RELEASE OF MERCURY DURING LEACHING OF FLY ASH

An Honors Thesis

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By

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ABSTRACT

Fly ash created in the generation of energy contains mercury. Currently, the most accepted use for fly ash is as an inexpensive alternative to Portland cement in concrete mixtures. Because of new mercury-air standards, determining the affect of mercury within concrete structures is important. Analyzing the make-up of the fly ash, then, is used in this research concept to gain an understanding of the impact of the chemical make-up of fly ash on a concrete structure. Pinpointing the fly ash - concrete interaction and synthesizing the characteristics demonstrated in a concrete containing fly ash ultimately leads to a perception of the release of mercury from these materials in their final state. Leachate tests were preformed to simulate the release of mercury from fly ash samples in Municipal Solid Waste Landfills and Construction Landfills. The results of these analyses led to the determination of the limited short and long-term release of mercury from the samples and these conclusions lead to a basic understanding of the impact fly ash sample release of mercury can have on concrete structures.

Dedicated to my family

ACKNOWLEDGMENTS

I wish to thank my adviser, Dr. Hal Walker, for guidance, support, encouragement and patience for allowing me to gain time management experience and emphasizing the importance of learning in a hands-on environment.

I thank Dan Golightly for introducing me to work in the laboratory and initially developing my comfort level in this working area.

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CHAPTER 1

INTRODUCTION

Coal fly ash is produced as a byproduct of energy generation. As coal-fired boilers generate electricity, fly ash and flue gas desulfurization byproducts are created. In the process of energy generation, mercury is volatized and converted to elemental mercury at the very high temperatures located within coal-fired utility boilers (EPA, 2000). A portion of this mercury is re-oxidized as the flue gas is cooled. As conversion from gaseous elemental mercury to $HgCl_2$ and HgO occurs, the mercury is effectively captured in fly ash material (EPA, 2000). $HgCl_2$ is effectively captured during this process with SO_2 control, but because some mercury forms that are created are more difficult to remove, it is important to understand the effect of their volatility and limited solubility. Once formed, fly ash can be utilized as an inexpensive alternative to Portland cement in concrete, as it has been found to enhance certain desirable properties in freshly prepared and hardened concrete.

Electrical power generator production of fly ash is approximately 15% of the fly ash that is incorporated into structural concretes and grout (American Coal Ash Association, 2002). Once included in the concrete mix, fly ash reduces the water requirements of the concrete mixture. A concrete made with fly ash also has increased workability, reduced heat of hydration and a reduced air content. After the concrete has cured, it has an increased compressive strength as a product of the reduced water content. Typically, the fly ash concrete will have lower absorption and permeability and generally improved defense against sulfate attack. Concrete is a porous material and mercury bound to fly ash ultimately may be released following concrete placement. In addition to the prolonged threat of mercury release is an initial potential for release through the mixing, pouring, curing and temperature increase of concrete. In any of these processes, the temperature of fly ash could increase the volatization and release of mercury from the concrete material.

Recently, the presence of mercury in fly ash material has been a topic of great importance based on the announcement of the Clean Air Mercury Rule. The rule, which is expected to come into effect in 2007, will significantly impact the reuse initiatives of coal combustion byproducts. Because fly ash contains mercury, especially when activated carbon injection is used as a means to achieve greater mercury reductions in generation, it is important to understand the impact of mercury levels in fly ash concrete applications. As mercury emissions controls are brought on-line, an increase in the amount of mercury contained in fly ash is expected, and because concrete is a porous material, the mercury bound to fly ash may ultimately be released to the atmosphere.

Because mercury is a well known neurotoxin, it is important to determine the fate of mercury in concrete. Therefore, the objectives of this research analysis are to identify the analyte makeup of typical fly ash samples and to determine the extent to which leaching releases mercury from fly ash to the atmosphere. In previous work, the gaseous release of mercury during curing of concretes was determined. In this study, investigation continues to examine the leaching of mercury to water during disposal and reuse of fly ash. The project centered around identifying the sample characteristics of fly ash specimens and analysis of their effects on mercury release. Leaching data was modeled using geochemical speciation methods to develop a better understanding of the roles of different solid phases in controlling the solution of chemistry of the leachate. The observations can then be correlated to the effects of fly ash utilized in concrete applications. Using two specific leach testing methods, fly ash samples were tested for reactions in landfills and reactions under acid rain conditions.

First, five different samples of fly ash were selected. Each sample of fly ash was created in a generation facility from a different location which could have had an affect on the level of mercury in the sample. The different fly ashes were then used in typical leachate testing procedures to synthesize the natural affects of rain water and landfill acid on the sample. The fly ash - leachate solutions were then analyzed using a Varian SpectrAA to determine the mercury in each sample. The solutions were also subjected to an Inductively Coupled Plasma Atomic Emissions Spectrometry test to determine the additional analyte make-up of the samples. In the end, the data collected from these tests were manipulated to determine if the effects of the mercury and additional analyte material in the fly ash could pose a threat to health if released through naturally occurring leaching.

This report is organized as a thorough investigation of fly ash, the elemental composition of the samples, the mercury content in the concrete ingredients and the result of that elemental makeup. The leaching test procedures are then discussed as an example of two ways that fly ash elemental makeup can leach into the water supply. The discussion will also serve as an attempt to prove the adequacy of this analysis for assessment of environmental impact. Finally the test methods and test results for the experiments are discussed and conclusions are drawn from the data collected.

CHAPTER 2

TEST METHODS

2.1 Concrete and Fly Ash

As one of several coal combustion by-products, fly ash is the finely divided mineral residue resulting from the combustion of coal in electric generation plants. Because fly ash is an inorganic incombustible matter present in the coal, it becomes fused during combustion into an amorphous structure. Once burned, fly ash becomes suspended in exhaust gas as a solidified material and typically is collected by electrostatic precipitators. Generally, fly ash particles are cylindrical and range in size from .4 micrometers to 100 micrometers. Fly ash particles are comprised mostly of aluminum oxide, silicon dioxide, and iron oxide. Because they are pozzolanic, they react to form cementious material. In 1996, America's coal-fired power plants produced 53 million tons of fly ash. Although the chemical and physical properties of coal ash make it ideal for a variety of engineering applications, it must compete against other inexpensive bulk materials like sand and gravel. As a result, there are only certain areas where it is economically advantageous to transport and handle the fly ash. About three-quarters of the fly ash produced in the United States is not recycled for commercial use. Instead, the fly ash is placed in a specifically designed landfill. To prevent environmental impacts, landfill sites are carefully chosen to avoid flood plains and wells are typically installed around the site so that the quality of the surrounding water can be routinely inventoried.

Fly ash that is recycled is utilized in several different ways. Power plant fly ash is used in autoclaved aerated concrete blocks, liquid fixation, blasting grit, highway ice control, masonry blocks, concrete admixture, as material in lightweight alloys, roadway and runway construction, flowable fill material, roofing granules, grouting and structural fill. Fly ash is used as a high-performance substitute for Portland cement and sometimes as an addition to the clinker which is ground to form Portland cement. The material can replace up to 50% of Portland cement by mass in concrete and changes the chemical make-up of the concrete mix in several different ways which can lead to higher final strength and reduced risk of chemical corruption. Replacing Portland cement with fly ash also decreases the greenhouse gas signature of concrete by reducing carbon dioxide production. Coal fly ash has been used around the world as an ingredient of concrete for 60 years and many United States suppliers routinely use fly ash in concrete mixtures. The ash is processed into pellets that make it more readily utilized as an aggregate in concrete as well.

Most health-related fly ash concerns focus on the potential health risk of inhalation, ingestion, direct contact or exposure to trace elements. Coal fly ash particles are essentially insoluble aluminosilicate glasses, however trace substances on the ash surface may still be soluble. Water, acid rain and other liquids can percolate through ash and dissolve, or leach, trace elements from the ash. The analyte make-up could then potentially reach a drinking water source such as groundwater, rivers or lakes. Suspended particles would be removed from the water through filtration at water treatment plant; however, the dissolved elements would not be removed through this process.

Recycling fly ash in products and construction carries many benefits – and the focus of this study has been to rule out potential hazards from this recycling process so that barriers to re-use of fly ash are minimized. Using coal ash as cement can mean that the process consumes less energy and limestone than production of conventional cement – and avoiding electricity production lessens overall emissions. In addition, carbon dioxide emissions from cement kiln firing are reduced in direct proportion to the amount of ash substituted in a concrete mix.

