Water", EPA 600/R-09/115, Office of Reserch and Development, United States Environmental Protection Agency, 2009.

Hunkeler, D., R.U. Meckenstock, B. Sherwood Lollar, T.C. Schmidt, J.T. Wilson, "A Guide for Assessing Biodegradation and Source Identification of Organic Ground Water Contaminants using Compound Specific Isotope Analysis", EPA 600/R-08/148, Office of Reserch and Development, United States Environmental Protection Agency, 2008.

Jeong, H.Y. and K.F. Hayes, "Reductive Dechlorination of Tetrachloroethylene and Trichloroethylene by Mackinawite (FeS) in the Presence of Metals: Reaction Rates", *Environ. Sci. Technol.*, 2007, 41:6390-6396.

Kennedy, L.G., J.W. Everett, J. Gonzales, "Assessment of Biogeochemical Attenuation and Treatment of Chlorinated Solvents, Altus Air Force Base, Altus, Oklahoma", *J. Contam. Hydrology*, 2006a, 83:221-236.

Kennedy, L.G., J.W. Everett, E. Becvar, D. Defeo, "Field-scale Demonstration of Induced Biogeochemical Reductive Dechlorination at Dover Air Force Base, Dover, Delaware", *J. Contam. Hydrology*, 2006b, 88:119-136.

Liang, X., Y. Dong, T. Kuder, L.R. Krumholz, R.P. Philip and E.C. Butler, "Distinguishing Abiotic and Biotic Transformation of Tetrachloroethylene and Trichloroethylene by Stable Carbon Isotope Fractionation", *Environ. Sci. Technol.*, 2007, 41:7094-7100.

Lee, W. and B. Batchelor, "Abiotic Reductive Dechlorination of Chlorinated Ethylenes by Iron-Bearing Soil Minerals. 1. Pyrite and Magnetite", *Environ. Sci. Technol.*, 2002, 36:5147-5154.

Major, D.W., E.H. Hodgins, B.H. Butler, "Field and Laboratory Evidence of In Situ Biotransformation of Tetrachloroethene to Ethene and Ethane at a Chemical Transfer Facility in North Toronto", in *In Situ and On Site Bioreclamation*, R.E. Hinchee and R. Olfenbuttel, Eds., Buttersworth-Heineman, Stoneham, MA, 1991.

Major, D., E. Cox, E. Edwards, P. Hare, "Intrinsic Dechlorination of Trichlorothene to Ethene in a Bedrock Aquifer", in *Intrinsic Bioremediation*, R.E. Hinchee, J.T. Wilson, D.C. Downey, Eds., Battelle Press, Columbus, OH, 1995, pp. 197-203.

Maillacheruvu, K.Y. and G.F. Parkin, "Kinetics of Growth, Substrate Utilization, and sulfide Toxicity for Proprionate, Acetate, and Hydrogen Utilizers in Anaerobic Systems", *Water Environ. Res.*, 1996, 68:1099-1106.

Maymo-Gatell, X., V. Tandoi, J.M. Gossett, S.H. Zinder, "Characterization of an H_2-Utilizing Enrichment Culture that Reductively Dechlorinates Tetrachloroethene to Vinyl Chloride and Ethene in the Absence of Methanogenesis and Acetogenesis", *Appl. Environ. Microbiol.*, 1995, 61:3928-3933.

McCarty, P.L., "An Overview of Anaerobic Transformation of Chlorinated Solvents", *Symposium on Intrinsic Bioremediation of Ground Water*, EPA/540/R-94/515, US Environmental Protection Agency, 1994, pp. 135-142.

Sung, Y., K.E. Fletcher, K.M. Ritalahti, R.P. Apkarian, N. Ramos-Hernandez, R.A. Sandord, N.M. Mesbach, F.E. Loffler, "*Geobacter lovleyi* sp. nov. Strain SZ, a novel Metal-Reducing and Tetrachloroethene-Dechlorinating Bacterium", *Appl. Environ. Microbiol*., 2006, 72:2775-2782.

Yang,Y. and P. L. McCarty, "Comparison Between Donor Substrates for Biologically Enhanced Tetrachloroethene DNAPL Dissolution", *Environ. Sci. Technol*., 2002, 36:3400-3404.

Appendix 1 – Mineral Phase Analyses

Table A1a: Results of XRF Analysis – Composition of Gypsum-Rich Bedrock

Analyte (all values in wt % and exclude C and O)

	Edgecliff LIMESTONE	Upper Manlius LIMESTONE	Lower Manlius DOLOSTONE	Roundout DOLOSTONE	Cobleskill LIMESTONE	Gypsum Rock (n = 3)
Magnesium	0.25	1.53	10.01	11.16	3.02	1.55 +/- 1.17
Aluminum	2.63	0.46	3.00	ND	2.41	3.30 +/- 1.46
Silicon	3.81	2.54	10.79	2.85	2.61	9.61 +/- 3.02
Sulfur	ND	0.20	0.44	ND	ND	7.88 +/- 4.14
Chlorine	ND	ND	ND	ND	ND	ND
Potassium	1.78	2.28	5.31	1.94	1.77	3.91 +/- 1.52
Calcium	91.53	92.98	70.45	84.05	90.20	34.40 +/- 13.83
Titanium	ND	ND	ND	ND	ND	0.25 +/- 0.22
Iron	ND	ND	ND	ND	ND	8.96 +/- 1.39
Strontium	ND	ND	ND	ND	ND	30.12 +/- 16.00

Table A1b: Results of XRF Analysis – Composition of Sediments

Analyte (all values in wt % and exclude C and O)

	B-31D3 SEDIMENT	B-32D3 SEDIMENT	B-33D3 SEDIMENT	B-53D3 SEDIMENT	Gypsum Rock (n = 3)
Magnesium	6.78	4.40	1.43	5.50	1.55 +/- 1.17
Aluminum	7.87	4.19	4.39	4.23	3.30 +/- 1.46
Silicon	23.97	19.39	12.74	17.30	9.61 +/- 3.02
Sulfur	2.69	2.83	5.31	4.07	7.88 +/- 4.14
Chlorine	0.81	0.23	ND	ND	ND
Potassium	5.48	4.93	3.68	4.60	3.91 +/- 1.52
Calcium	38.20	50.92	59.17	49.01	34.40 +/- 13.83
Titanium	0.68	0.47	0.35	0.67	0.25 +/- 0.22
Iron	13.52	12.65	12.93	14.63	8.96 +/- 1.39
Strontium	ND	ND	ND	ND	30.12 +/- 16.00

Table A2: Results of XRD Analysis

Sample	Mineral	Formula	Concentration
B-55D3	Celestine	SrSO4	Major
Core	Calcite	CaCO3	Major
	Silica	SiO2	Minor
B-32D3	Ankerite	Ca(Mg,Fe)(CO3)2	Major
Sediment	Calcite	CaCO3	Major
	Silica	SiO2	Major
	Paranatisite	(Na2TiSiO5)	Minor
	Sulphohalite	(Na6(SO4))2ClF	Minor
B-53D3	Calcite	CaCO3	Major
Sediment	Dolomite	CaMg(CO3)2	Major
	Dolomite Ferioan	Ca(Mg,Fe)(CO3)2	Major
	Silica	SiO2	Minor
	Pyrite	(FeS2)	Minor

Table A3 - Summary of AMIBA Data

Well ID	**B-31D3**	**B-32D3**	**B-33D3**	**B-53D3**
Sample Date	9 June 2010	8 June 2010	8 June 2010	9 June 2010
Parameter				
Acid Volatile Sulfide (mg/kg)	500	1700	1400	690
Chromium Extractable Sulfide (mg/kg)	2600	1200	1800	1300
AVS/CES Ratio	0.19	1.42	0.78	0.53
Bioavailable Ferric Iron (mg/kg)	9	24.3	< 7.6	45
Weak Acid Soluble Ferric Iron (mg/kg)	< 14.7	< 16.2	< 15.2	< 13.5
Strong Acid Soluble Ferric Iron (mg/kg)	65.7	69.4	439	616
Weak Acid Soluble Ferrous Iron (mg/kg)	52.4	< 16.2	< 15.2	< 13.5
Strong Acid Soluble Ferrous Iron (mg/kg)	2260	4130	< 30.3	< 27.0
Oxidized Iron (mg/kg)	< 7.4	< 8.2	< 7.6	< 6.8
Bioavailable Manganese (mg/L)	< 7.4	< 8.2	< 7.6	< 6.8
Weak Acid Divalent Manganese (mg/kg)	< 14.7	16.6	< 15.2	< 13.5
Strong Acid Divalent Manganese (mg/kg)	530	133	< 30.3	< 27.0
Water content (%)	32	39	34	26

Appendix 2 – Microcosm Data

Lab	Sample ID	Exp. Time (Day)	total TCE umoles	total cDCE umoles	total VC umoles	total Eth umoles	TOTAL umoles
		Time	TCE	cDCE	VC	Eth	Total
GE	1A	1	21.09257	4.8832391	0	0	25.97581
GE	1A	14	20.83162	4.8685878	0	0	25.70021
GE	1A	29	20.4329	4.7363796	0	0	25.16928
GE	1A	42	18.53097	4.2697901	0	0	22.80076
GE	1A	57	19.33729	4.3108813	0	0	23.64817
GE	1A	72	16.82525	4.0553684	0	0	20.88062
GE	1A	85	18.97012	4.3421013	0	0	23.31222
GE	1A	99	17.0123	4.1535939	0	0	21.16589
GE	1A	120	16.03891	4.0239771	0	0	20.06289
GE	1A	143	14.64747	3.7216141	0	0	18.36908
GE	1A	169	13.5061	3.6206385	0	0	17.12674
GE	1A	198	12.37506	3.2087207	0	0	15.58378
GE	1A	228	12.92116	3.5307771	0	0	16.45193
GE	1A	252	13.25802	3.2582327	0	0	16.51625

Lab	Sample ID	Exp. Time (Day)	total TCE umoles	total cDCE umoles	total VC umoles	total Eth umoles	TOTAL umoles
		Time	TCE	cDCE	VC	Eth	Total
GE	1B	1	20.93874	5.067975	0	0	26.00672
GE	1B	14	20.65168	5.008314	0	0	25.65999
GE	1B	29	20.13966	4.594275	0	0	24.73394
GE	1B	42	19.92637	4.821156	0	0	24.74753
GE	1B	57	19.55007	4.622506	0	0	24.17258
GE	1B	72	16.96574	4.372737	0	0	21.33848
GE	1B	85	17.42703	4.326066	0	0	21.75309
GE	1B	99	15.8364	4.062988	0	0	19.89939
GE	1B	120	16.07681	4.241181	0	0	20.31799
GE	1B	143	14.92312	4.100341	0	0	19.02346
GE	1B	169	13.36853	3.788588	0	0	17.15712
GE	1B	198	12.96376	3.510683	0	0	16.47444
GE	1B	228	14.10373	3.862173	0	0	17.96591
GE	1B	252	13.27604	3.445037	0	0	16.72107

		Time	TCE	cDCE	VC	Eth	Total
GE	2A	1	19.88528	5.4538284	0	0	25.33911
GE	2A	14	19.57856	5.2156198	0	0	24.79418
GE	2A	29	19.12482	5.2045806	0	0	24.3294
GE	2A	42	18.42698	5.0733166	0	0	23.5003
GE	2A	57	17.23703	4.5008611	0	0	21.73789
GE	2A	72	15.45148	4.4120598	0	0	19.86354
GE	2A	85	16.77098	4.7084735	0	0	21.47945
GE	2A	99	15.69843	4.7816333	0	0	20.48006
GE	2A	120	15.46551	5.1253183	0	0	20.59083
GE	2A	143	13.24795	5.1980951	0	0	18.44604
GE	2A	169	13.02916	5.4885112	0	0	18.51767
GE	2A	198	11.35282	4.6319312	0	0	15.98475
GE	2A	228	13.20752	4.7282561	0	0	17.93578
GE	2A	252	12.38156	5.3355291	0	0	17.71709

		Time	TCE	cDCE	VC	Eth	Total
GE	2B	1	19.69697	5.281409	0	0	24.97838
GE	2B	14	19.03351	5.125926	0	0	24.15944
GE	2B	29	18.63919	5.026062	0	0	23.66525
GE	2B	42	17.3411	4.806612	0	0	22.14771
GE	2B	57	17.95436	4.589515	0	0	22.54387
GE	2B	72	15.97356	4.624829	0	0	20.59839
GE	2B	85	17.30011	4.705979	0	0	22.00609
GE	2B	99	16.08024	4.594725	0	0	20.67496
GE	2B	120	16.04624	5.006924	0	0	21.05317
GE	2B	143	13.38156	4.410833	0	0	17.79239
GE	2B	169	13.60281	4.805129	0	0	18.40793
GE	2B	198	11.77195	4.173564	0	0	15.94552
GE	2B	228	16.04115	3.816474	0	0	19.85763
GE	2B	252	13.27028	4.422762	0	0	17.69304