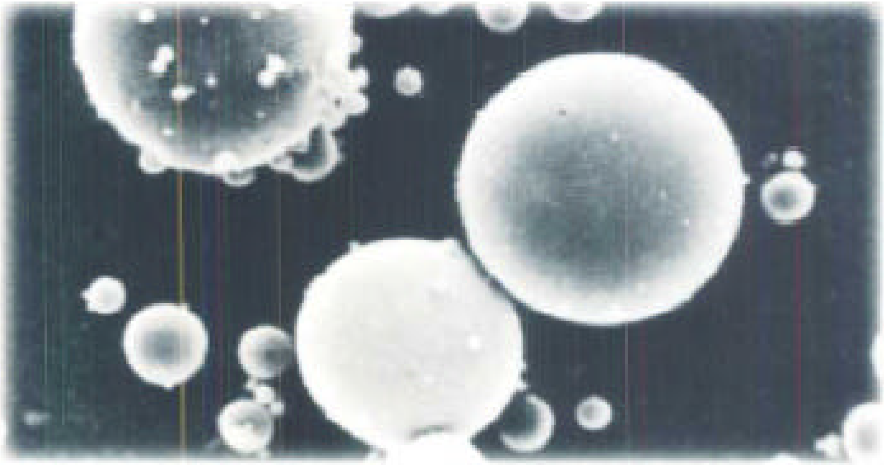

Figure 2.1: Fly ash beads at the microscopic level

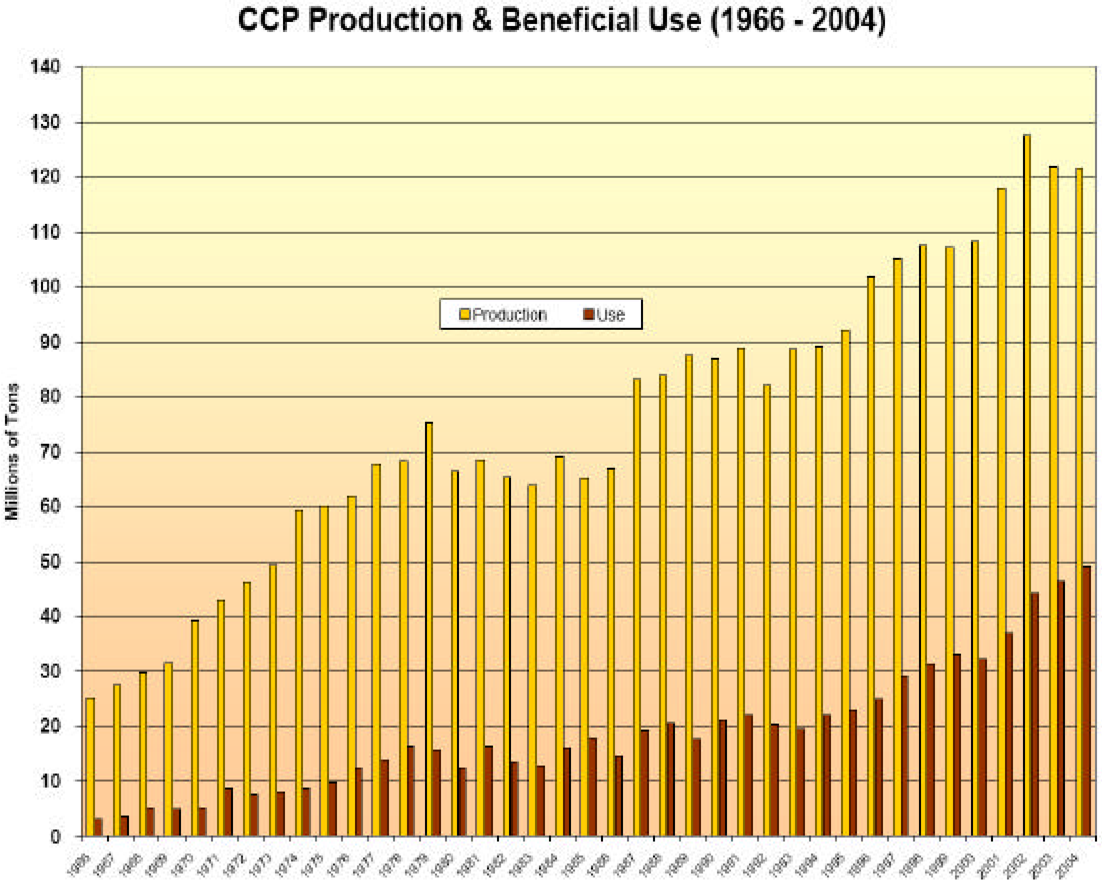

Figure 2.2: Usage of Coal Combustion Products

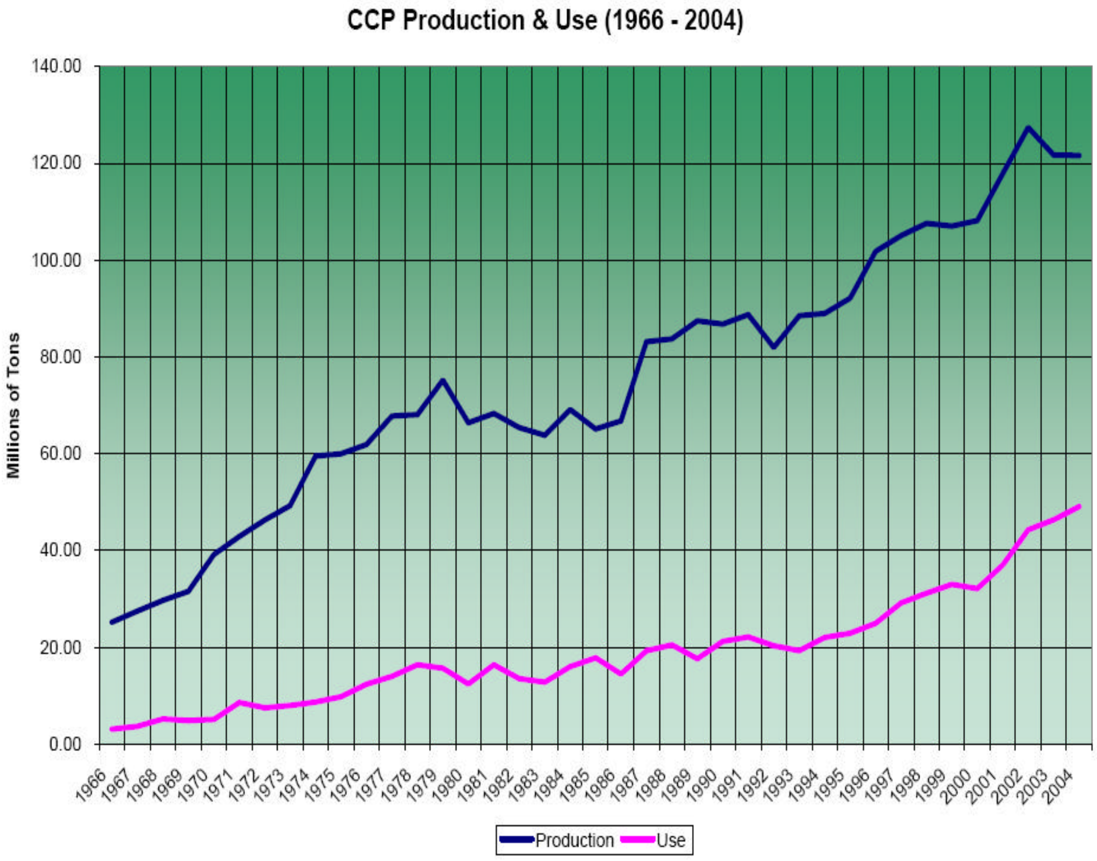

Figure 2.3: Production and Usage of Coal Combustion Products

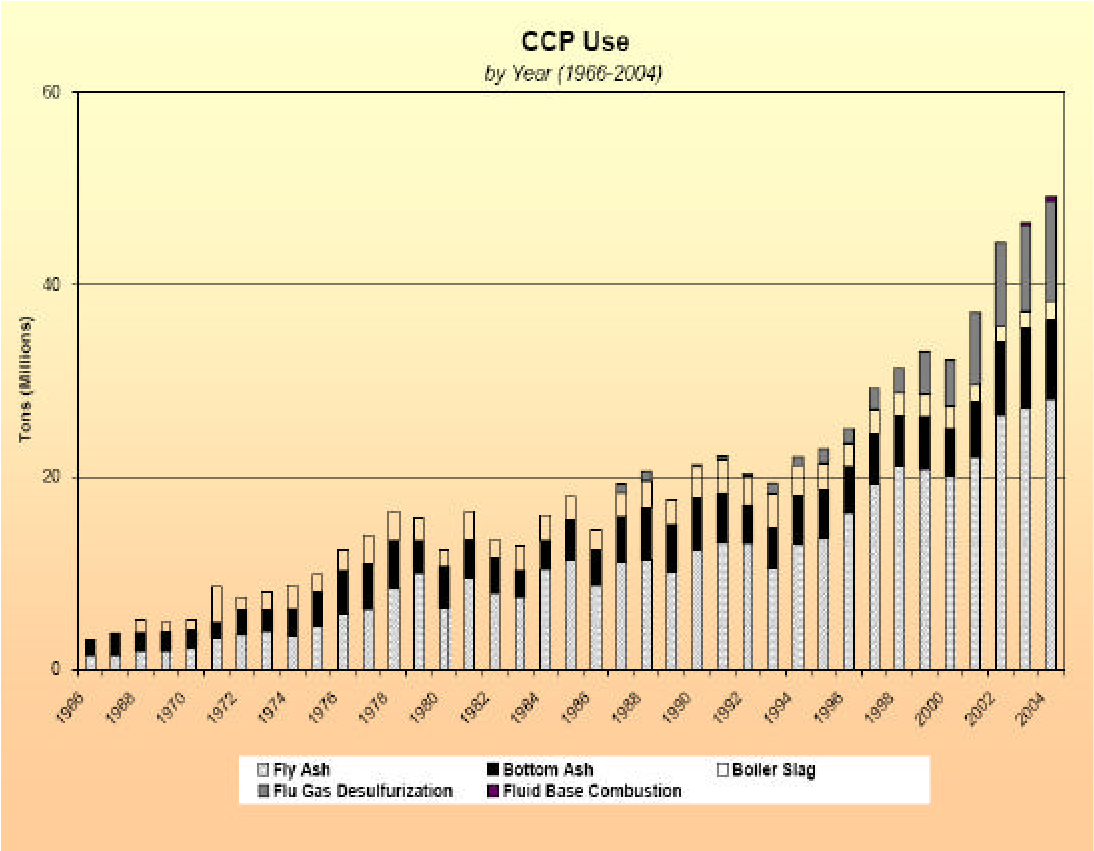

Figure 2.4: Potential Uses of Coal Ash By-products

2.2 Fly Ash Elemental Composition, Samples and Mercury Content in Concrete Elements

Five different coal fly ash samples were utilized in this research study. The fly ash was classified as Class F and it originated from eastern bituminous coal combusted electrical utilities. Class F fly ash is characterized for the content, specific surface area and loss of ignition values. As required by ASTM, Class F fly ash should have an LOI less than 6%. The concentrations of SiO_2, Fe_2O_3 and Al_20_3 must be greater than 70%. In a previous study, the elemental composition of the fly ash was verified using Cold Vapor

Atomic Adsorption Spectrometry and Cold Vapor Atomic Fluorescence Spectrometry in determining the mercury and inductively coupled plasma – atomic emission spectrometry to verify the concentrations of silicon, iron, aluminum and sulfur.

Elemental Composition	**Concentration (%)**
Aluminum	15.1
Barium	0.3
Calcium	2.4
Iron	2.3
Magnesium	0.7
Potassium	1.5
Silicon	26.9
Sodium	0.7
Sulfur	0.1
Zinc	0.1
Arsenic	16.6
Cadmium	2.5
Cobalt	34.8
Chromium	129
Copper	127
Lead	27.2
Lithium	197
Manganese	129
Mercury	0.117
Molybdenum	15.1
Nickel	84.7
Phosphorus	930
Selenium	18.8
Strontium	75

Table 2.1: Elemental Composition of Fly Ash Samples

As the demand for finer, more accurately sized fly ash grows, classification methods for fly ash ingredients have become more sophisticated. Generally speaking, most powders are the result of a comminution process that creates a combination of fly ash samples which dictate characteristic hardness or abrasive nature of the material.

There are a range of machines available for the comminution process and each has its own particular ability to break compounds through compression, impact or attrition. Therefore the classification of dry powders using conventional sieving techniques becomes progressively more important. For a given classified sample, the specific gravity of materials and the separation or cut size moves the sample up or down the classification scale. There are many reasons to classify the fly ash produced through electrical generation and the criterion can range from simply the size of the largest particle to the decorative finish or surface coating of the materials. Because the ASTM codes have a very heavy emphasis on the chemistry of fly ash and the chemistry of fly ash is highly dependent on the mineralogy and particle size, it is therefore important to understand this classification process and the impact of the particle size.

There are two parameters that determine the reactivity of fly ash – mineralogy and particle characteristics. Particles are mostly glassy, solid, and spherical in shape and there may also be unburned carbon present depending on burn efficiency. Particles of fly ash range in size from 1 to 10 microns and regardless of the type of classification, the ash will contribute to the 7 and 28 day strengths of concrete.

To determine elemental concentrations of the samples before leaching tests were preformed, a solution of fly ash was prepared in a microwave-heated digestion method of a closed vessel containing 300mg of fly ash and an acid mixture of nitric, hydrochloric and hydrofluoric acids. (EPA 2000) The Varian VISTA was calibrated using matrix matched sample solutions and the concentrations of each test produced background-corrected relative intensities for the 9 spectral lines that correlate with aluminum, iron and silicon for a simultaneous available emissions of 1.2kW plasma.

The classification of fly ash is important in the selection of ash that is used in concrete mixtures and each different classification can mean something different for the mercury content of the samples. Fly ash is most beneficially used as a plasticizer, and the charged cement particles tend to break bonds and flocculate. This action is different than the normal effect of cement in concrete which disperses through cement particles and tends to adsorb to surfaces and act as a repellent. Certain types of reactive fly ash particles act as a very powerful repellent which because of their charges and dependent on the presence of reactive crystalline phases in the ash.