		Time	TCE	cDCE	VC	Eth	Total
GE	3A	1	21.00696	5.4455752	0	0	26.45254
GE	3A	14	20.48224	5.4367392	0	0	25.91898
GE	3A	29	20.08839	5.5288295	0	0	25.61722
GE	3A	42	18.7355	5.737067	0	0	24.47257
GE	3A	57	18.57028	6.097169	0	0	24.66745
GE	3A	72	15.40209	6.1985272	0	0	21.60062
GE	3A	85	17.05568	7.558021	0	0	24.6137
GE	3A	99	14.63541	7.4954025	0	0	22.13081
GE	3A	120	14.83512	8.5061002	0	0	23.34122
GE	3A	143	12.05591	7.1318642	0	0	19.18778
GE	3A	169	13.33562	8.1889432	0.60376	0	22.12832
GE	3A	198	11.74563	7.0304121	0.11493	0	18.89098
GE	3A	228	14.19678	5.7906935	0	0	19.98747
GE	3A	252	10.97636	7.1612595	0	0	18.13762

		Time	TCE	cDCE	VC	Eth	Total
GE	3B	1	21.0662	5.528405	0	0	26.5946
GE	3B	14	19.72666	5.13306	0	0	24.85972
GE	3B	29	19.72817	4.996269	0	0	24.72444
GE	3B	42	17.61922	4.645421	0	0	22.26464
GE	3B	57	18.82987	5.037686	0	0	23.86756
GE	3B	72	17.11851	5.451331	0	0	22.56984
GE	3B	85	17.9713	5.748486	0	0	23.71978
GE	3B	99	16.4721	5.986949	0	0	22.45905
GE	3B	120	17.37143	6.605257	0	0	23.97669
GE	3B	143	14.56715	5.992087	0	0	20.55923
GE	3B	169	14.15612	5.73169	0	0	19.88781
GE	3B	198	13.01587	5.117231	0.114932	0	18.24804
GE	3B	228	12.78804	5.667417	0	0	18.45546
GE	3B	252	13.06635	5.885157	0	0	18.9515

		Time	TCE	cDCE	VC	Eth	Total
GE	4A	1	19.63201	4.3921303	0.57721	0	24.60136
GE	4A	14	0.84892	30.689873	0	0	31.53879
GE	4A	29	0.0384	33.265891	0	0	33.30429
GE	4A	42	0	31.693428	0	0	31.69343
GE	4A	57	0	30.448364	0	0	30.44836
GE	4A	72	0	30.271289	0	0	30.27129
GE	4A	85	0	30.301932	0	0	30.30193
GE	4A	99	0	27.582459	0.50473	0	28.08719
GE	4A	120	0	23.14808	7.51265	0	30.66073
GE	4A	143	1.356785	5.5324062	22.6915	0	29.58071
GE	4A	169	0.302709	0.3927371	29.5226	0	30.21809
GE	4A	198	0	0	25.9423	2.980434	28.92272
GE	4A	228	0	0	15.0306	11.39379	26.42443
GE	4A	252	0	0.1370118	8.26987	14.19318	22.60006

		Time	TCE	cDCE	VC	Eth	Total
GE	4B	1	19.82954	4.725635	0.518701	0	25.07387
GE	4B	14	0.57155	31.14335	0	0	31.7149
GE	4B	29	0.0384	32.826	0	0	32.8644
GE	4B	42	0	32.793	0	0	32.793
GE	4B	57	0	32.11637	0	0	32.11637
GE	4B	72	0	30.97342	0	0	30.97342
GE	4B	85	0	30.50007	1.517988	0	32.01806
GE	4B	99	0	19.6412	10.63332	0	30.27452
GE	4B	120	0	5.753983	26.89898	0	32.65297
GE	4B	143	0	0	28.12967	1.581046	29.71071
GE	4B	169	0	0	19.25041	0.142878	19.39329
GE	4B	198	0	0	1.550496	20.62148	22.17198
GE	4B	228	0.220942	0	0	21.09491	21.31585
GE	4B	252	0	0	0	20.0524	20.0524

		Time	TCE	cDCE	VC	Eth	Total
GE	5A	1	19.78356	5.1308784	0	0	24.91444
GE	5A	14	7.246114	22.323034	0	0	29.56915
GE	5A	29	0.334098	32.559668	0	0	32.89377
GE	5A	42	0	30.502485	0	0	30.50248
GE	5A	57	0	31.056594	0	0	31.05659
GE	5A	72	0	30.190266	0	0	30.19027
GE	5A	85	0	30.546422	1.13005	0	31.67648
GE	5A	99	0	18.136293	11.6473	0	29.78359
GE	5A	120	0	8.8239938	22.8654	0	31.68944
GE	5A	143	0	0.3712628	28.3876	0.656446	29.41532
GE	5A	169	0	0	15.0822	0.124896	15.20708
GE	5A	198	0	0	0	21.5762	21.5762
GE	5A	228	0	0	0	18.94379	18.94379
GE	5A	252	0	0	0	19.59066	19.59066

		Time	TCE	cDCE	VC	Eth	Total
GE	5B	1	19.70498	5.205037	0	0	24.91001
GE	5B	14	8.312313	16.92537	0	0	25.23768
GE	5B	29	0.496857	31.88753	0	0	32.38439
GE	5B	42	0.340506	29.38532	0	0	29.72582
GE	5B	57	0.309439	30.11677	0	0	30.42621
GE	5B	72	0	27.77809	0.279421	0	28.05751
GE	5B	85	0	22.50458	6.441791	0	28.94637
GE	5B	99	0	8.169774	22.0141	0	30.18387
GE	5B	120	0	1.367815	29.87072	0.665623	31.90416
GE	5B	143	0	0	23.97806	1.977885	25.95594
GE	5B	169	0	0	18.94448	0.120077	19.06456
GE	5B	198	0	0	5.330772	15.6873	21.01807
GE	5B	228	0	0	0	17.67096	17.67096
GE	5B	252	0	0	0	18.3098	18.3098

		Time	TCE	cDCE	VC	Eth	Total
GE	6A	1	17.46629	24.371098	0.56185	0	42.39924
GE	6A	14	16.47035	23.322245	0.54897	0	40.34156
GE	6A	29	15.79069	22.558413	0.49996	0	38.84906
GE	6A	42	14.22682	21.441898	0.49415	0	36.16287
GE	6A	57	14.86903	20.957853	0.44599	0	36.27287
GE	6A	72	12.90975	20.665433	0.44063	0	34.01581
GE	6A	85	14.17765	21.160573	0.42719	0	35.76541
GE	6A	99	12.69163	19.846089	0.44236	0	32.98008
GE	6A	120	11.6798	20.163569	0.45606	0	32.29943
GE	6A	143	10.32363	18.984693	0.54883	0	29.85715
GE	6A	169	9.985657	18.858432	0.44278	0.034333	29.3212
GE	6A	198	9.612185	17.436487	0.59969	0.128216	27.77658
GE	6A	228	9.195601	16.924006	0.37043	0	26.49003
GE	6A	252	9.738425	16.869212	0.64373	0	27.25137

		Time	TCE	cDCE	VC	Eth	Total
GE	6B	1	17.38393	23.84285	0.396822	0	41.6236
GE	6B	14	15.74286	22.55528	0.364522	0	38.66266
GE	6B	29	15.19732	22.23201	0.341422	0	37.77075
GE	6B	42	11.88684	19.58625	0.259778	0	31.73287
GE	6B	57	13.65389	19.77607	0.275417	0	33.70538
GE	6B	72	12.43818	20.14162	0.271784	0	32.85159
GE	6B	85	12.57653	19.32089	0.239955	0	32.13738
GE	6B	99	11.32579	18.5608	0.185967	0	30.07256
GE	6B	120	11.22314	19.72966	0.285888	0	31.23869
GE	6B	143	8.769094	17.1955	0.201892	0	26.16649
GE	6B	169	8.908822	17.29296	0.219523	0.051137	26.47244
GE	6B	198	8.676986	16.33139	0	0	25.00837
GE	6B	228	0	0	24.36533	9.441896	33.80723
GE	6B	252	8.182331	15.15818	0.470579	0	23.81109

		Time	TCE	cDCE	VC	Eth	Total
GE	7A	1	15.32037	22.151168	3.94985	0	41.4214
GE	7A	14	9.793767	19.980942	12.1624	0	41.93713
GE	7A	29	3.515431	11.212698	26.6317	0	41.35983
GE	7A	42	0.831159	4.4174093	36.8634	0	42.11199
GE	7A	57	0.293326	1.0523752	40.2646	0.808205	42.4185
GE	7A	72	0	0	37.2763	1.435559	38.71187
GE	7A	85	0	0	37.6334	2.174861	39.80823
GE	7A	99	0	0	36.7709	3.726442	40.4973
GE	7A	120	0	0	31.2655	5.133425	36.3989
GE	7A	143	0	0	24.1452	5.953501	30.09866
GE	7A	169	0.254785	0.0709585	23.9992	0.117816	24.44279
GE	7A	198	0	0	15.757	12.92064	28.67768
GE	7A	228	0	0	17.3427	13.03106	30.3738
GE	7A	252	0	0	14.0059	13.40334	27.40924

		Time	TCE	cDCE	VC	Eth	Total
GE	7B	1	15.26935	22.74669	4.018805	0	42.03484
GE	7B	14	9.635092	20.14805	11.51309	0	41.29623
GE	7B	29	3.771146	12.07542	25.93816	0	41.78472
GE	7B	42	0.814351	4.901996	33.98367	0	39.70001
GE	7B	57	0	1.170302	38.78887	0.703393	40.66257
GE	7B	72	0	0	39.59656	1.290088	40.88665
GE	7B	85	0	0	38.89534	2.271631	41.16697
GE	7B	99	0	0	34.83954	3.340043	38.17958
GE	7B	120	0	0.142955	32.27244	5.113743	37.52914
GE	7B	143	0	0	26.46243	6.05467	32.5171
GE	7B	169	0	0.030559	23.99219	0.125813	24.14857
GE	7B	198	0	0	18.3109	13.94488	32.25578
GE	7B	228	0	0	24.94188	7.937177	32.87905
GE	7B	252	0	0	16.41892	13.42311	29.84203

		Time	TCE	cDCE	VC	Eth	Total
GE	8A	1	15.64466	24.113571	4.82758	0	44.58581
GE	8A	14	6.920232	17.868787	18.0029	0	42.79189
GE	8A	29	1.656547	7.8303957	34.4177	0	43.90461
GE	8A	42	0	1.7933374	40.3257	0.678808	42.79781
GE	8A	57	0	0	36.4957	1.261256	37.75699
GE	8A	72	0	0	34.5033	1.626588	36.12992
GE	8A	85	0	0	35.9936	2.141084	38.13465
GE	8A	99	0	0	35.0122	2.960613	37.97285
GE	8A	120	0	0	33.9029	4.172782	38.07569
GE	8A	143	0	0	24.3189	4.33439	28.65328
GE	8A	169	0	0	28.748	0.125673	28.87367
GE	8A	198	0	0	23.767	8.565276	32.3323
GE	8A	228	0	0	27.5121	9.143309	36.65538
GE	8A	252	0	0	26.2513	8.298017	34.54935

		Time	TCE	cDCE	VC	Eth	Total
GE	8B	1	14.38928	21.03386	4.089093	0	39.51224
GE	8B	14	6.217867	15.60307	16.01493	0	37.83586
GE	8B	29	1.242241	6.35416	29.66486	0	37.26126
GE	8B	42	0	1.284424	33.6744	0.62938	35.5882
GE	8B	57	0	0	35.38131	1.390579	36.77188
GE	8B	72	0	0	32.05047	1.690306	33.74077
GE	8B	85	0	0	35.19021	2.261356	37.45157
GE	8B	99	0	0	32.07815	2.91266	34.99081
GE	8B	120	0	0	30.68802	4.055119	34.74314
GE	8B	143	0	0	21.35163	3.680848	25.03247
GE	8B	169	0	0	25.21211	0.120602	25.33271
GE	8B	198	0	0	21.47966	9.313593	30.79325
GE	8B	228	0	0	26.0512	10.16518	36.21638
GE	8B	252	0	0	24.09641	8.988151	33.08456

		Time	TCE	cDCE	VC	Eth	Total
GE	9A	1	14.17039	20.401775	3.19785	0	37.77002
GE	9A	14	7.514392	21.435934	11.7235	0	40.67383
GE	9A	29	2.896433	13.90548	26.67	0	43.47186
GE	9A	42	0	1.0803774	39.059	0.967395	41.10677
GE	9A	57	0	0	33.2368	4.237307	37.47412
GE	9A	72	0	0	26.1536	7.235389	33.38898
GE	9A	85	0	0	8.56763	14.30145	22.86907
GE	9A	99	0	0	0	18.22579	18.22579
GE	9A	120	0	0	0	19.60354	19.60354
GE	9A	252	0	0	0	22.59935	22.59935
GE							
GE							
GE							
GE							

		Time	TCE	cDCE	VC	Eth	Total
GE	9B	1	14.11412	20.77804	3.040668	0	37.93283
GE	9B	14	8.395432	21.09549	11.0714	0	40.56232
GE	9B	29	3.445032	14.00077	26.28289	0	43.72869
GE	9B	42	0	1.112144	37.2577	0.858288	39.22813
GE	9B	57	0	0	32.53704	3.700249	36.23729
GE	9B	72	0	0	30.39945	5.366568	35.76602
GE	9B	85	0	0	25.25177	7.877519	33.12929
GE	9B	99	0	0	5.639428	18.06678	23.70621
GE	9B	120	0	0	0	20.13935	20.13935
GE	9B	143	0	0	0	19.1944	19.1944
GE	9B	252	0	0	0	25.03616	25.03616
GE							
GE							
GE							