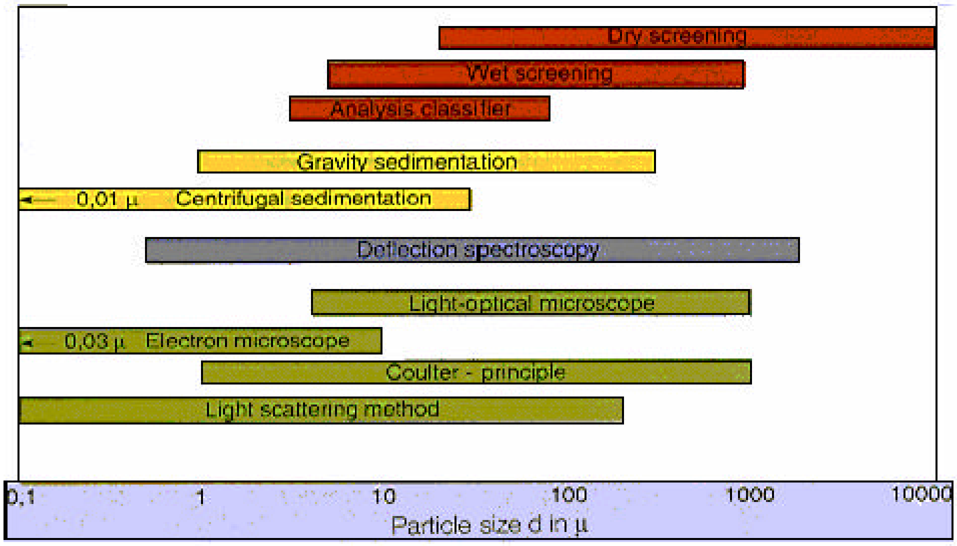

Figure 2.5: Summary of processes for classification of fly ash

Previous experiments were designed to determine the background mercury concentration in Portland cement. The analysis was conducted using a Varian Hot Block and samples were digested and then transferred to high-density polyethylene bottles and subjected to Cold Vapor Atomic Adsorption Spectrometry and Cold Vapor Atomic Fluorescence Spectrometry testing. The intent of this project was to submit the fly ash to a similar test to determine the extent of release of mercury, iron, silicon and sulfur, which is found in the chemical makeup, to the environment during leaching.

2.3 Experimental Setup and Leaching Testing

Leaching tests serve to quantify the source terms for fate and transport modeling. The purpose of the testing is to obtain aqueous phase concentrations of constituents which are released from solids when placed in a land disposal unit. The underlying assumption is that if the constituent does not leach from the waste, then land disposal of that constituent is not a threat to groundwater. Toxicity characteristic leaching procedure (TCLP) and synthetic precipitation leaching procedure (SPLP) have been widely used to generate leachate concentrations for all types of solids for both organic and inorganic constituents. The assumption is that potentially hazardous wastes comprise at most 5% of the volume of the material deposited in municipal solid waste landfills. The municipal waste is assumed to degrade and produce an acidic liquid to which the waste is exposed. Thus, a 5%/95% relationship leads to the specific composition of the acetic acid solution used in the TCLP test.

To separate forms of leaching, test procedures exist that are applicable to a study focusing on the effects of fly ash in the environment. The toxicity characteristic leaching procedure (TCLP) works to determine the mobility of organic and inorganic analytes in solid wastes. The TCLP test method is utilized in this project when the liquid fractions of the TCLP extract indicated a regulated compound was present. In this method, the fly ash samples are subjected to 18 hour and 7 day interaction with the leaching solution. For liquids containing .5% solids, the liquid was separated from the solid phase using a filtration device and then stored for analysis. The leaching solution in this method is a mixture of glacial CH_3CH_2OOH, reagent water, and NaOH. The solution is diluted to a volume of 1 liter and made to have a pH of 4.93. This method also places requirements on the minimal size of the field sample, depending on the physical state of the waste. Immediately after TCLP extracts are extracted, the samples were prepared for analysis as specified in the procedure. Samples are allowed to be refrigerated, and were refrigerated in this project following preparation for analysis. After all samples were gathered for analysis, the ICP-AES and SpectrAA analyses were utilized. The method was completed in duplicate.

Synthetic Precipitation Leaching Procedure (SPLP) is designed to simulate a monodisposal of waste and reveal the soluble phases of a sample being tested. The test aids in predicting the geochemical effect of a "flush" on a material and the extraction liquid used in this method is similar to the TLCP method; however, it mirrors the effects of precipitation leaching rather than municipal landfill leachate. Static leaching tests, like these, are short term tests and involved agitating samples using a rotator device and then sampling the resulting solution. The SPLP test is a method designed to predict and determine the potential for leaching metals into ground and surface waters and uses a 1:20 liquid to solid ratio. There is a rigorous leach of the material (for 18 hours and 7 days) and the extraction fluid is intended to simulate precipitation which occurs naturally east of the Mississippi river as a fluid slightly acidic to reflect industrialization and air pollution impacts on precipitation.

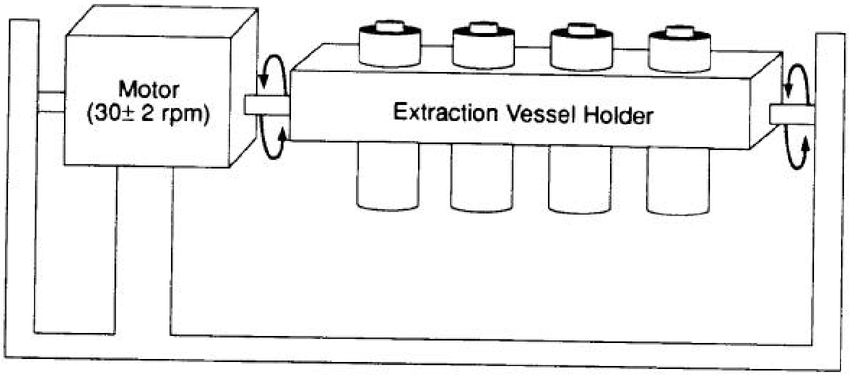

Figure 2.6: Rotator Device for TCLP and SPLP testing

2.4 Inductively Coupled Plasma Atomic Emissions Spectrometry (ICP-AES)

Flame spectroscopy, the distinctive optical colors that are produced when compounds of certain metals are vaporized in flames, is a highly sensitive and specific means of identifying minute quantities of certain elements in materials. Optical emission spectrometry developed into a powerful method of chemical analysis and in these developments, the concentration of a specific element in a sample can be related to the intensity of lines in its optical spectrum. Modern inductively coupled plasma atomic emissions spectrometry relies on the same principles as flame spectrometry and determines minute amounts of a very wide range of elements even in the presence of much greater quantities of other elements. In analyzing samples, the inductively coupled plasma atomic emissions spectrometry machine relates the chemical solution samples to a set of calibrating standard. Each standard contains an accurately known concentration of analyte element and a range of concentration for each element in the set is chosen to include the expected concentration of that element in the sample solutions. The calibrating solutions and sample solutions are sprayed into the plasma which is created in the machine using Argon, and the intensities of appropriate emission lines are recorded. The concentrations of the element in each sample solution are determined from the calibrating graphs.

The plasma used in this method for analysis is simply a gas whose properties are influenced by the presence of a significant concentration of ions and electrons. These exist in approximately equal numbers over the volume of the plasma, so overall electrical neutrality is maintained. ICP instrumentation relies on the used of the tesla coil to ignite the plasma and then inject the sample flow into the base of the plasma. The bench top ICP-AES is the third generation of ICP instrumentation and coordinates usage of computer control, innovative optical design and lower argon and power consumption over the life of the machine. The sample introduction system transports the analytes of interested to the excitation source that causes the sample to undergo desolvation and excitation resulting in emission of characteristic radiation. Due to the high temperature of the ICP, singly charged ions dominate and the spectrometer separates the radiation of interest so that the detection system measures the intensity of the selected radiation as compared to the standard.

2.5 Varian SpectrAA Testing

Samples were also analyzed by the Varian SpectrAA 880Z Zeeman Atomic Absorption Spectrometer (AAS). Because all atoms can absorb light in certain wavelengths, these wavelengths can identify an atomic spectra based on characteristic spectroscopic lines. Wavelengths are sharply defined and when a range of wavelengths is surveyed and compared, lines which originate in the ground state atom are most often of interest in atomic absorption spectroscopy and are called resonance lines. With particular spectroscopic characteristics, each element comprises a number of discrete lines. Using atomic absorption spectroscopy in conjunction with the analysis of this experiment therefore allows analyte elements in a leachate solution to be compared spectroscopic ally to calibration solutions enabling the concentration of analyte to be defined for a given sample. Using the Beer-Lambert Law to define a relationship between analyte concentration and light absorption, it can be seen that increased sensitivity can be achieved in electrothermal atomization – in the case of this experiment, allowing the mercury concentration in a sample of fly ash to be more highly detected.

Graphite furnace atomic absorption has become a field of analytic chemistry focused on determining very low levels of trace metals in a variety of sample types. In this form of analysis, molecules and compounds are broken down to atoms and ions. Because light absorption or emissions is in discrete energy packets, the different in energy between the energy levels is inversely proportional to the wavelength of emitted light. Using a hollow cathode lamp, a furnace creates and contains atoms in the light path. Atom population is then exposed to HCL emission at the resonance wavelength and the light transmission is measured and absorbance is calculated. The detection limit for CVAAS is .1 parts per billion.

CHAPTER 3

TEST RESULTS AND DISCUSSION

3.1 Fly Ash Characterization: Sampling, Sample pH testing, Total Dissolved Solids Test

Testing procedures, including quality control, were conducted in accordance with EPA Test Methods 1131 and 1132. First, fly ash samples were analyzed to ensure that the particle size was less than 1.0cm. Two different leaching solutions were used to complete the experiment. In this method, the fly ash samples were subjected to 18 hour and 7 day interaction with the leaching solution. To do this, 100g of fly ash was combined with 2 L of leaching solution to achieve an acceptable liquid-to-solution ratio. The initial pH of the mixture was then determined to ensure the method requirements were met. The leaching solution in the TCLP method is a mixture of glacial CH_3CH_2OOH, reagent water, and NaOH. The solution is diluted to a volume of 1 liter and made to have a pH of 4.93. In the SPLP method, the solution is sulfuric acid/nitric acid (60/40 weight percent mixture) H_2SO_4 /HNO_3 . To create the solution, 60 g of concentrated sulfuric acid is cautiously mixed with 40 g of concentrated nitric acid.