		Time	TCE	cDCE	VC	Eth	Total
GE	10A	1	15.52795	23.837677	4.14921	0	43.51484
GE	10A	14	8.583438	18.912446	13.2025	0	40.69838
GE	10A	29	3.04435	11.528122	28.2692	0	42.84167
GE	10A	42	0	0.5050597	42.0046	1.64911	44.15876
GE	10A	57	0	0	32.9704	4.141491	37.11189
GE	10A	72	0	0	21.6404	7.523808	29.16418
GE	10A	85	0	0	7.10974	14.52262	21.63236
GE	10A	99	0	0	0	18.58698	18.58698
GE	10A	120	0	0	0	18.11696	18.11696
GE	10A	252	0	0	0	23.17815	23.17815
GE							
GE							
GE							
GE							

		Time	TCE	cDCE	VC	Eth	Total
GE	10B	1	14.84829	22.93836	4.272863	0	42.05951
GE	10B	14	8.145384	18.57789	12.91042	0	39.6337
GE	10B	29	3.128424	11.54497	28.11953	0	42.79292
GE	10B	42	0	0.947597	43.06493	1.476786	45.48931
GE	10B	57	0	0	35.48152	3.287912	38.76943
GE	10B	72	0	0	30.52554	5.62924	36.15478
GE	10B	85	0	0	22.45333	9.999027	32.45236
GE	10B	99	0	0	13.10649	14.93715	28.04363
GE	10B	120	0	0	1.816207	19.00781	20.82402
GE	10B	143	0	0	0	17.4941	17.4941
GE	10B	169	0	0	0.060281	0.271872	0.332153
GE	10B	198	0	0	0	27.35083	27.35083
GE	10B	228	0	0	0	24.84248	24.84248
GE	10B	252	0	0	0	20.62201	20.62201

Lab	Sample	Exp. Time	total TCE	total cDCE	total VC	total Eth	TOTAL
	ID	(Day)	umoles	umoles	umoles	umoles	umoles
		Time	TCE	cDCE	VC	Eth	Total
GE	11A	1	15.62748	8.8294134	0.63958	0	25.09647
GE	11A	14	13.9406	8.2074476	0.66296	0	22.811
GE	11A	29	13.42456	8.0886116	0	0	21.51317
GE	11A	42	12.52215	7.8829471	0	0	20.4051
GE	11A	57	13.31127	8.6515073	0	0	21.96277
GE	11A	72	12.36283	7.9606654	0	0	20.3235
GE	11A	85	11.54517	7.5431676	0	0	19.08833
GE	11A	99	10.36636	7.302537	0	0	17.66889
GE	11A	120	10.17433	7.1205914	0	0	17.29492
GE	11A	143	9.473667	6.9555538	0	0	16.42922
GE	11A	169	8.881709	7.0909622	0	0	15.97267
GE	11A	198	7.698356	6.2186373	0	0	13.91699
GE	11A	228	8.072124	6.7442758	0	0	14.8164
GE	11A	252	7.517966	6.379716	0	0	13.89768

Lab	Sample ID	Exp. Time (Day)	total TCE umoles	total cDCE umoles	total VC umoles	total Eth umoles	TOTAL umoles
		Time	TCE	cDCE	VC	Eth	Total
GE	11B	1	15.97897	8.817632	0.655837	0	25.45244
GE	11B	14	13.92883	8.211302	0	0	22.14013
GE	11B	29	13.12813	7.929416	0	0	21.05754
GE	11B	42	12.92405	8.272024	0	0	21.19607
GE	11B	57	13.11347	8.556134	0	0	21.66961
GE	11B	72	12.24761	7.964532	0	0	20.21214
GE	11B	85	11.43345	7.668812	0	0	19.10226
GE	11B	99	10.72406	7.546241	0	0	18.2703
GE	11B	120	10.26859	7.355512	0	0	17.6241
GE	11B	143	9.91924	7.248033	0	0	17.16727
GE	11B	169	8.542199	7.04682	0	0	15.58902
GE	11B	198	7.680112	6.260366	0	0	13.94048
GE	11B	228	8.619891	7.070968	0	0	15.69086
GE	11B	252	6.849985	6.023537	0	0	12.87352

		Time	TCE	cDCE	VC	Eth	Total
GE	12A	1	15.36972	9.2328619	0.63026	0	25.23285
GE	12A	14	13.61365	8.5462459	0	0	22.1599
GE	12A	29	13.19421	8.4104028	0	0	21.60461
GE	12A	42	12.48032	8.3598844	0	0	20.8402
GE	12A	57	6.266271	16.164942	0	0	22.43121
GE	12A	72	0.481172	22.019658	0	0	22.50083
GE	12A	85	0.654486	20.645517	0	0	21.3
GE	12A	99	0.593855	20.683378	0	0	21.27723
GE	12A	120	0.491878	20.35522	0	0	20.8471
GE	12A	143	0.668471	18.693423	0	0	19.36189
GE	12A	169	0.619598	19.568419	0	0	20.18802
GE	12A	198	0	17.66886	0	0	17.66886
GE	12A	228	0.288594	19.834461	0	0	20.12305
GE	12A	252	0.286071	17.000834	0.16533	0	17.45223

		Time	TCE	cDCE	VC	Eth	Total
GE	12B	1	15.18529	8.833494	0.621703	0	24.64049
GE	12B	14	14.48431	9.039007	0	0	23.52331
GE	12B	29	13.45134	8.602944	0	0	22.05428
GE	12B	42	11.88149	8.279546	0	0	20.16103
GE	12B	57	0.928157	23.04644	0	0	23.9746
GE	12B	72	0.379327	22.31699	0	0	22.69632
GE	12B	85	0.503788	21.65759	0	0	22.16138
GE	12B	99	0.454449	21.45099	0	0	21.90544
GE	12B	120	0.389612	20.83346	0	0	21.22307
GE	12B	143	0.413286	18.12185	0	0	18.53514
GE	12B	169	0.423972	19.61691	0	0	20.04088
GE	12B	198	0	17.46403	0	0	17.46403
GE	12B	228	0.249236	19.362	0.143971	0	19.75521
GE	12B	252	0.264974	17.99743	0.135199	0	18.3976

		Time	TCE	cDCE	VC	Eth	Total
GE	13A	1	15.51965	9.3569174	0.69546	0	25.57203
GE	13A	14	13.02355	9.276472	0	0	22.30003
GE	13A	29	11.68784	8.9068036	0	0	20.59464
GE	13A	42	10.45393	9.7068541	0.15268	0	20.31347
GE	13A	57	8.64466	11.231615	0.58068	0	20.45696
GE	13A	72	6.589395	11.819123	1.46989	0	19.87841
GE	13A	85	3.621451	11.655722	3.41011	0	18.68728
GE	13A	99	0	4.6447762	17.0477	0	21.69251
GE	13A	120	0	0.9251271	18.3866	0	19.31175
GE	13A	143	0	0	19.728	0.540068	20.26808
GE	13A	169	0	0	19.7147	0.027709	19.7424
GE	13A	198	0	0	17.7817	1.324241	19.10593
GE	13A	228	0	0	18.8945	1.192341	20.08681
GE	13A	252	0.153526	0	16.2574	1.343862	17.75474

		Time	TCE	cDCE	VC	Eth	Total
GE	13B	1	15.75408	9.104594	0.300375	0	25.15905
GE	13B	14	12.90399	8.279331	0	0	21.18332
GE	13B	29	12.21601	9.114057	0	0	21.33007
GE	13B	42	10.61188	9.43118	0.159732	0	20.20279
GE	13B	57	8.78868	10.75119	0.658728	0	20.1986
GE	13B	72	6.408157	11.04248	1.547353	0	18.99799
GE	13B	85	4.239559	11.5765	3.046353	0	18.86241
GE	13B	99	0	6.21999	13.20006	0	19.42005
GE	13B	120	0	1.43202	18.66149	0	20.09351
GE	13B	143	0	0	20.34232	0.482181	20.8245
GE	13B	169	0	0	19.65425	0.058762	19.71302
GE	13B	198	0	0	17.81292	1.290837	19.10376
GE	13B	228	0	0	21.47381	1.61317	23.08698
GE	13B	252	0	0	17.78692	1.408513	19.19543

		Time	TCE	cDCE	VC	Eth	Total
GE	14A	1	15.27672	9.0387315	0.71056	0	25.02601
GE	14A	14	2.540799	22.022375	0	0	24.56317
GE	14A	29	0.961552	19.840308	1.48825	0	22.29011
GE	14A	42	0.566597	15.525996	5.16957	0	21.26216
GE	14A	57	0	2.9294849	19.3254	0	22.25488
GE	14A	72	0	0	19.7328	3.099325	22.83208
GE	14A	85	0	0	0.48559	11.98461	12.47019
GE	14A	99	0	0	0	13.15138	13.15138
GE	14A	120	0	0	0	12.17857	12.17857
GE	14A	252	0	0	0	14.30331	14.30331
GE							
GE							
GE							

		Time	TCE	cDCE	VC	Eth	Total
GE	14B	1	15.47918	9.406383	0.693827	0	25.57939
GE	14B	14	1.000188	23.84653	0	0	24.84671
GE	14B	29	0.262085	22.19203	1.854116	0	24.30823
GE	14B	42	0	16.00955	6.050372	0	22.05992
GE	14B	57	0	2.006449	20.53696	0.472149	23.01556
GE	14B	72	0	0	19.81058	2.719301	22.52988
GE	14B	85	0	0	0.515764	13.03875	13.55452
GE	14B	99	0	0	0	13.0892	13.0892
GE	14B	120	0	0	0	12.6753	12.6753
GE	14B	252	0	0	0	13.56511	13.56511
GE							
GE							
GE							

		Time	TCE	cDCE	VC	Eth	Total
GE	15A	1	15.54342	8.7971878	0.58556	0	24.92617
GE	15A	14	12.16707	8.6142907	0	0	20.78136
GE	15A	29	8.947563	10.8675	0.81987	0	20.63494
GE	15A	42	0.707793	13.441978	7.2887	0	21.43847
GE	15A	57	0	3.2150883	18.5756	0	21.79072
GE	15A	72	0	0.3468295	19.5327	1.333154	21.21271
GE	15A	85	0	0	12.1196	4.553991	16.6736
GE	15A	99	0	0	1.77534	9.760559	11.5359
GE	15A	120	0	0	0	9.77235	9.77235
GE	15A	143	0	0	0	10.2479	10.2479
GE	15A	252	0	0	0	12.94965	12.94965
GE							
GE							

		Time	TCE	cDCE	VC	Eth	Total
GE	15B	1	15.66538	9.46446	0.635373	0	25.76521
GE	15B	14	13.0734	9.052267	0	0	22.12567
GE	15B	29	9.168862	10.4496	0.618195	0	20.23666
GE	15B	42	0.629853	14.61488	6.243672	0	21.48841
GE	15B	57	0	4.760638	17.65546	0	22.4161
GE	15B	72	0	0.626195	20.93828	1.372582	22.93705
GE	15B	85	0	0	20.4932	1.558846	22.05205
GE	15B	99	0	0	18.789	2.136857	20.92586
GE	15B	120	0	0	15.73083	2.734826	18.46566
GE	15B	143	0	0	0	12.73609	12.73609
GE	15B	198	0	0	0	15.53363	15.53363
GE	15B	252	0	0	0	13.03295	13.03295
GE							

		Time	TCE	cDCE	VC	Eth	Total
GE	16A	1	16.16948	17.455054	0	0	33.62453
GE	16A	14	14.35913	16.760345	0	0	31.11947
GE	16A	29	13.41093	16.097796	0	0	29.50873
GE	16A	42	12.74249	15.95483	0	0	28.69732
GE	16A	57	12.87156	16.582339	0	0	29.45389
GE	16A	72	12.28008	15.770851	0	0	28.05093
GE	16A	85	11.57417	13.268285	0	0	24.84245
GE	16A	99	10.48989	14.051439	0	0	24.54133
GE	16A	120	8.891608	13.1275	0	0	22.01911
GE	16A	143	9.331777	13.389805	0	0	22.72158
GE	16A	169	8.559003	13.933804	0	0	22.49281
GE	16A	198	7.553374	12.082111	0	0	19.63548
GE	16A	228	8.253614	12.872102	0	0	21.12572
GE	16A	252	7.094807	11.987912	0	0	19.08272