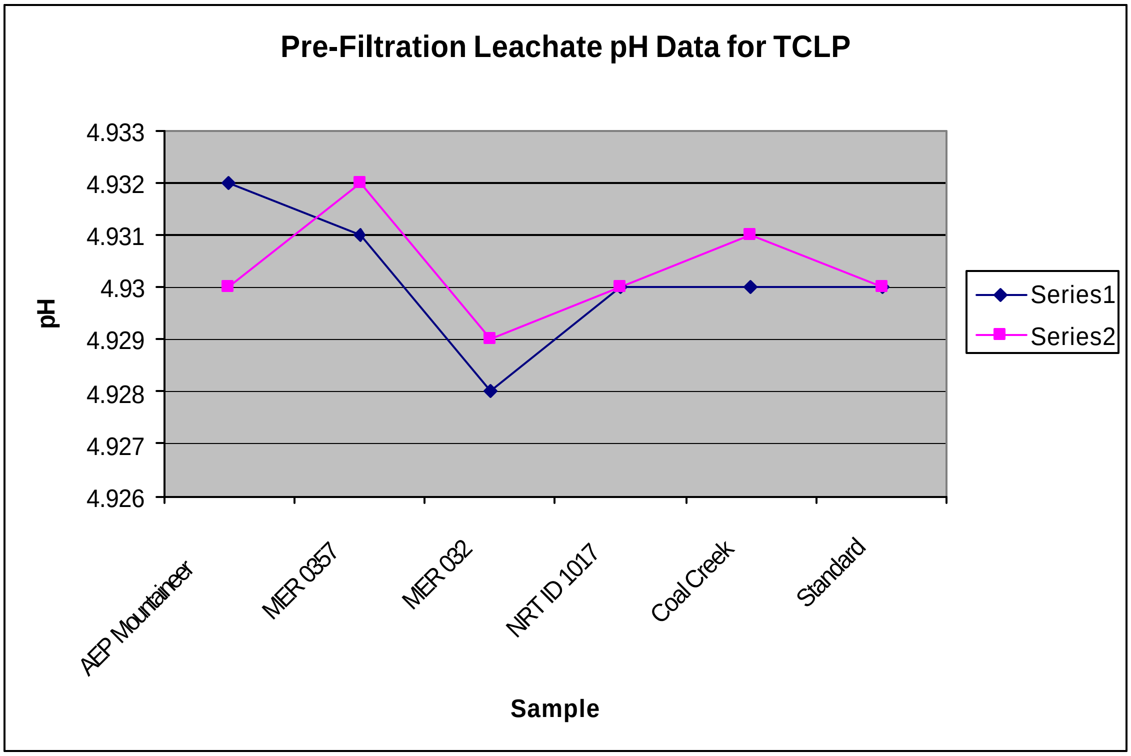

Figure 3.1: Initial Leachate Data for TCLP Method

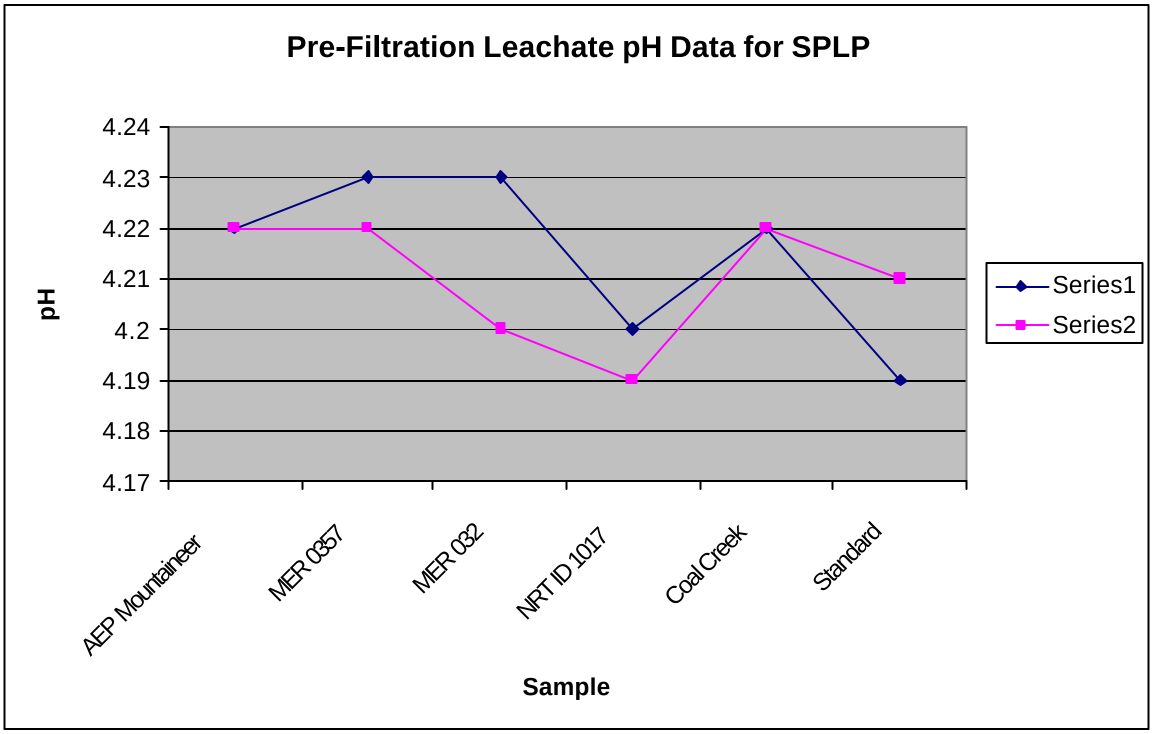

Figure 3.2: Initial pH Data for SPLP Method

The test utilized the rotation device to mix the samples for 18 hours and 7 days – tests were conducted in duplicate and samples were taken as specified in the EPA procedures. As stated in the method, samples for both tests may be refrigerated unless refrigeration results in irreversible physical change to the waste. The samples were collected in "store" type containers and refrigerated. Once ready for evaluation, extreme acre was taken to minimize the loss of volatiles. Samples were collected and stored in a manner intended to prevent the loss of volatile analytes and therefore the waste samples were collected in Teflon-line capped vials. The extracts for metallic analyte determinations were acidified with nitric acid to a pH less than 2. Immediately after sampling and prior to this storing technique, the liquid was separated from the solid phase using a filtration device. The solution was then tested for pH and total dissolved solid content.