		Time	TCE	cDCE	VC	Eth	Total
GE	16B	1	13.95029	15.82836	0	0	29.77865
GE	16B	14	13.07264	15.70431	0	0	28.77694
GE	16B	29	12.16519	14.55394	0	0	26.71914
GE	16B	42	12.55025	15.43247	0	0	27.98272
GE	16B	57	12.37206	15.51775	0	0	27.88981
GE	16B	72	12.29219	15.27348	0	0	27.56567
GE	16B	85	11.44846	14.29194	0	0	25.7404
GE	16B	99	10.42565	14.03492	0	0	24.46057
GE	16B	120	9.580874	13.71902	0	0	23.29989
GE	16B	143	9.82766	13.49545	0	0	23.32311
GE	16B	169	8.783592	13.34065	0	0	22.12424
GE	16B	198	8.159439	12.15717	0	0	20.31661
GE	16B	228	8.711324	12.81143	0	0	21.52275
GE	16B	252	7.207043	11.33703	0	0	18.54407

		Time	TCE	cDCE	VC	Eth	Total
GE	17A	1	16.38271	18.028519	0	0	34.41123
GE	17A	14	14.43	16.047415	0	0	30.47742
GE	17A	29	15.14898	17.041787	0	0	32.19077
GE	17A	42	14.25559	16.428333	0	0	30.68392
GE	17A	57	15.39115	18.124626	0	0	33.51578
GE	17A	72	13.91782	15.954992	0	0	29.87281
GE	17A	85	13.4993	15.589149	0	0	29.08845
GE	17A	99	11.89106	14.49906	0	0	26.39012
GE	17A	120	10.84311	14.432837	0	0	25.27594
GE	17A	143	11.21999	13.84851	0	0	25.0685
GE	17A	169	10.40632	14.416444	0	0	24.82276
GE	17A	198	9.438053	12.661297	0	0	22.09935
GE	17A	228	9.624583	12.843529	0	0	22.46811
GE	17A	252	10.64857	13.086718	0	0	23.73528

		Time	TCE	cDCE	VC	Eth	Total
GE	17B	1	16.38017	18.56632	0	0	34.94648
GE	17B	14	15.78931	18.06763	0	0	33.85694
GE	17B	29	14.90147	16.72838	0	0	31.62985
GE	17B	42	14.48995	16.48908	0	0	30.97903
GE	17B	57	14.66359	17.92419	0	0	32.58778
GE	17B	72	14.37007	17.27957	0	0	31.64964
GE	17B	85	12.57489	15.1015	0	0	27.67638
GE	17B	99	11.99572	14.9772	0	0	26.97292
GE	17B	120	11.10911	15.38331	0	0	26.49242
GE	17B	143	11.39532	14.85285	0	0	26.24817
GE	17B	169	10.4968	14.96821	0	0	25.46501
GE	17B	198	9.046855	12.72179	0	0	21.76865
GE	17B	228	10.13939	13.65594	0	0	23.79533
GE	17B	252	10.71343	13.86813	0	0	24.58156

		Time	TCE	cDCE	VC	Eth	Total
GE	18A	1	15.87808	18.564035	0.21136	0	34.65348
GE	18A	14	11.2961	16.320554	0	0	27.61665
GE	18A	29	10.8792	16.864368	0	0	27.74357
GE	18A	42	10.65022	16.404107	0	0	27.05433
GE	18A	57	10.5836	16.831781	0	0	27.41538
GE	18A	72	10.36921	15.718567	0	0	26.08777
GE	18A	85	11.23855	16.062583	0	0	27.30113
GE	18A	99	9.072297	15.123675	0	0	24.19597
GE	18A	120	8.046818	14.543108	0	0	22.58993
GE	18A	143	9.243651	15.172009	0	0	24.41566
GE	18A	169	8.082957	14.733365	0	0	22.81632
GE	18A	198	6.990258	12.494009	0	0	19.48427
GE	18A	228	7.412733	12.639643	0	0	20.05238
GE	18A	252	7.842935	12.942792	0	0	20.78573

		Time	TCE	cDCE	VC	Eth	Total
GE	18B	1	15.56497	16.67521	0	0	32.24017
GE	18B	14	12.91853	16.34068	0	0	29.25921
GE	18B	29	11.73224	16.18758	0	0	27.91982
GE	18B	42	11.40278	15.9857	0	0	27.38849
GE	18B	57	11.31298	16.54526	0	0	27.85824
GE	18B	72	11.19371	15.92999	0	0	27.1237
GE	18B	85	10.27764	14.48236	0	0	24.76001
GE	18B	99	10.20636	14.75992	0	0	24.96628
GE	18B	120	8.716658	13.01377	0	0	21.73042
GE	18B	143	9.391532	14.0827	0	0	23.47423
GE	18B	169	8.688677	13.57526	0	0	22.26394
GE	18B	198	7.88218	11.76495	0	0	19.64713
GE	18B	228	8.861379	12.77687	0	0	21.63825
GE	18B	252	8.722207	12.40823	0	0	21.13044

		Time	TCE	cDCE	VC	Eth	Total
GE	19A	1	15.07197	17.648929	0	0	32.7209
GE	19A	14	3.857074	25.113658	0	0	28.97073
GE	19A	29	1.94542	29.03782	0	0	30.98324
GE	19A	42	1.969429	29.609886	0	0	31.57932
GE	19A	57	1.942135	28.938436	0	0	30.88057
GE	19A	72	1.871722	28.193414	0	0	30.06514
GE	19A	85	1.952763	26.475456	0	0	28.42822
GE	19A	99	1.785983	26.176933	0	0	27.96292
GE	19A	120	1.610478	24.409176	0	0	26.01965
GE	19A	143	1.891529	25.72603	0	0	27.61756
GE	19A	169	1.754829	25.046765	0	0	26.80159
GE	19A	198	1.563532	23.044812	0	0	24.60834
GE	19A	228	1.010021	18.756675	6.48521	0	26.25191
GE	19A	252	0.301945	10.370944	15.0656	0	25.7385

		Time	TCE	cDCE	VC	Eth	Total
GE	19B	1	16.03289	18.09685	0	0	34.12974
GE	19B	14	10.30521	18.28563	0	0	28.59083
GE	19B	29	8.947506	19.14615	0	0	28.09366
GE	19B	42	8.385651	17.92962	0	0	26.31527
GE	19B	57	8.726569	19.399	0	0	28.12557
GE	19B	72	8.030145	17.75305	0	0	25.78319
GE	19B	85	7.954047	17.47083	0	0	25.42488
GE	19B	99	7.40429	16.87309	0	0	24.27738
GE	19B	120	6.695078	15.62673	0	0	22.3218
GE	19B	143	7.379736	16.69274	0	0	24.07247
GE	19B	169	6.800953	16.1682	0	0	22.96915
GE	19B	198	6.08409	14.54001	0	0	20.6241
GE	19B	228	4.046346	15.17074	3.249472	0	22.46656
GE	19B	252	1.507668	12.02329	9.301025	0	22.83198

		Time	TCE	cDCE	VC	Eth	Total
GE	20A	1	16.35898	19.163671	0.18494	0	35.70759
GE	20A	14	10.9418	17.655565	0	0	28.59736
GE	20A	29	9.42186	17.502554	0	0	26.92441
GE	20A	42	9.941069	18.341485	0	0	28.28255
GE	20A	57	9.618592	18.712927	0	0	28.33152
GE	20A	72	9.110542	17.370621	0	0	26.48116
GE	20A	85	8.944955	16.746	0	0	25.69095
GE	20A	99	8.696384	17.150887	0	0	25.84727
GE	20A	120	7.136566	15.415956	0	0	22.55252
GE	20A	143	7.002973	15.706047	0.17619	0	22.88521
GE	20A	169	0	19.178916	2.4666	0.031753	21.67727
GE	20A	198	0	4.3344047	16.3651	1.408553	22.10808
GE	20A	228	0	1.0101217	18.8742	3.525098	23.40939
GE	20A	252	0	0.3008631	15.978	6.898547	23.17737

		Time	TCE	cDCE	VC	Eth	Total
GE	20B	1	15.70577	18.06609	0	0	33.77186
GE	20B	14	11.75209	17.45381	0	0	29.2059
GE	20B	29	10.144	16.49366	0	0	26.63766
GE	20B	42	10.1102	16.33654	0	0	26.44674
GE	20B	57	10.0183	16.66507	0	0	26.68336
GE	20B	72	9.992818	17.27693	0	0	27.26975
GE	20B	85	9.501795	15.98741	0	0	25.4892
GE	20B	99	8.674516	15.06488	0	0	23.7394
GE	20B	120	7.866015	14.74814	0	0	22.61416
GE	20B	143	7.757026	15.0754	0	0	22.83243
GE	20B	169	5.247921	16.45474	0	0.085504	21.78816
GE	20B	198	1.045871	10.87929	10.12434	0	22.0495
GE	20B	228	0.625956	6.996214	14.68755	0.467802	22.77753
GE	20B	252	0.316875	4.996959	17.53197	0.842449	23.68825

	ID			Total umoles	Total umoles	Total umoles	Total umoles	umoles
	Sample	Days		TCE	cDCE	VC	Ethene	Sum Total
GE	21A	0		8.22270062	0	0	0	8.222701
GE	21A	5		6.3852666	0	0	0	6.385267
GE	21A	20		6.04382419	0	0	0	6.043824
GE	21A	41		5.46255783	0	0	0	5.462558
GE	21A	71		5.13017838	0	0	0	5.130178
GE	21A	91		5.06140748	0	0	0.03488231	5.09629
GE	21A	126		4.41884329	0	0	0	4.418843
GE	21A	152		5.84648424	0	0	0	5.846484
GE	21A	173		6.29227955	0	0	0	6.29228

	Sample	Days		TCE	cDCE	VC	Ethene	Sum Total
GE	21B	0		8.99985941	0	0	0	8.999859
GE	21B	5		7.4831749	0	0	0	7.483175
GE	21B	20		6.50933068	0	0	0	6.509331
GE	21B	41		6.05704099	0	0	0	6.057041
GE	21B	71		6.65514461	0	0	0	6.655145
GE	21B	91		6.27255376	0	0	0	6.272554
GE	21B	126		4.97189025	0	0	0	4.97189
GE	21B	152		6.53374548	0	0	0	6.533745
GE	21B	173		6.6991411	0	0	0	6.699141

	Sample	Days		TCE	cDCE	VC	Ethene	Sum Total
GE	21C	0		12.4028237	0	0	0	12.40282
GE	21C	5		11.439101	0	0	0	11.4391
GE	21C	20		9.99218822	0	0	0	9.992188
GE	21C	41		8.20658726	0	0	0	8.206587
GE	21C	71		8.26618444	0.31049373	0	0	8.576678
GE	21C	91		7.03124	0.19053093	0	0.04330191	7.265073
GE	21C	126		5.95984546	0	0	0	5.959845
GE	21C	152		7.67130451	0.51789837	0	0	8.189203
GE	21C	173		7.9670451	0.33635044	0	0	8.303396

	Sample	Days		TCE	cDCE	VC	Ethene	Sum Total
GE	21D	0		12.8786666	0	0	0	12.87867
GE	21D	5		12.3392389	0	0	0	12.33924
GE	21D	20		11.473309	0	0	0	11.47331
GE	21D	41		9.83724912	0	0	0	9.837249
GE	21D	71		9.90209426	0.38945178	0	0	10.29155
GE	21D	91		10.5762009	0.27994517	0	0.07403562	10.93018
GE	21D	126		7.86991034	0	0	0	7.86991
GE	21D	152		9.10330725	0.57207141	0	0	9.675379
GE	21D	173		10.1255431	0.46129187	0	0	10.58684

	Sample	Days		TCE	cDCE	VC	Ethene	Sum Total
GE	21E	0		13.2028377	0	0	0	13.20284
GE	21E	5		12.7369233	0	0	0	12.73692
GE	21E	20		10.9044588	0.24652459	0	0	11.15098
GE	21E	41		11.3121139	0.29098788	0	0	11.6031
GE	21E	71		9.64181487	0.48802188	0	0	10.12984
GE	21E	91		8.45698113	0.36582158	0	0.08145566	8.904258
GE	21E	126		7.15310203	0	0	0	7.153102
GE	21E	152		8.60174869	0.69828776	0	0	9.300036
GE	21E	173		9.33996665	0.55847488	0	0	9.898442

Appendix 3 – Microcosm Figures

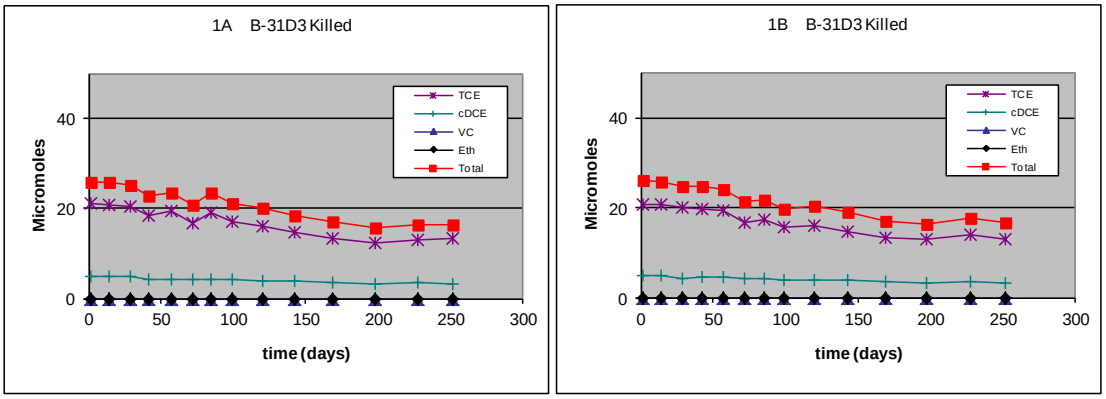

Figure A4 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-31D3 autoclaved controls (treatment 1).

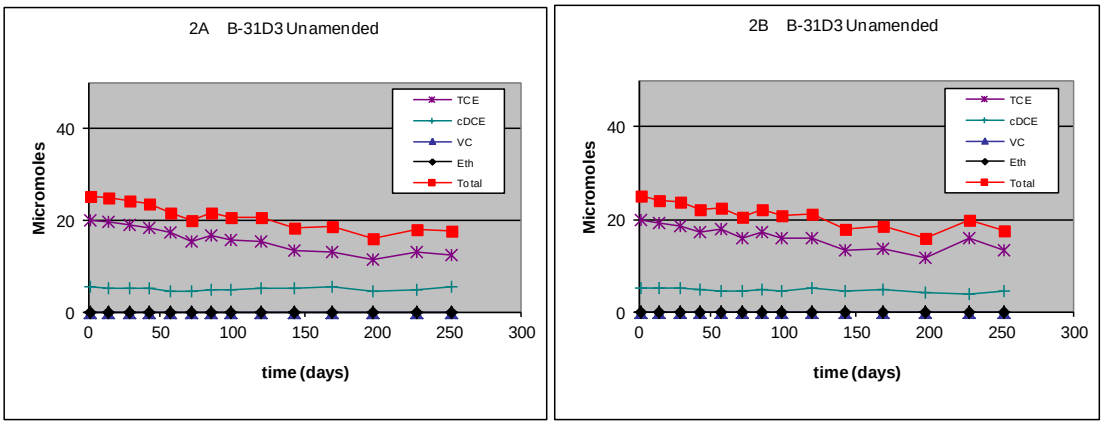

Figure A5 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-31D3 unamended bottles (treatment 2).

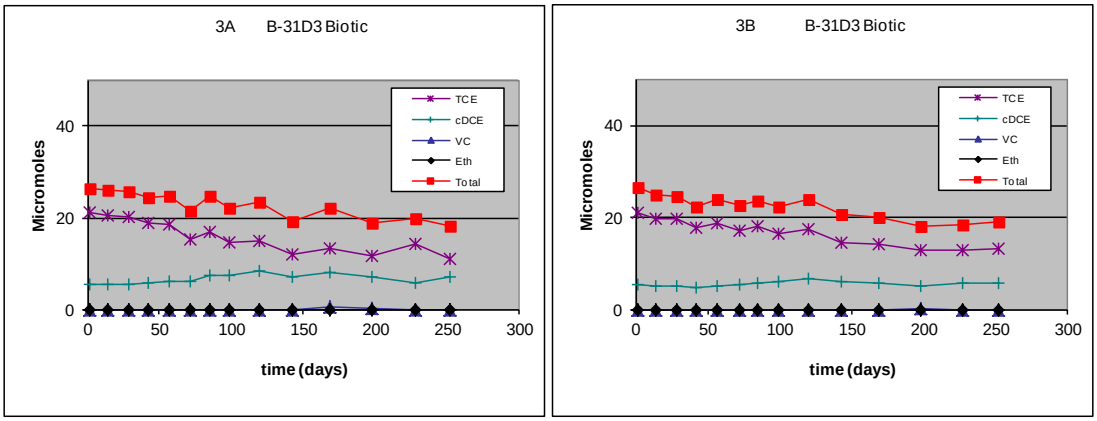

Figure A6 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-31D3 lactate amended bottles (treatment 3).

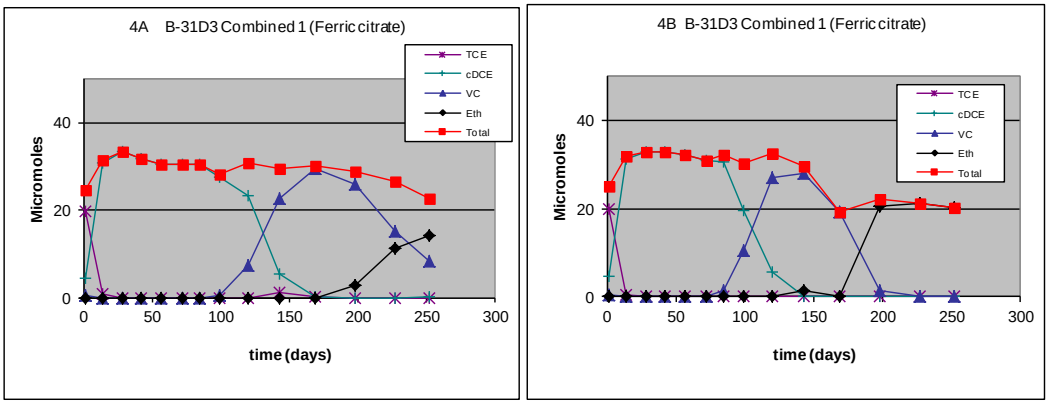

Figure A7 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-31D3 combined 1 bottles (treatment 4).

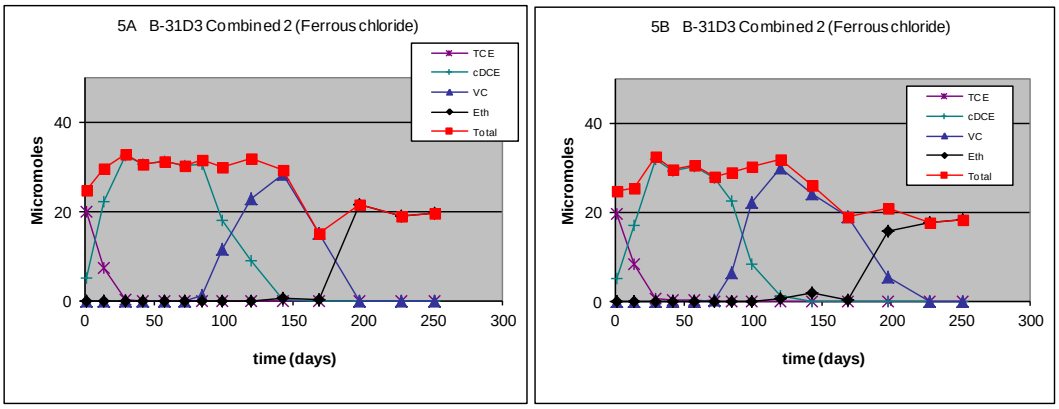

Figure A8 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-31D3 combined 2 bottles (treatment 5).

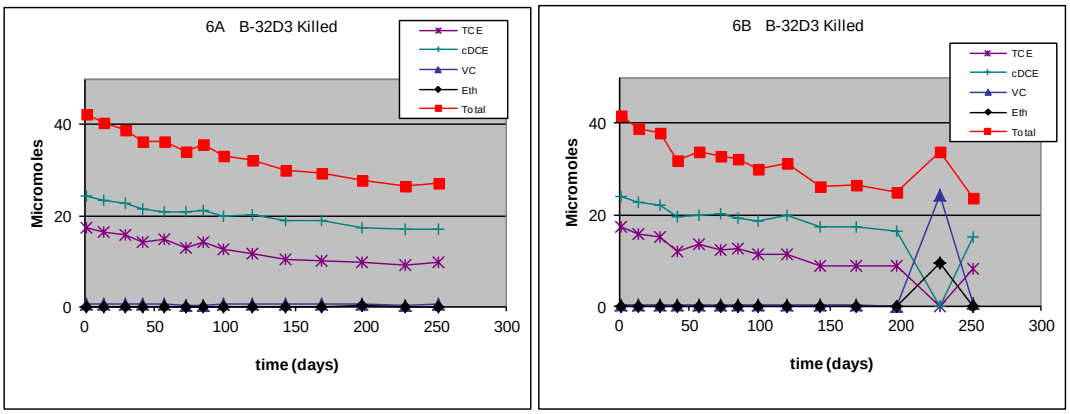

Figure A9 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-32D3 autoclaved controls (treatment 6). Note possible sampling error on day 230.

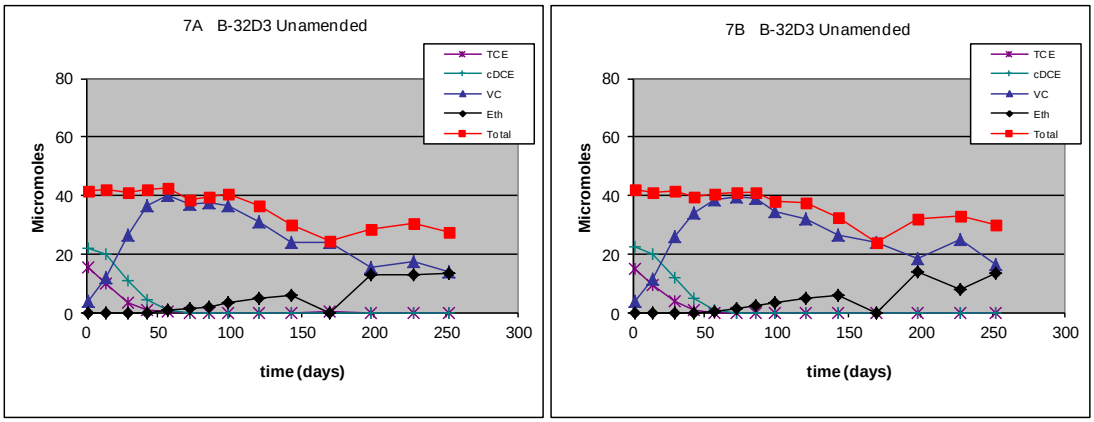

Figure A10 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-32D3 unamended bottles (treatment 7).

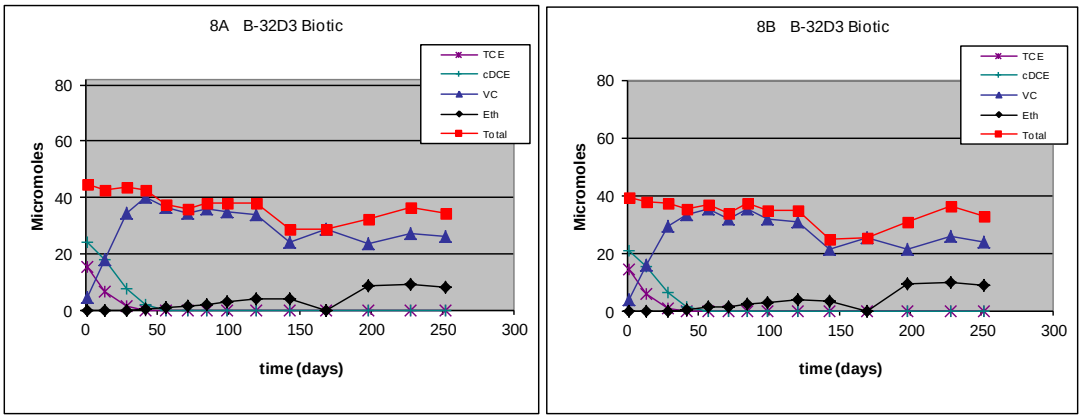

Figure A11 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-32D3 lactate amended bottles (treatment 8).

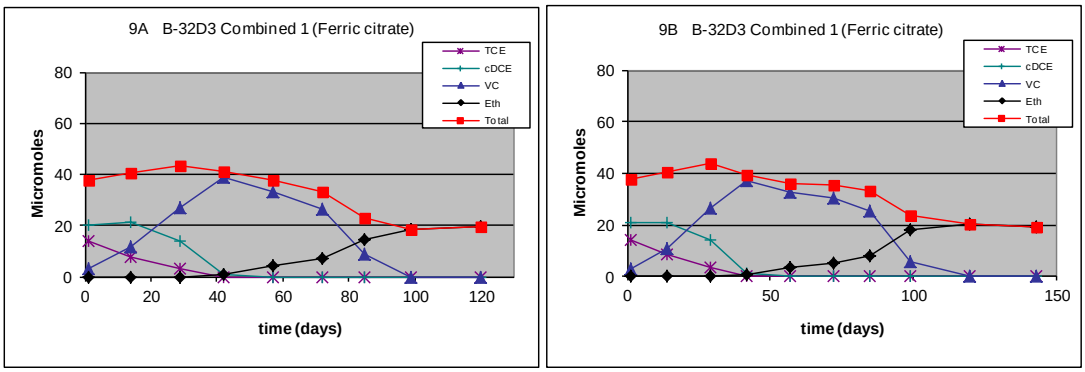

Figure A12 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-32D3 combined 1 bottles (treatment 9). Note different x-axis scale.