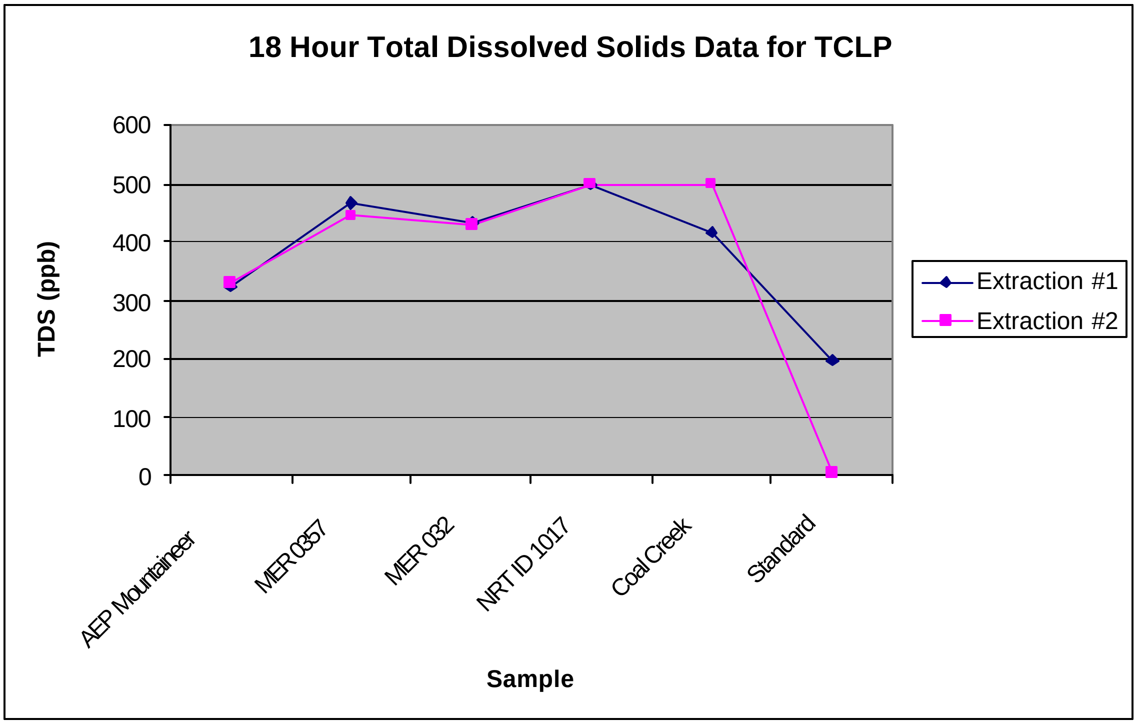

Figure 3.3: 18 Hour Total Dissolved Solids Data for TCLP

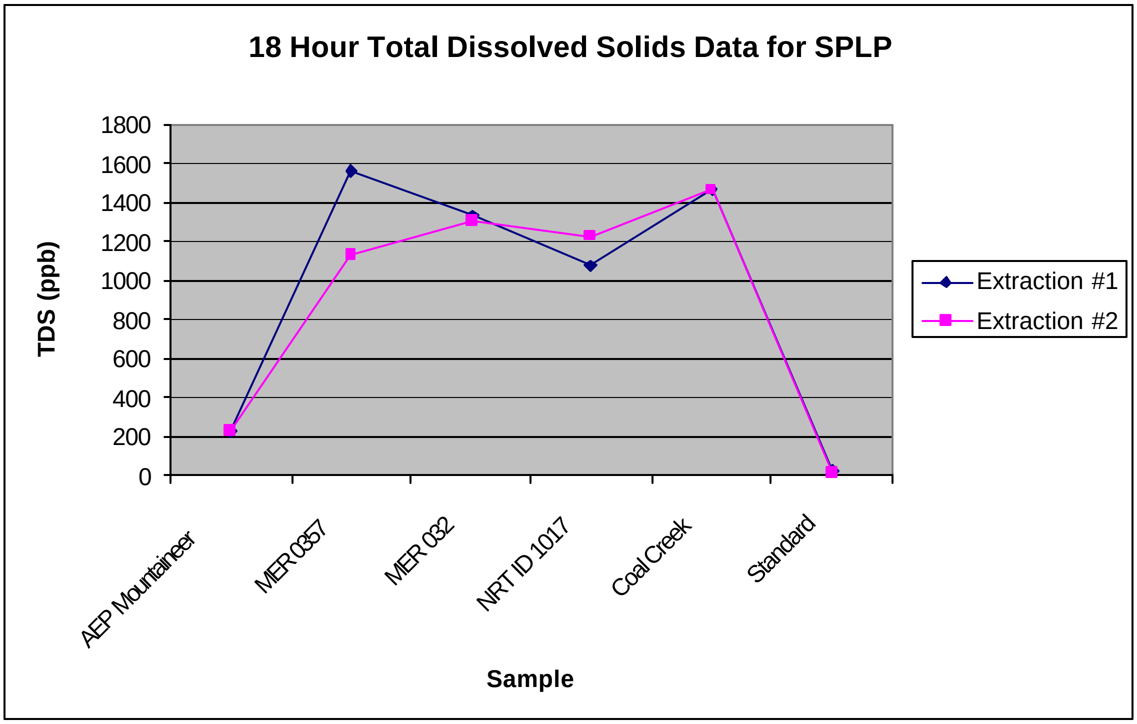

Figure 3.4: 18 Hour Total Dissolved Solids Data for SPLP

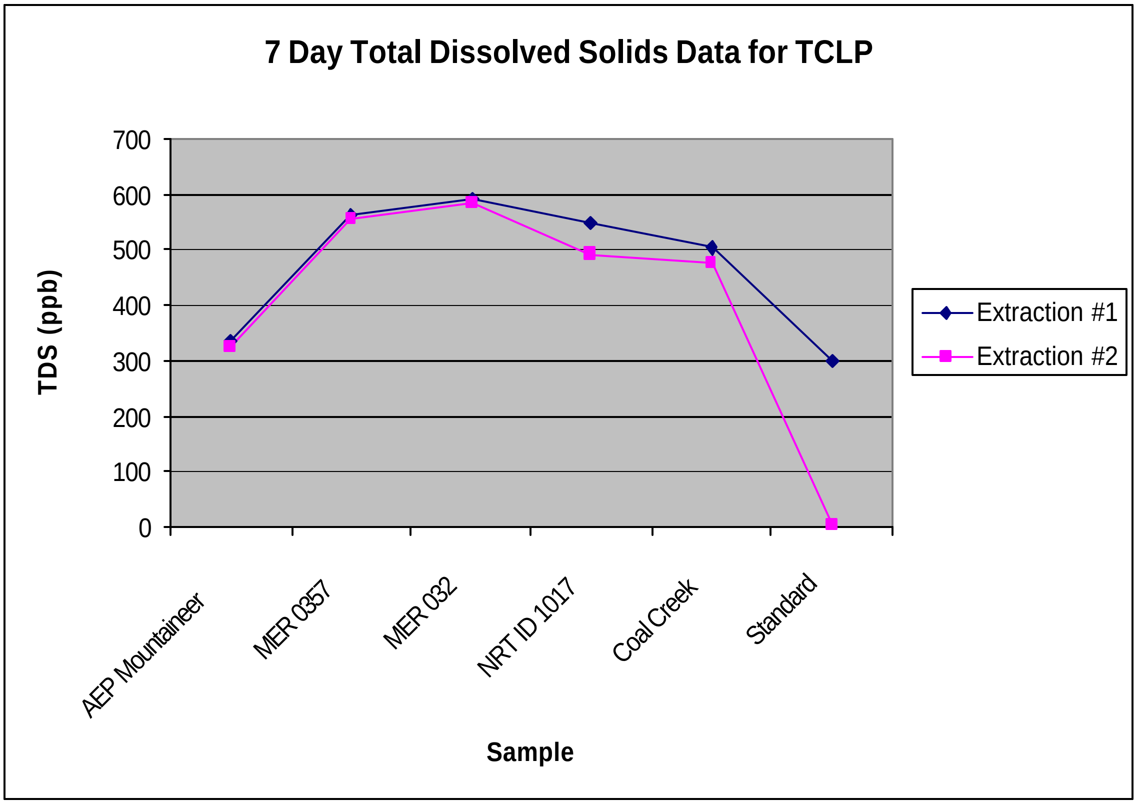

Figure 3.5: 7 Day Total Dissolved Solids Data for TCLP

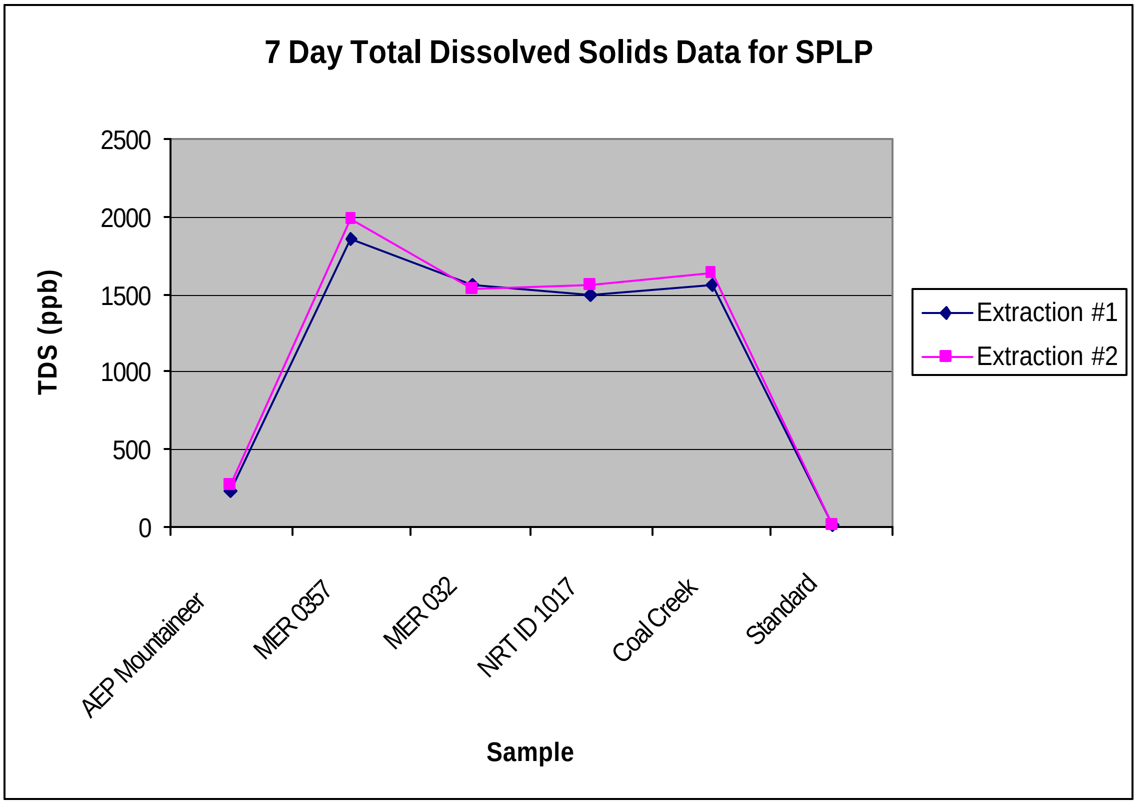

Figure 3.6: 7 Day Total Dissolved Solids Data for SPLP

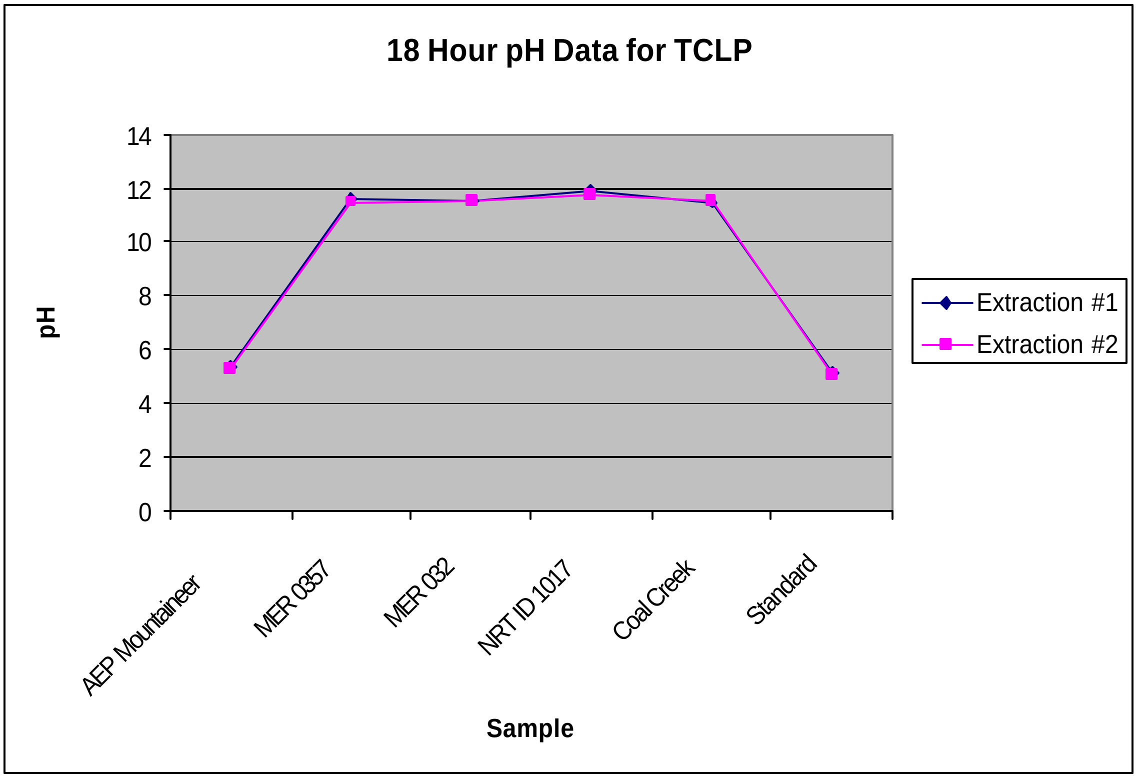

Figure 3.7: 18 Hour pH Data for TCLP

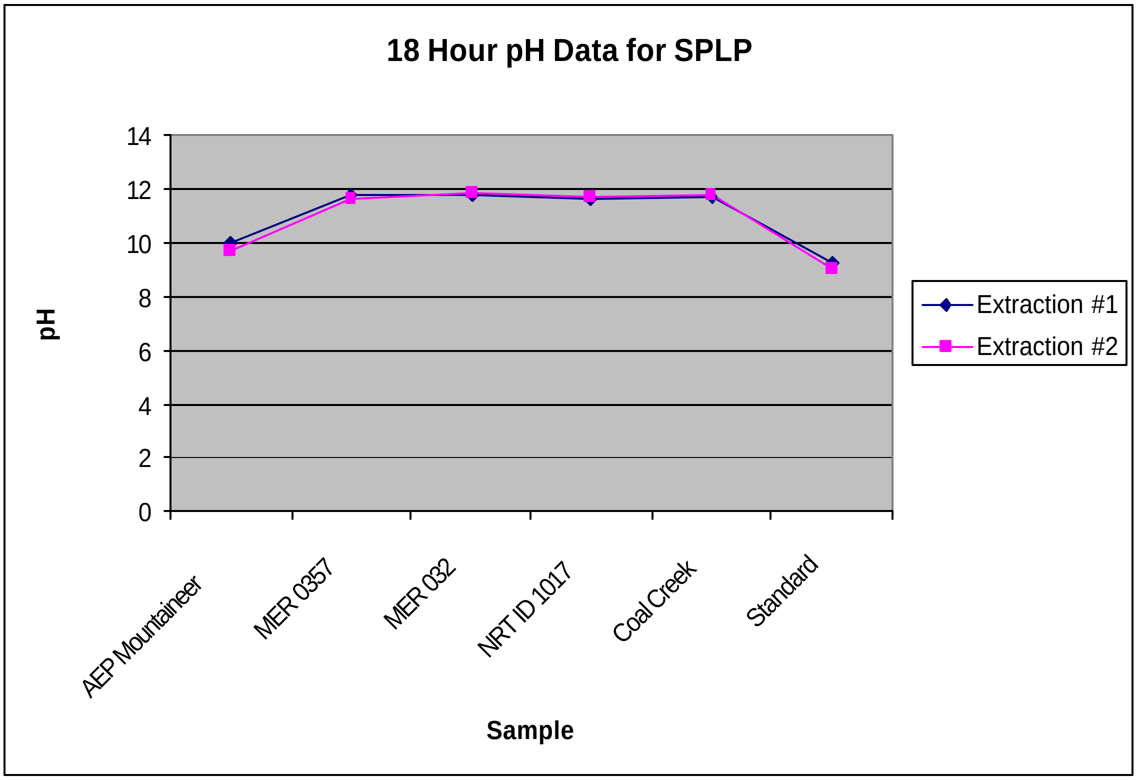

Figure 3.8: 18 Hour pH Data for SPLP

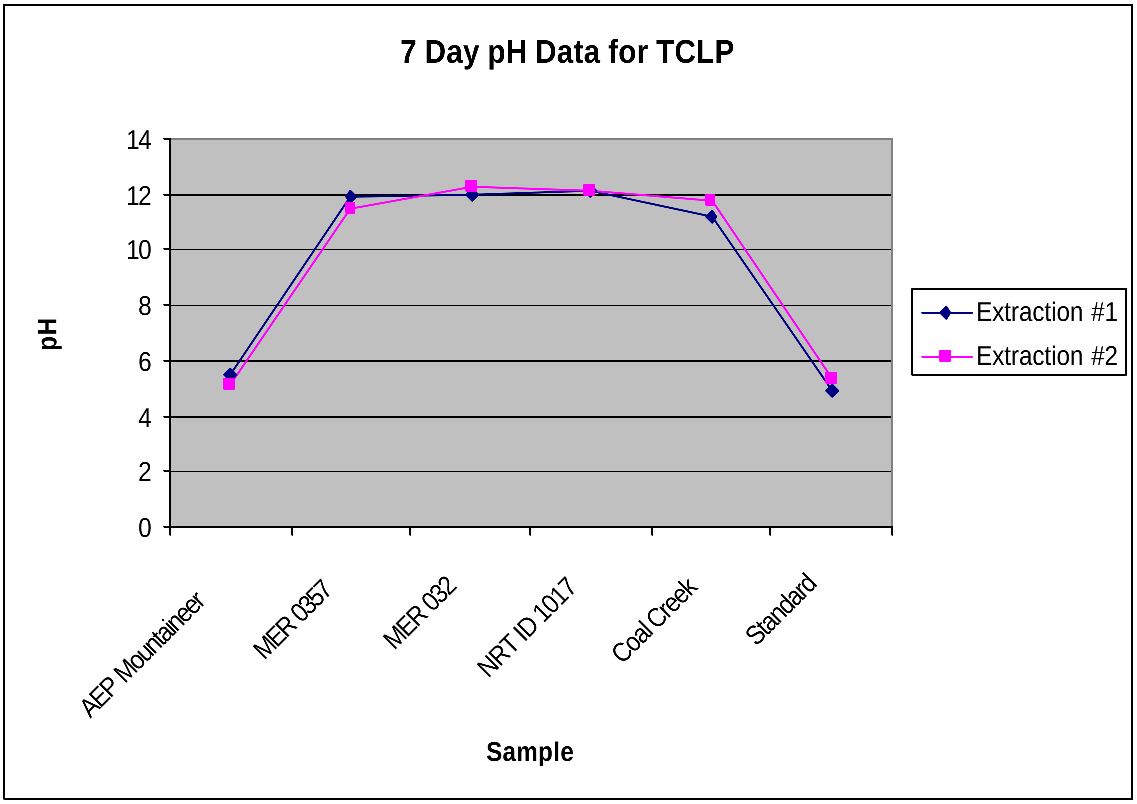

Figure 3.9: 7 Day pH Data for TCLP

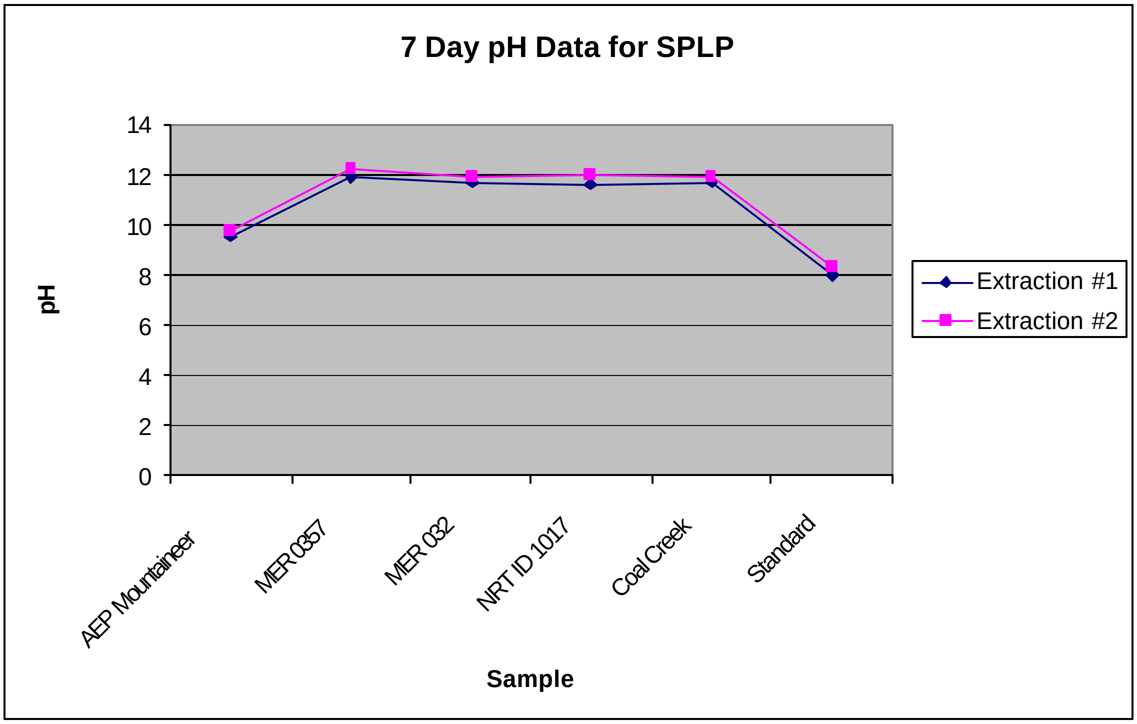

Figure 3.10: 7 Day pH Data for SPLP

3.2 Sample Analysis

To analyze the concentration of mercury and other analyte elements, the Atomic Fluorescence spectroscopy method was used in addition to the Inductively Coupled Plasma-Atomic Emissions Spectrometry technique as discussed earlier in this report. Both of these experimental analysis procedures can be completed utilizing Minteq A2 computer modeling programs to compare experimental results and determine the importance of different solid phases in controlling solution composition.

The ICP-AES utilizes a diffraction grating fixed in space at the far end of the spectrometer. Rotation of the diffraction grating sequentially moves each wavelength into the detector. The computer control ensures that the detector is synchronized with the grating so that the intensity at the detector at any given time is correlated with the wavelength being diffracted by the grating. Using standard spectroscopic techniques, sequential ICP-AES can provided extremely flexible and rapid analysis of a number of chemical elements. The spectrometer was flushed with N_2 gas to improve the detection limits of elements and to ensure quality with emission