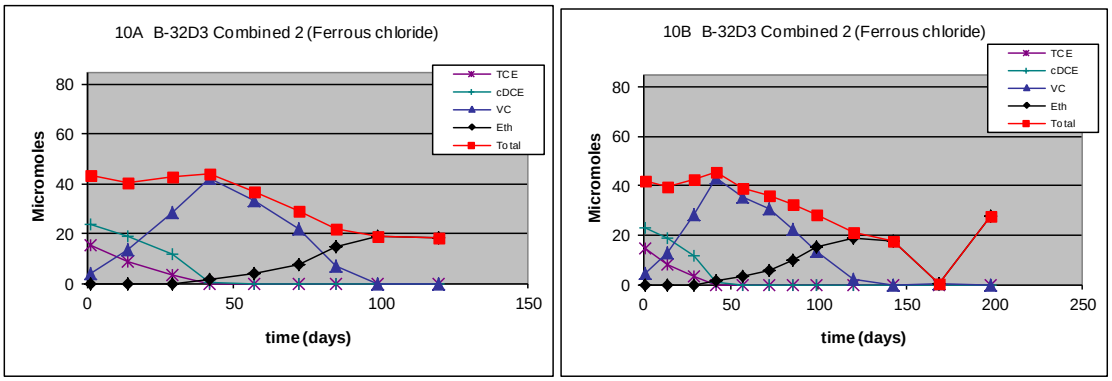

Figure A13 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-32D3 combined 2 bottles (treatment 10). Note different x-axis scale.

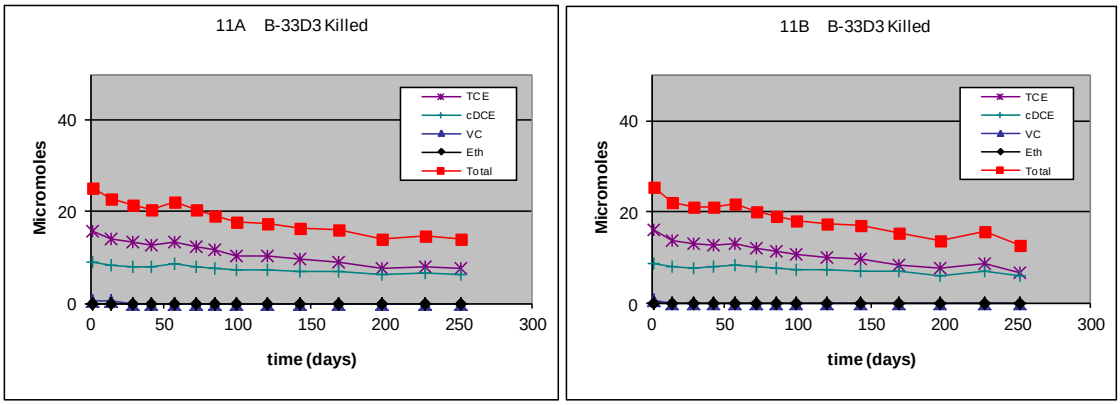

Figure A14 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-33D3 autoclaved controls (treatment 11).

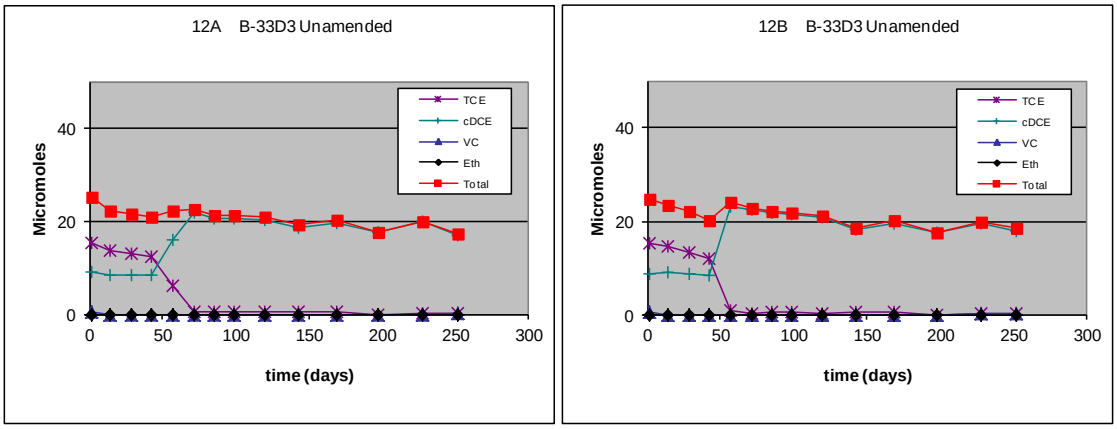

Figure A15 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-33D3 unamended bottles (treatment 12).

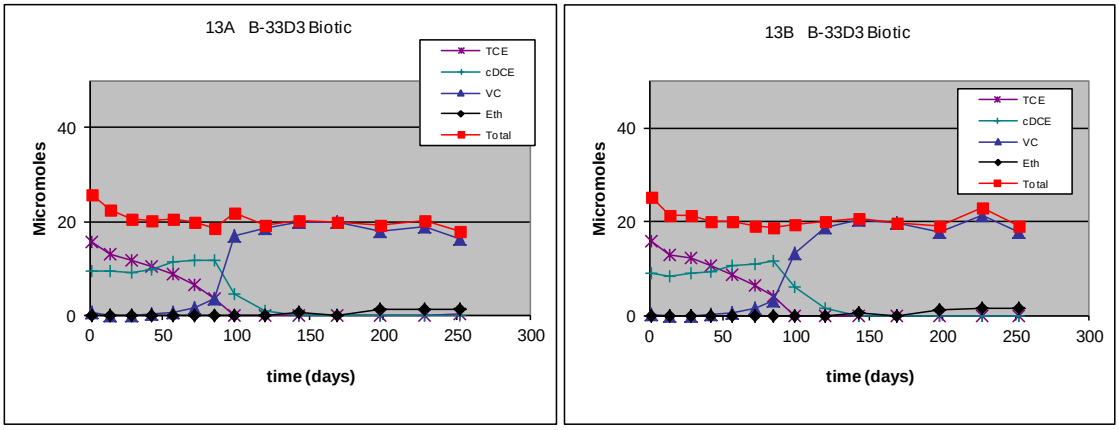

Figure A16 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-33D3 lactate amended bottles (treatment 13).

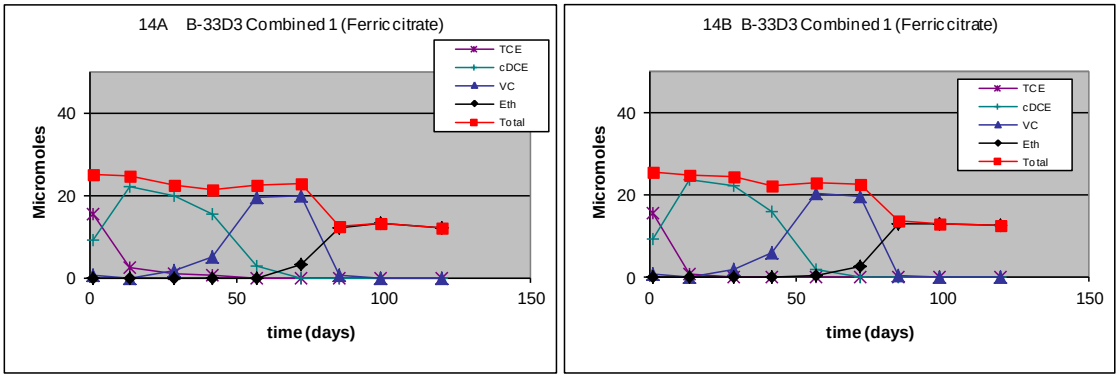

Figure A17 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-33D3 combined 1 bottles (treatment 14). Note different x-axis scale.

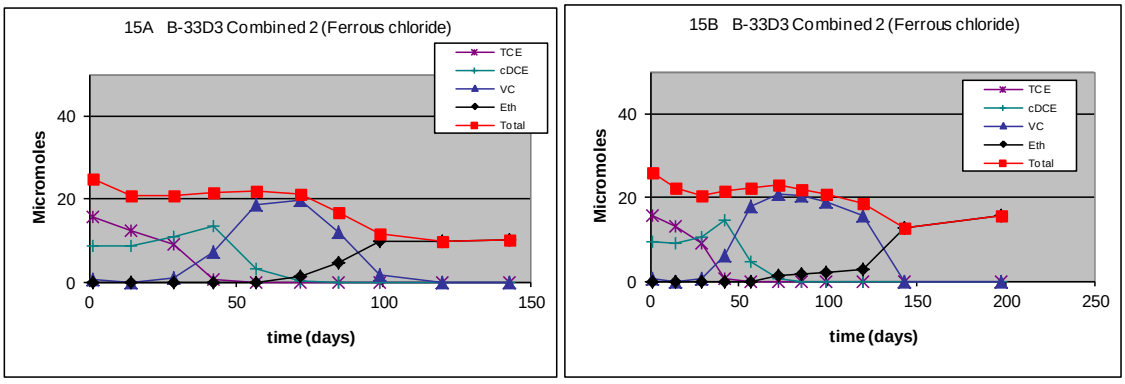

Figure A18 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-33D3 combined 2 bottles (treatment 15). Note different x-axis scale.

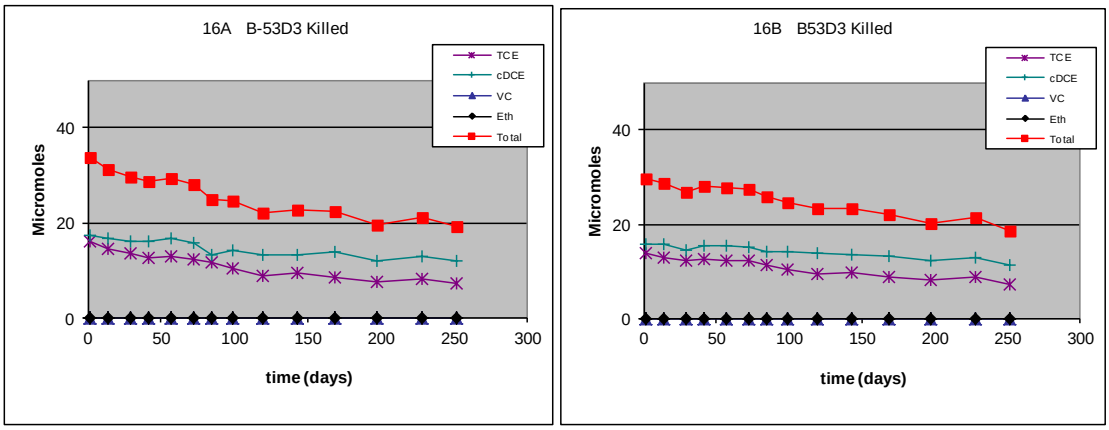

Figure A19 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-53D3 autoclaved controls (treatment 16).

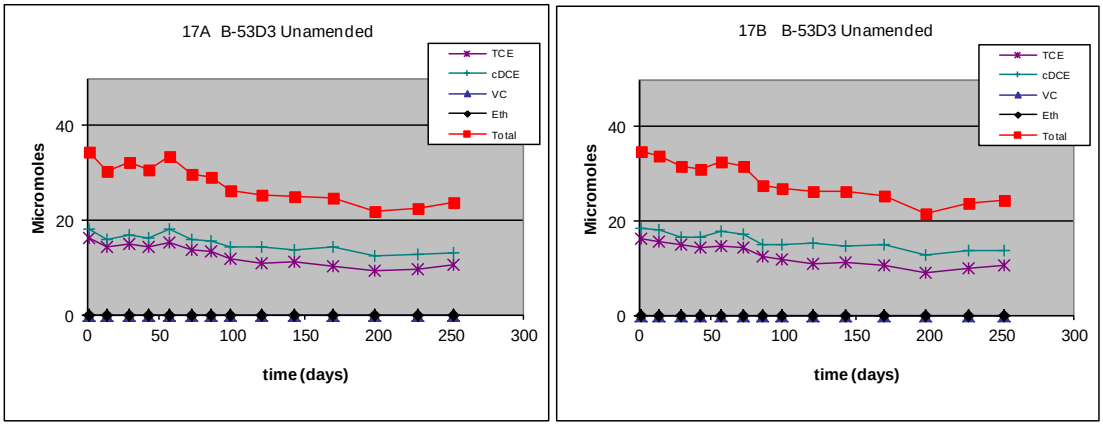

Figure A20 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-53D3 unamended bottles (treatment 17).

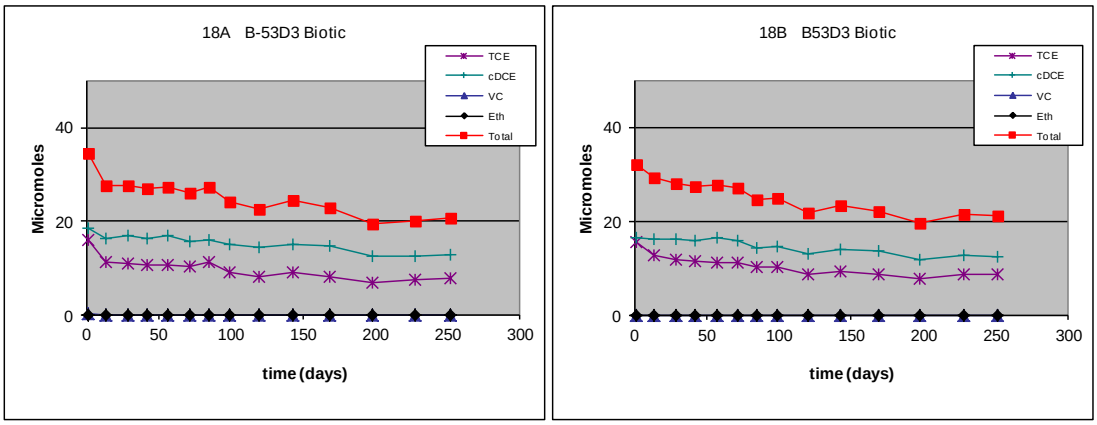

Figure A21 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-53D3 lactate amended bottles (treatment 18).

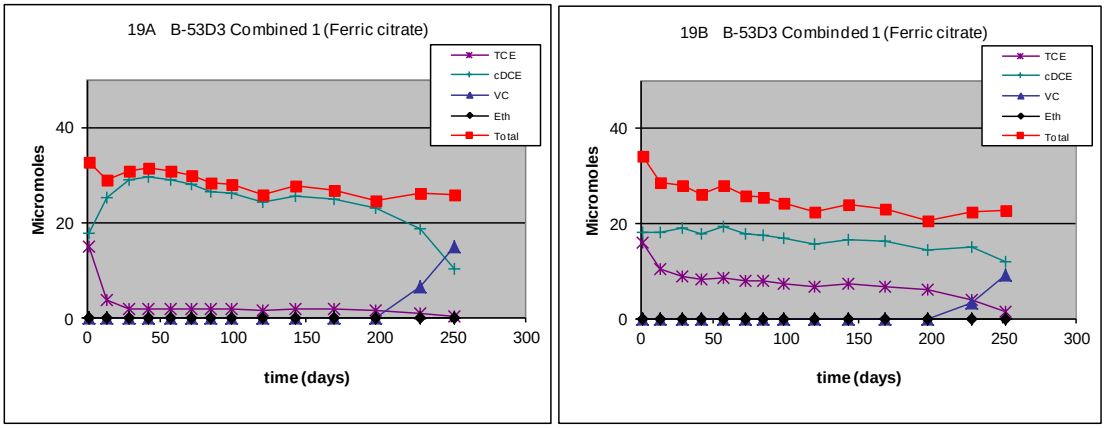

Figure A22 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-53D3 combined 1 bottles (treatment 19).

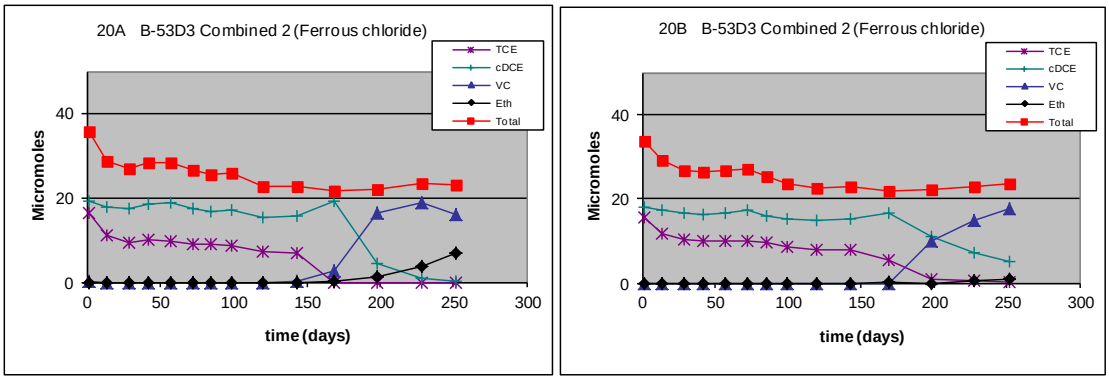

Figure A23 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-53D3 combined 2 bottles (treatment 20).

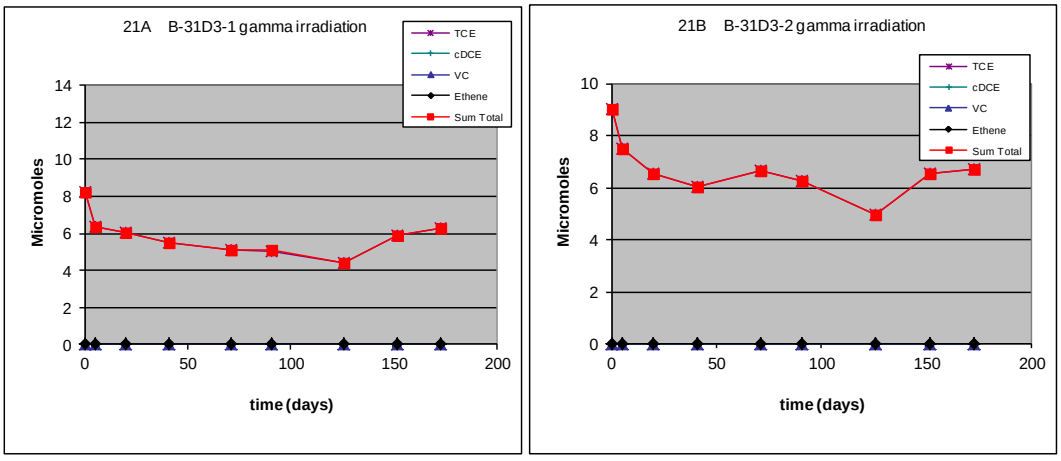

Figure A24 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-31D3 gamma-irradiated controls (treatment 21A&B).

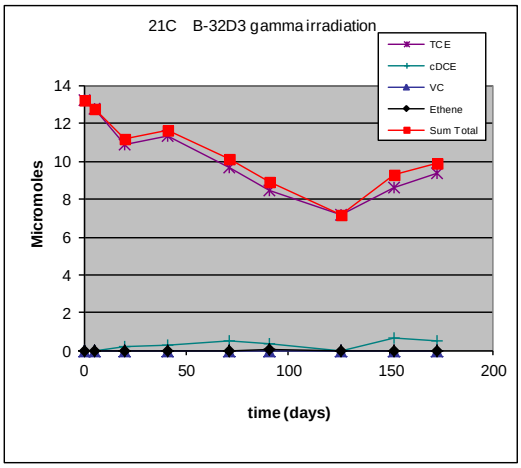

Figure A25 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-32D3 gamma-irradiated controls (treatment 21C).

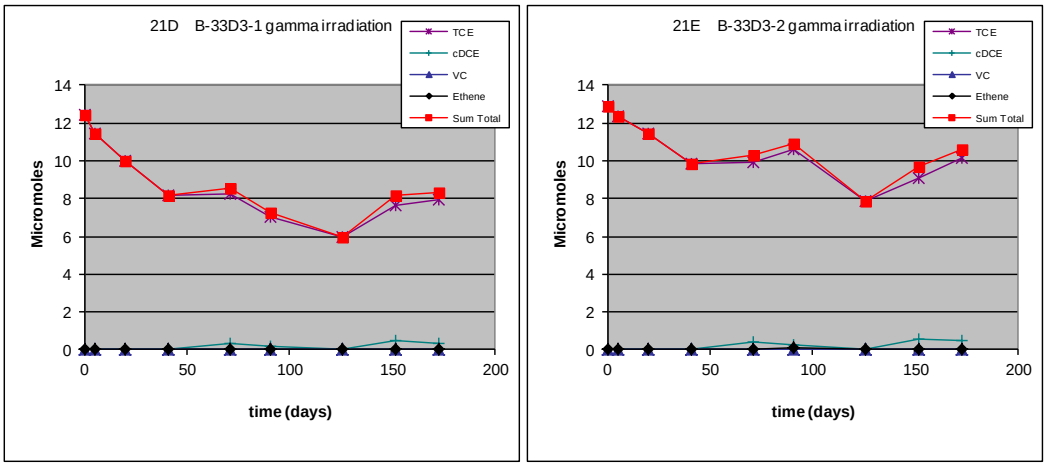

Figure A26 – Micromoles of TCE, cDCE, VC, ethene, and total constituents over time in B-33D3 gamma-irradiated controls (treatment 21D&E).

Appendix 4 – Sulfate, Sulfide, Iron, and pH Data

Table A4 - Sulfate Data from Main Experiment (mg/L)

		1	14	29	42	57	72	85	99	120	141	169	194
31D3	1 Killed	667.5	650	660	660	660	645	650	660	670	679	690	690
31D3	2 Unamended	664	670	665	675	680	660	675	670	680	673	650	630
31D3	3 Lactate	674	670	570	635	480	390	340	240	190	20	380	72
31D3	4 Ferric	652	590	540	420	160	41	16			10		
31D3	5 Ferrous	669	640	580	520	230	41	16			10		
32D3	6 Killed	735	720	730	740	740	710	750	745	740	747	755	770
32D3	7 Unamended	750	735	745	730	720	690	700	705	700	700	700	700
32D3	8 Lactate	748.5	730	730	660	265	93.5	35		415	35	335	530
32D3	9 Ferric	726	670	640	330	20	15	16			10		
32D3	10 Ferrous	738.5	525	600	330	150	15	16			10		
33D3	11 Killed	677	630	650	640	645	630	640	645	640	661	675	680
33D3	12 Unamended	784	830	890	725	715	710	715	745	905	805.5	920	910
33D3	13 Lactate	757.5	950	780	690	210	42.5	72		440	20	680	470
33D3	14 Ferric	668.5	600	520	360	275	15	16			10		
33D3	15 Ferrous	682.5	800	640	385	135	15	16			10		
53D3	16 Killed	749	730	740	725	740	730	740	735	780	732	775	790
53D3	17 Unamended	788.5	890	865	865	720	840	805	855	860	825	900	870
53D3	18 Lactate	789	990	710	957	590	540	490	435	920	385	560	400
53D3	19 Ferric	750.5	790	780	775	630	360	230	80	170	10		
53D3	20 Ferrous	759	840	735	680	575	420	270	80	50	10		

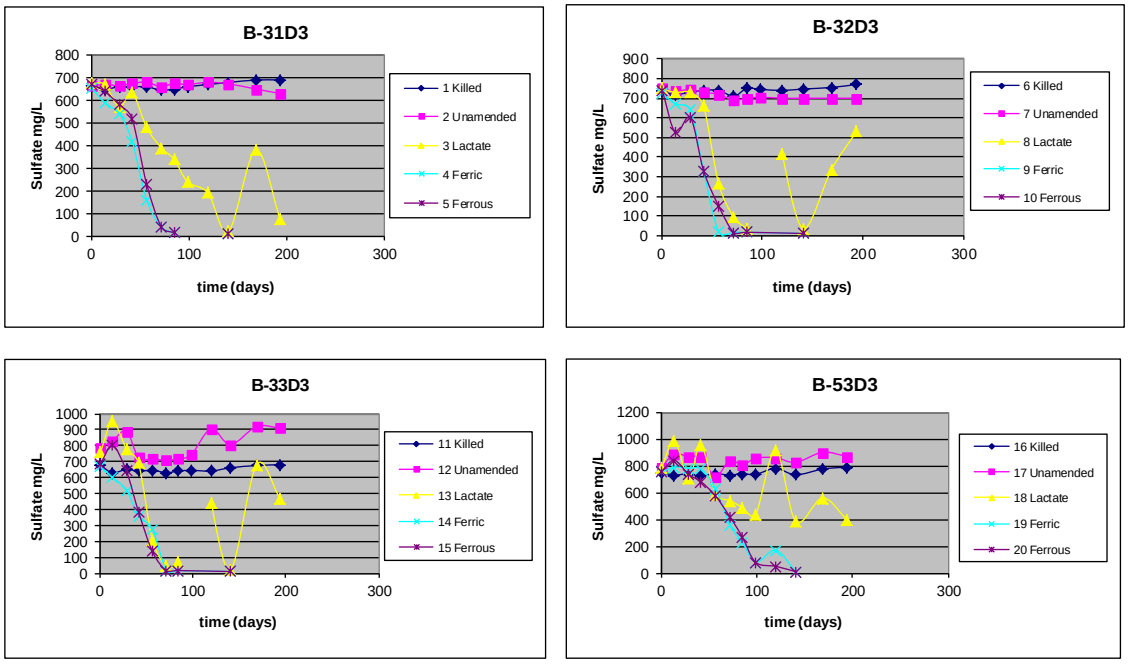

Figure A27 – Concentration of sulfate over time in all bottles from the main experiment.