wavelengths that are severely compromised by interference with air. This N_2 flush, which is constantly maintained in the instrument regardless of whether such elements are being analyzed, also protects the optics from the corrosive aspects of the atmosphere, which are particularly acute at sea. First, the machine was allowed to warm up for 30 minutes. Next, a zero-order check was conducted. Zero-order is the term used to define when the grating within the spectrometer behaves as a mirror, reflecting incoming light rather than refracting it into several wavelengths. A zero-order check physically moves the diffraction grating to its zero position, where all light is reflected. An *autosearch* is preformed next to allow the spectrometer to identify an acceptable reference peak. The machine is calibrated using standards and finally the test was completed. The TCLP leachate concentration of the AEP fly ash sample and the SPLP leachate concentration of the MER0357 fly ash sample provide examples of typical ICP-AES results for this experiment.

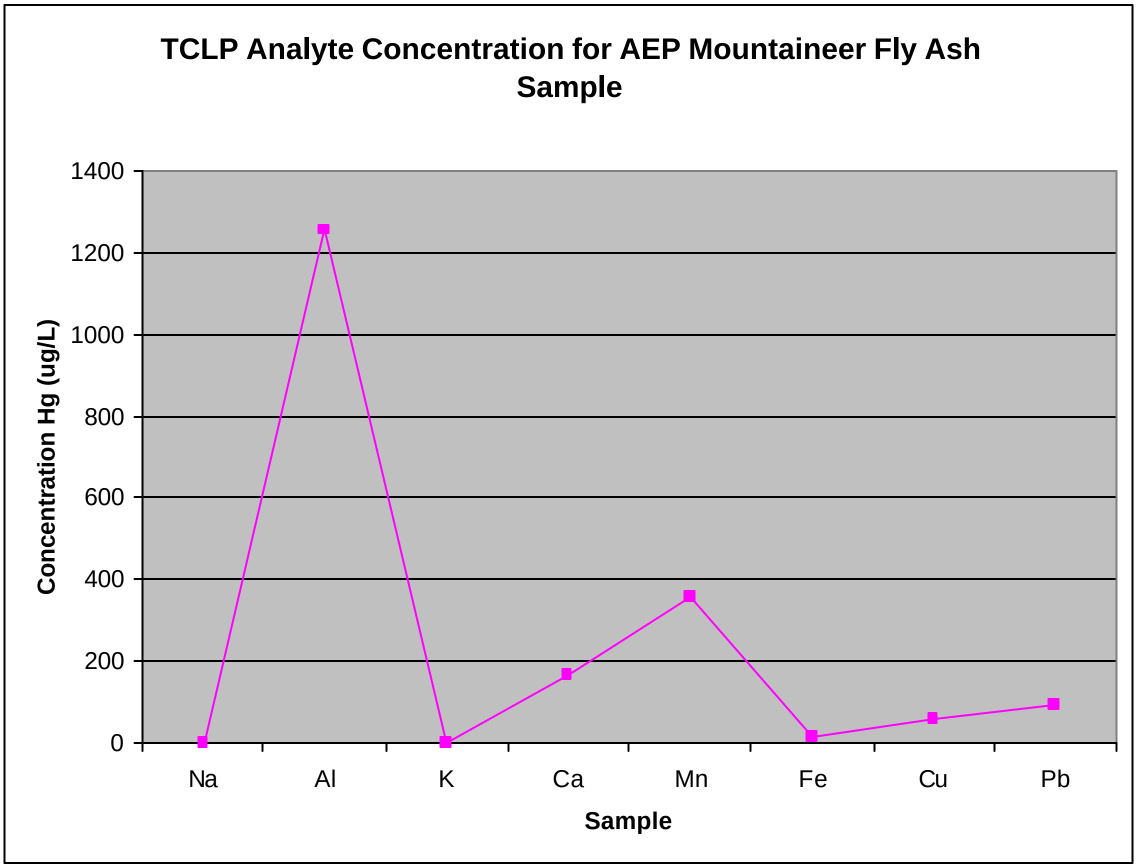

Figure 3.11: TCLP Analyte Concentration for AEP Mountaineer Fly Ash Sample

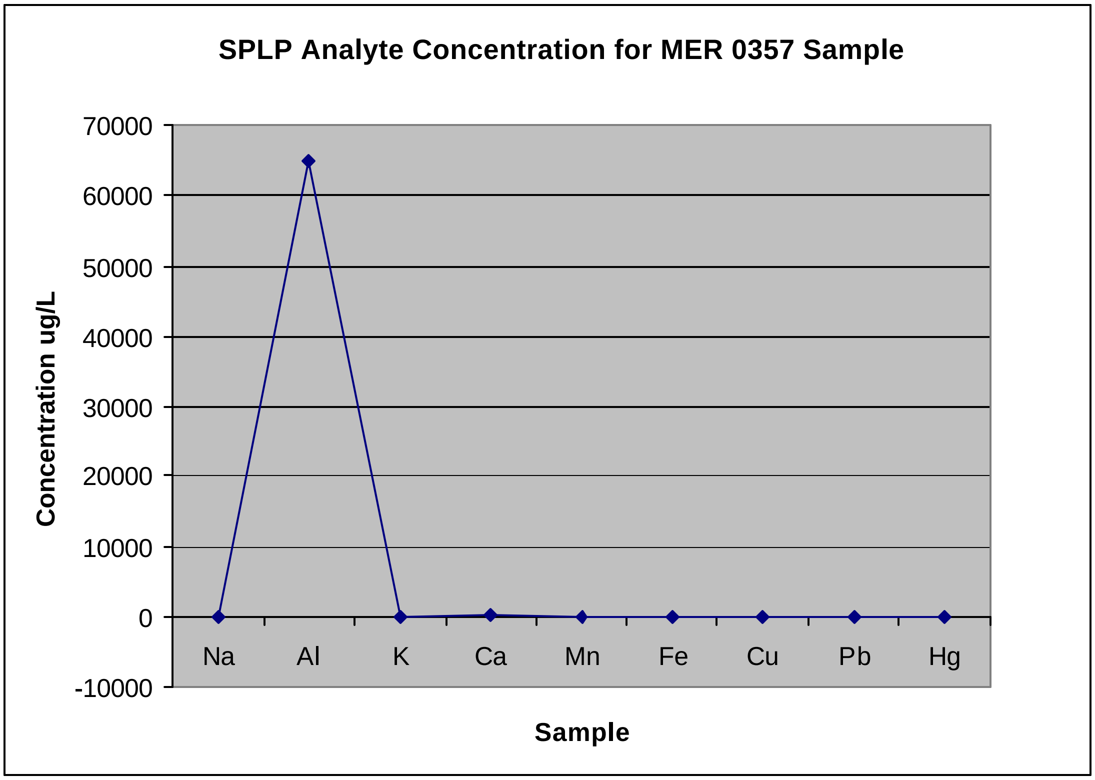

Figure 3.12: SPLP Analyte Concentration for MER 0357 Fly Ash Sample

A lamp of desired wavelength and a PMT detector provide absorbance values based on the amount of the element present. When compared to a generated standard curve, the element of interest can be quantified. Detection limits for the instrument vary according the element under consideration, but for the analysis of mercury content in fly ash leachate samples the detection limits test returned a 99% confidence rating that the Hg concentrations reported were are less than 0.2ppb as recorded in the tables below. The data collected through this method gave a standard deviation of .012246.