Table A5 - Sulfide Data from Main Experiment (mg/L)

Location	Treatment	1	29	57	85	120	154	210	234
B-31D3	Killed	0	0	0	0	0	0	0	0
B-31D3	Unamended	0	0	3	2	3	4	6	4
B-31D3	Lactate	0	0	30	30	120	180	150	150
B-31D3	Combined 1 (Ferric)	0	0	15	0	0	0	0	0
B-31D3	Combined 2 (Ferrous)	0	0	3	0	0	0	0	0
B-32D3	Killed	0	0	0	0	0	0	0	0
B-32D3	Unamended	0	0	2.5	3	3	3	3	2
B-32D3	Lactate	0	0	100	100	200	150	200	200
B-32D3	Combined 1 (Ferric)	0	0	60	1	0	1	2	2
B-32D3	Combined 2 (Ferrous)	0	0	3	0	0	0	0	0
B-33D3	Killed	0	0	10	8	15	8	6	0
B-33D3	Unamended	0	0	40	60	45	60	60	50
B-33D3	Lactate	0	0	200	240	250	300	200	200
B-33D3	Combined 1 (Ferric)	0	3_4	100	4	2	3	2	2
B-33D3	Combined 2 (Ferrous)	0	10_20	20	0	0	0	0	0
B-53D3	Killed	0	0	4	1	1	0	0	0
B-53D3	Unamended	0	0	40	40	50	125	75	50
B-53D3	Lactate	0	80-100	140	280	300	300	200	300
B-53D3	Combined 1 (Ferric)	0	35-40	112	40	60	40	2	2
B-53D3	Combined 2 (Ferrous)	0	40	28	12	10	0	0	0

Table A6 – Ferrous Iron Data from Main Experiment (mg/L)

	4A B-31D3	4B B-31D3	5A B-31D3	5B B-31D3	9A B-32D3	9B B-32D3	10A B-32D3	10B B-32D3
1	12.44	8.40	5.99	5.80	8.43	7.60	5.05	5.23
14	65.02	62.46	5.76	4.66	66.11	59.17	12.29	9.91
29	30.10	18.03	16.76	13.74	39.42	30.78	14.63	9.32
42	6.78	0.65	48.66	38.60	0.49	0.19	1.53	1.03
57	0.31	0.32	0.78	0.70	0.26	0.28	0.69	0.55
72	24.77	26.41	0.55	0.52	5.57	10.53	0.72	1.20
85	13.13	17.86	24.84	23.96	6.23	8.78	42.92	32.94
99	17.29	25.19	59.11	60.76	7.40	12.10	76.09	62.11
127	22.80	27.25	54.83	53.87	5.92	12.28	59.17	51.68
154	15.47	14.38	72.90	69.06	2.79	5.57	69.71	46.14
195	8.25	11.73	112.08	113.99	3.67	5.07	141.13	106.23
235	5.08	7.54	118.59	60.79	2.55	5.13	120.66	120.66
	14A B-33D3	14B B-33D3	15A B-33D3	15B B-33D3	19A B-53D3	19B B-53D3	20A B-53D3	20B B-53D3
1	63.51	55.98	1.87	1.56	98.21	95.64	27.82	25.34
14	8.72	9.24	0.34	0.30	0.28	0.44	0.14	0.08
29	0.44	0.38	0.31	0.31	0.15	0.17	0.15	0.17
42	0.64	1.56	0.94	1.87	0.12	0.52	0.25	0.72
57	0.60	0.59	0.53	0.55	0.23	0.23	0.21	0.26
72	1.01	1.49	0.45	0.37	0.30	0.49	0.36	0.14
85	0.95	1.58	3.95	1.93	0.15	0.11	0.47	0.59
99	1.51	1.64	95.98	78.96	0.60	0.78	0.11	0.25
127	2.54	3.66	96.11	80.27	0.54	0.50	0.73	0.57
154	1.76	3.08	100.54	97.99	5.16	4.78	21.49	11.60
195	2.42	2.57	193.09	168.82	7.27	6.01	94.10	79.30
235	2.39	3.31	205.58	183.59	8.85	9.88	99.81	89.58

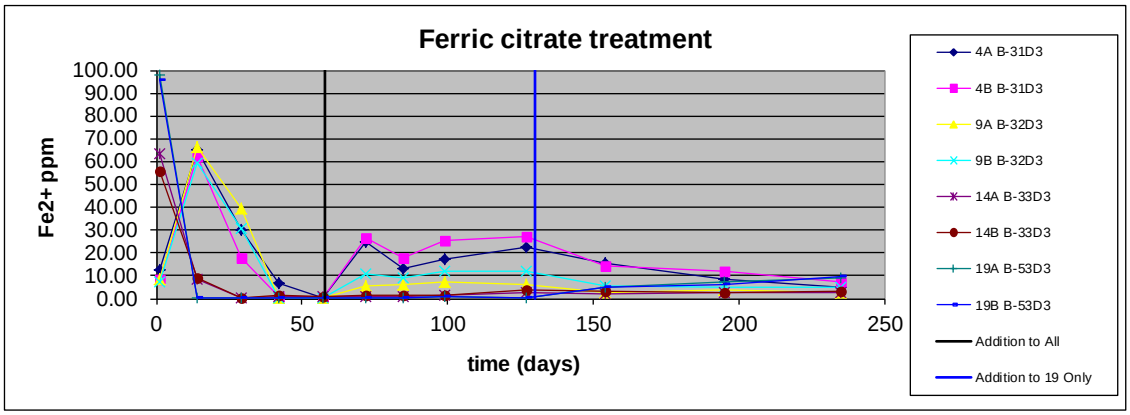

Figure A27 – Concentration of ferrous iron over time in lactate + ferric citrate amended bottles from the main experiment. Ferric citrate was added to all bottles at the beginning of the study and on day 60 and to the treatment 19 bottles on day 130.

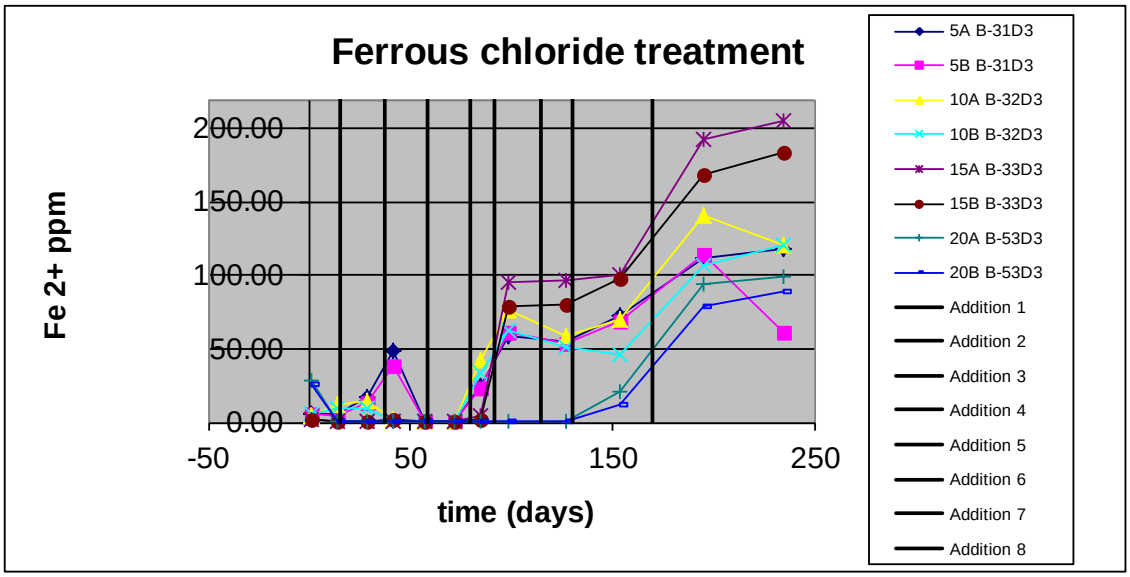

Figure A28 – Concentration of ferrous iron over time in lactate + ferrous chloride amended bottles from the main experiment. Ferrous chloride was added to all bottles at the beginning of the study and on the eight intervals shown.

Table A7 – pH Data from Main Experiment

Date	Time (days)	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
7/13/2010	1	7.7		7.7		7.7		7.1		7.1	
7/26/2010	14		6.8		7.4		7.4/7.7		6.5/6.8		7.4
8/10/2010	29	7.4/7.7		7.9		7.7		7.1		7.1	
8/23/2010	42		7.4/7.7		7.9/8.1		7.9/8.1		7.9/8.1		7.1
9/7/2010	57	7.7		7.7/7.9		7.9/8.1		7.7/7.9		7.4/7.7	
9/21/2010	72		7.4/7.7		7.7/7.9		7.9/8.1		7.7/7.9		7.4/7.7
10/4/2010	85	7.4/7.7		7.7/7.9		8.1/8.3		7.7/7.9		7.7	
10/18/2010	99		7.4/7.7		7.4/7.7		8.1		8.1		7.4
11/8/2010	120	7.9/8.1		7.7/7.9		8.3/8.5		7.1/7.4		7.1/7.4	
12/1/2010	143		7.4		7.1		8.3		7.4		7.1
12/27/2010	169	7.7		7.9/8.1		8.5		7.7		7.1	
2/1/2011	205		7.4		7.4/7.7		8.3/8.5		7.4		7.1
2/28/2011	231	8.1		8.1		8.3		8.1		7.1	
stop testing	252		7.4		7.4		7.7		7.9		7.1

Date	Time (days)	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B
7/13/2010	1	7.7		7.7		7.1		7.1		6.8/7.1	
7/26/2010	14		7.4/7.7		7.7		7.7		6.8		6.8
8/10/2010	29	7.1/7.4		7.4		7.4/7.7		7.4		7.4/7.7	
8/23/2010	42		7.7/7.9		8.1/8.3		8.1/8.3		7.4/7.7		7.4
9/7/2010	57	8.1		8.1/8.3		8.5		7.9/8.1		8.1/8.3	
9/21/2010	72		7.9/8.1		8.1/8.3		8.3/8.5		7.7/7.9		7.9/8.1
10/4/2010	85	7.9/8.1		8.1		8.3/8.5		8.1/8.3		7.4	
10/18/2010	99		7.9/8.1		7.9/8.1		8.5		7.9/8.1		7.4
11/8/2010	120	8.1		8.1		8.5		8.1		7.4	
12/1/2010	143		7.4		7.4		8.3				7.4
12/27/2010	169	7.4		7.4		8.5					
2/1/2011	205		7.4		7.4		8.5				6.8
2/28/2011	231	8.1	7.4	8.1		8.7					7.4
stop testing	252		7.4		7.4		8.5	7.7		7.1	

Date	Time (days)	11A	11B	12A	12B	13A	13B	14A	14B	15A	15B
7/13/2010	1	7.7		7.7		7.7		7.1		7.1	
7/26/2010	14		7.4/7.7		7.4/7.7		7.7		7.4		7.1/7.4
8/10/2010	29	7.4/7.7		7.4/7.7		7.9/8.1		7.4/7.7		7.7/7.9	
8/23/2010	42		7.9/8.1		8.1/8.3		8.1		8.1/8.3		7.7/7.9
9/7/2010	57	7.7/7.9		8.1/8.3		8.1/8.3		8.1/8.3		7.7/7.9	
9/21/2010	72		7.9/8.1		7.7/7.9		8.3/8.5		7.9/8.1		7.7/7.9
10/4/2010	85	7.9/8.1		8.1		8.5/8.7		8.1		7.4/7.7	
10/18/2010	99		7.4		7.9/8.1		8.5		8.1		7.4
11/8/2010	120	7.4/7.7		8.1		8.5		8.1		8.1	
12/1/2010	143		7.4/7.7		8.1		8.3				7.1
12/27/2010	169	7.7		7.7/7.9		8.3					
2/1/2011	205		7.4/7.7		8.1/8.3		8.3/8.5				
2/28/2011	231	8.1		8.3		8.7					
stop testing	252		7.9		7.7		8.5	7.9		7.1	

Date	Time (days)	16A	16B	17A	17B	18A	18B	19A	19B	20A	20B
7/13/2010	1	7.7		7.7		7.1		7.1		6.8/7.1	
7/26/2010	14		7.4/7.7		7.7		7.4/7.7		7.4		7.1/7.4
8/10/2010	29	7.7		7.9/8.1		7.9/8.1		7.7/7.9		7.4/7.7	
8/23/2010	42		7.4/7.7		8.3		8.1/8.3		7.4		7.4
9/7/2010	57	7.7		8.1/8.3		8.1/8.3		7.4/7.7		7.7	
9/21/2010	72		7.9/8.1		8.1/8.3		8.1/8.3		7.7		7.4/7.7
10/4/2010	85	7.4/7.7		8.5		8.5		7.9/8.1		7.9/8.1	
10/18/2010	99		7.4/7.7		8.1		8.5		8.1		8.1
11/8/2010	120	7.7/7.9		7.4/7.7		7.4/7.7		8.1		8.1	
12/1/2010	143		7.4		8.1		8.5		7.4		8.1
12/27/2010	169	7.4		7.7/7.9		8.5		7.4		7.4	
2/1/2011	205		8.1		8.5		7.4		7.4		7.4
2/28/2011	231										
stop testing	252		7.4		7.9		8.5		7.4		7.1

Table A7 (continued) – pH Data for Gamma Controls

Date	Time (days)	21A	21B	21C	21D	21E
10/7/2010	1					
10/11/2010	5					
10/26/2010	20	7.4/7.7	7.4/7.7	7.4/7.7	7.9	7.9
11/8/2010	41	7.4/7.7	7.4/7.7	7.4/7.7	7.4/7.7	7.4/7.7
12/8/2010	71		7.4		7.4/7.7	
12/28/2010	91	7.4		7.4		
2/1/2011	126			7.4/7.7	7.4/7.7	7.4/7.7
2/28/2011	152					
3/21/2011	173		7.1		7.7	