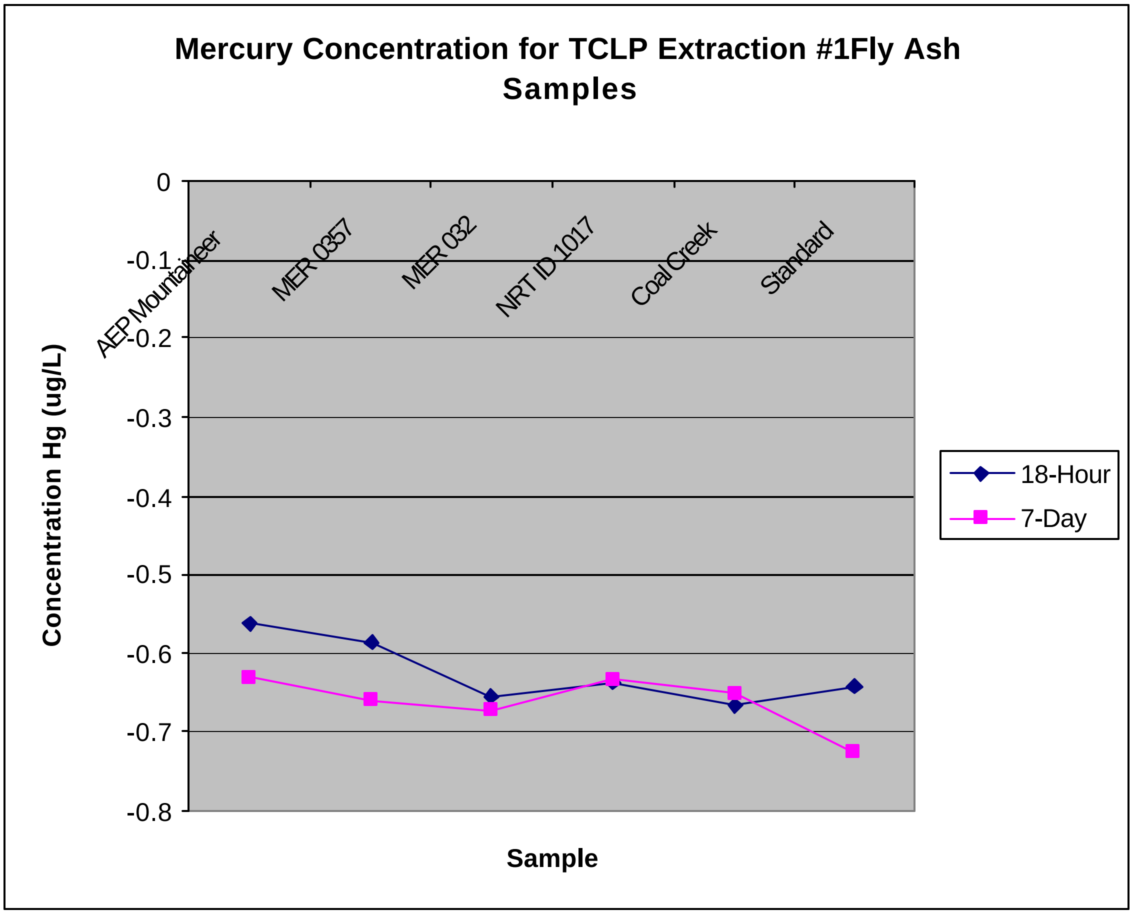

Figure 3.13: Mercury Concentration for TCLP Extraction #1

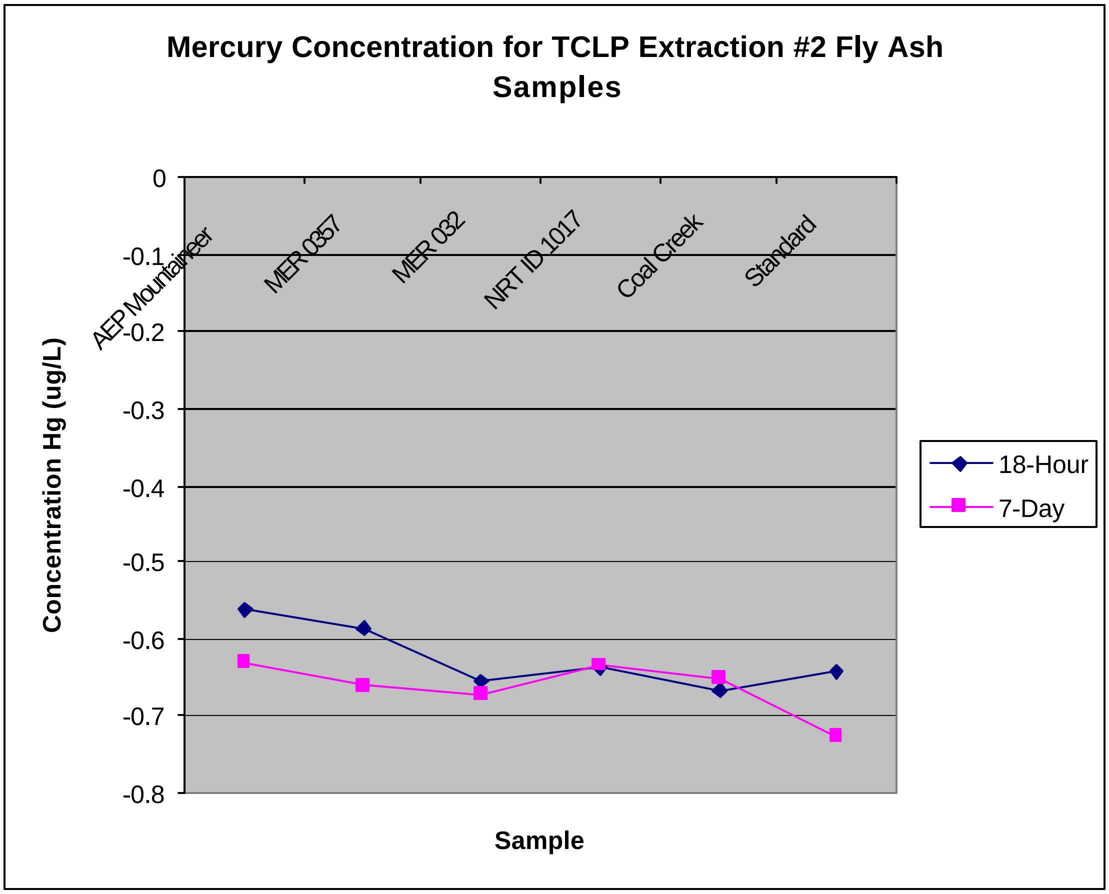

Figure 3.14: Mercury Concentration for TCLP Extraction # 2

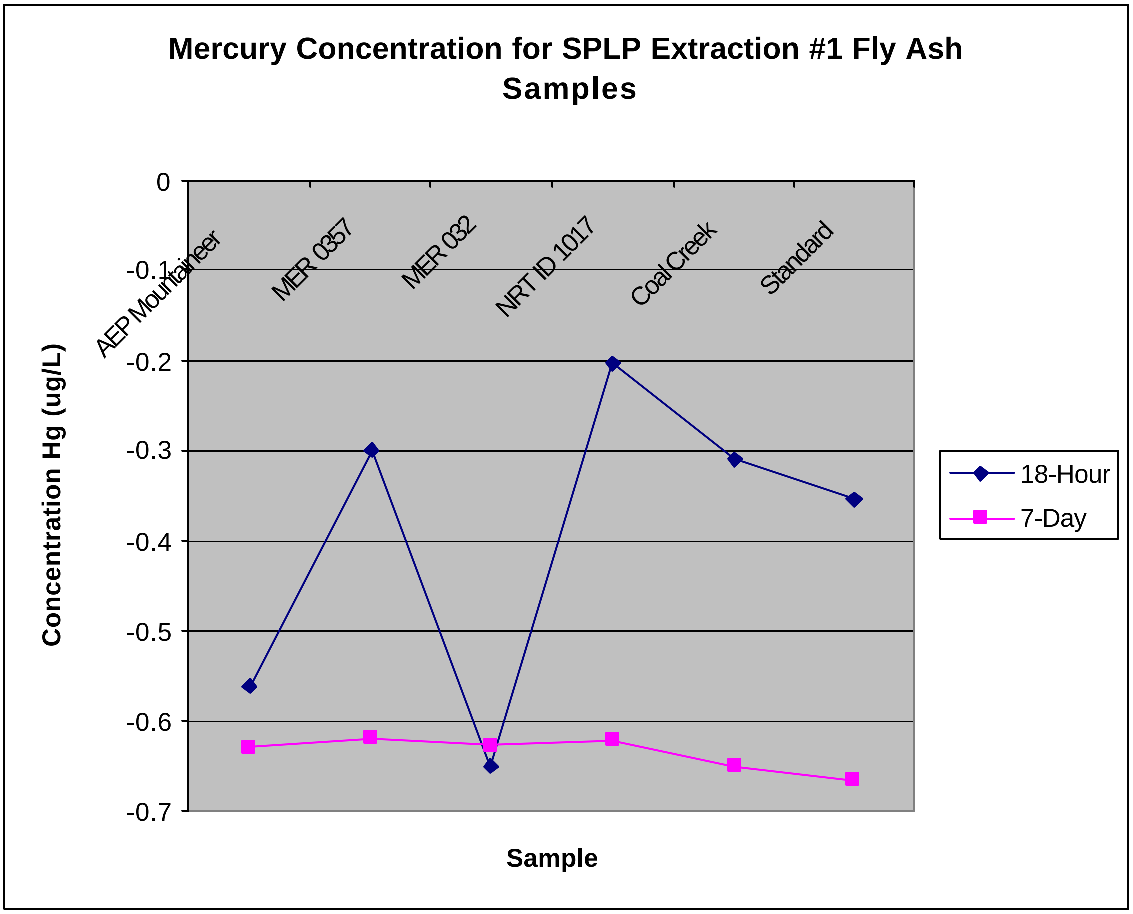

Figure 3.15: Mercury Concentration for SPLP Extraction #1

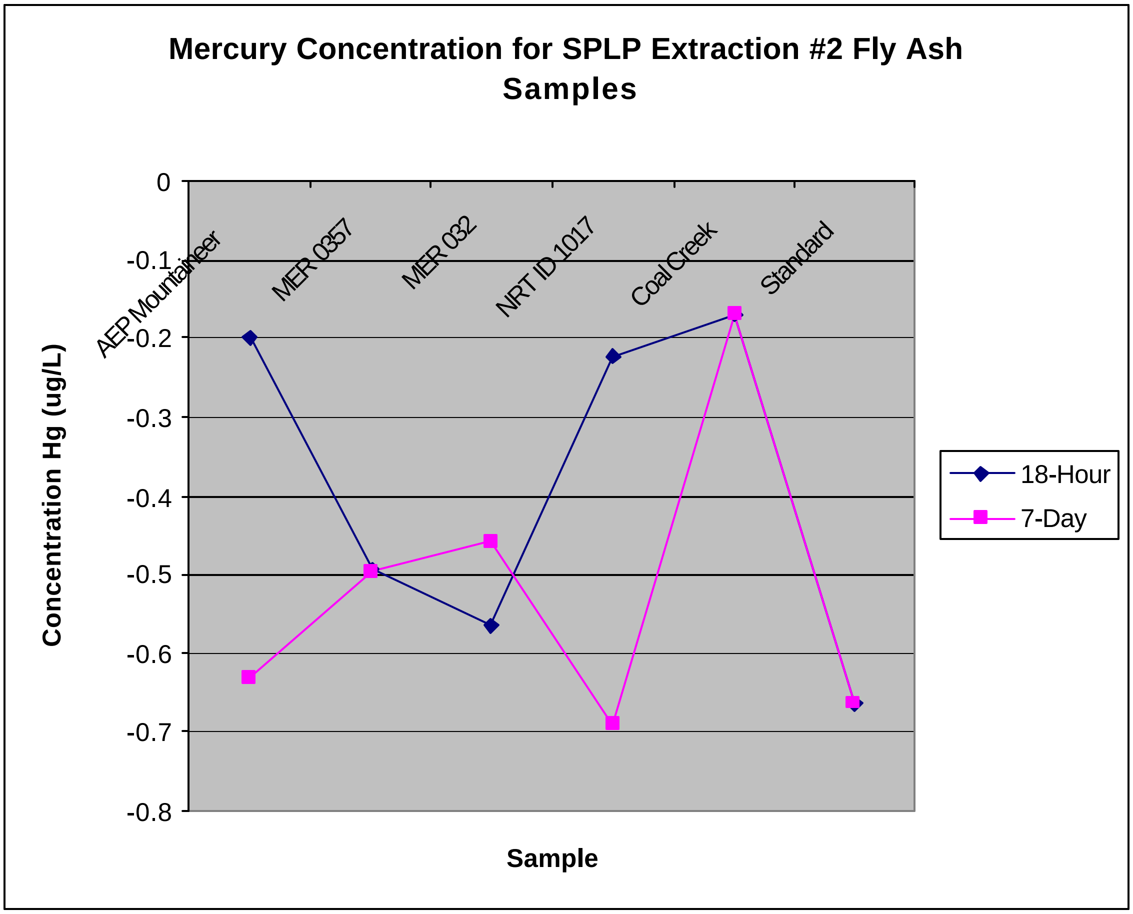

Figure 3.16: Mercury Concentration for SPLP Extraction #2

TCLP # 1						
	Mass (grams)	Initial pH	18 Hour TDS	18 Hour pH	7 Day TDS	7 Day pH
AEP Mountaineer	100	4.932	325	5.315	338	5.47
MER 0357	100	4.931	467	11.64	564	11.934
MER 032	100.1	4.928	433	11.57	593	11.98
NRT ID 1017	100.1	4.93	497	11.9	547	12.156
Coal Creek	100.1	4.93	416	11.49	502	11.2
Standard	N.A.	4.93	196	5.1	299	4.9
TCLP # 2						
AEP Mountaineer	100	4.93	329	5.28	326	5.13
MER 0357	100.1	4.932	445	11.489	554	11.5
MER 032	99.9	4.929	429	11.57	585	12.3
NRT ID 1017	100	4.93	497	11.79	492	12.17
Coal Creek	100	4.931	498	11.56	476	11.806
Standard	N.A.	4.93	2.8	5.06	2.7	5.3
SPLP # 1						
	Mass (grams)	Initial pH	18 Hour TDS	18 Hour pH	7 Day TDS	7 Day pH
AEP Mountaineer	99.8	4.22	231	9.97	240	9.56
MER 0357	99.9	4.23	1559	11.75	1858	11.91
MER 032	100.1	4.23	1335	11.75	1563	11.68
NRT ID 1017	100	4.2	1077	11.66	1495	11.66
Coal Creek	100.1	4.22	1463	11.74	1558	11.67
Standard	N.A.	4.19	19.05	9.24	15	8
SPLP # 2						
AEP Mountaineer	100	4.22	229	9.71	278	9.76
MER 0357	100.1	4.22	1134	11.66	1985	12.24
MER 032	100.1	4.2	1307	11.82	1529	11.92
NRT ID 1017	100	4.19	1227	11.74	1567	11.99
Coal Creek	100.1	4.22	1469	11.81	1640	11.91
Standard	N.A.	4.21	14	9.01	12	8.29

Table 3.1: TCLP and SPLP Data for Fly Ash Leachate Samples

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Data from these laboratory experiments on fly ash samples suggests that release of mercury from fly ash subjected to leachate solutions such as those found in municipal landfills and natural precipitation is low and almost undetectable through modern testing technology. Mercury release from samples subjected to both SPLP and TCLP testing methods returned negative results through atomic absorption analysis and this phenomenon exists only when mercury levels in samples are so low that the analysis is barely sensitive enough to detect the element. The additional analyte elements identified in the ICP-AES analysis of data ensures that fly ash material used in concrete, once subjected to leaching, are not harmful. This study has shown that even where some leaching of fly ash has occurred, its effects do not pose public health risks. The study has proven that the fly ash ingredient utilized in several concrete applications does not add potential mercury leaching to the concrete mix. In fact, the level of mercury in leachate from fly ash material is so low that it is nearly undetectable. The importance of using valid leaching protocols when evaluating complex inorganic materials was taken into account throughout the study and complex chemical reactions that could occur were restricted before they could have an impact on the generation of leachate.

4.2 Recommendations

Several additional studies have found similar results to the analysis of this research experiment. Leaching studies conducted at a structural fill site in Minnesota and an embankment in Illinois indicated that even though some groundwater contamination had occurred, only very small localized changes in trace element concentration were detected off site after 8 years. Similarly, nearly 15 years after ash was used to construct a highway overpass embankment, sampling and analysis of groundwater, soils and vegetation in another study showed only slightly elevated levels of some constituents related to fly ash. A University of Pittsburg study conducted environmental and physical testing of concrete made from fly as and concluded that in all areas, leachate compositions of 17 different elements show fly as materials to be nonhazardous and likely environmentally benign.

Throughout the course of this research study, questions about the utilization accuracy of the TCLP and SPLP methods have been uncovered. One study suggested that the solutions used to simulate the leachate were highly inadequate. Another study concluded that the solid to liquid ratio requirement from the EPA test methods were in accurate. These issues could negatively effect the results of this study – if the solutions were inadequate in leaching the fly ash material, an incorrect measurement of the elements in the leachate could be reported.

It is recommended that fly ash in concrete be continually monitored for future mercury leachate. A study focusing on the long term effects of leaching on fly ash is also suggested as a means to determine the degenerative effect of time on the samples. Though fly ash samples can only simulate the actions of the fly ash materials in concrete, the results from this study can be extended to provide insight into the overall contribution of fly ash to concrete structures. In the end, this study recommends that fly ash utliziation is an economical alternative to Portland cement that will not cause environmental or public harm.

CHAPTER 5

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APPENDIX

Mercury Concentration Sample Data

Coal Creek-SPLP-2	-0.170	4.9	-0.0028	-0.0027	-0.0028	-0.0030
Standard-SPLP-2-	-0.253	4.5	-0.0040	-0.0039	-0.0040	-0.0042
10ppb	8.820	0.9	0.1271	0.1257	0.1274	0.1281
AEP-TCLP-2-18	-0.199	5.3	-0.0033	-0.0031	-0.0034	-0.0033
NRT-TCLP-2-18	-0.223	5.0	-0.0036	-0.0035	-0.0035	-0.0038
Coal Creek-SPLP-1	-0.309	2.4	-0.0048	-0.0048	-0.0048	-0.0050
NRT-SPLP-1-18	-0.204	1.4	-0.0033	-0.0034	-0.0033	-0.0033
0357-SPLP-1-18	-0.300	1.1	-0.0047	-0.0047	-0.0047	-0.0048
Standard-SPLP-1-	-0.355	0.4	-0.0055	-0.0056	-0.0055	-0.0056
Standard-TCLP-2-	-0.389	2.3	-0.0060	-0.0061	-0.0060	-0.0059
AEP-TCLP-2-7	-0.406	1.0	-0.0062	-0.0062	-0.0062	-0.0063
b	-0.444	1.2	-0.0068	-0.0068	-0.0068	-0.0067
10ppb	9.679	1.1	0.1396	0.1379	0.1398	0.1410
032-SPLP-2-7	-0.363	4.5	-0.0056	-0.0053	-0.0057	-0.0058
032-TCLP-2-7	-0.457	1.1	-0.0070	-0.0070	-0.0069	-0.0071
Coal Creek-TCLP-2	-0.477	1.0	-0.0073	-0.0072	-0.0073	-0.0073
NRT-TCLP-2-7	-0.488	1.2	-0.0074	-0.0074	-0.0073	-0.0075
0357-TCLP-2-7	-0.500	0.9	-0.0076	-0.0076	-0.0077	-0.0075
Coal Creek-TCLP-2	-0.525	1.5	-0.0080	-0.0079	-0.0079	-0.0081
0357-TCLP-2-18	-0.493	1.9	-0.0075	-0.0073	-0.0076	-0.0075
032-TCLP-2-18	-0.566	0.9	-0.0086	-0.0086	-0.0085	-0.0085
Standard-TCLP-2-	-0.605	0.5	-0.0091	-0.0091	-0.0091	-0.0092
b	-0.607	1.3	-0.0091	-0.0090	-0.0091	-0.0093
10ppb	9.524	1.2	0.1373	0.1356	0.1377	0.1388
0357-SPLP-2-7	-0.497	4.5	-0.0076	-0.0072	-0.0075	-0.0079
032-SPLP-1-18	-0.650	1.9	-0.0098	-0.0099	-0.0098	-0.0098
AEP-SPLP-1-18	-0.664	1.3	-0.0100	-0.0100	-0.0101	-0.0098
032-TCLP-1-7	-0.673	2.0	-0.0101	-0.0103	-0.0101	-0.0099
Coal Creek-TCLP-1	-0.665	0.4	-0.0100	-0.0100	-0.0100	-0.0099
0357-TCLP-1-7	-0.660	1.7	-0.0099	-0.0098	-0.0098	-0.0101
AEP-TCLP-1-7	-0.660	0.8	-0.0099	-0.0100	-0.0098	-0.0099
NRT-TCLP-1-7	-0.634	0.5	-0.0095	-0.0096	-0.0095	-0.0095
Standard-TCLP-1-	-0.727	0.6	-0.0109	-0.0108	-0.0109	-0.0109
NRT-SPLP-2-7	-0.690	1.2	-0.0103	-0.0105	-0.0103	-0.0103
b	-0.735	0.9	-0.0110	-0.0109	-0.0110	-0.0111
10ppb	9.511	1.0	0.1372	0.1357	0.1374	0.1385
MNTR-SPLP-2-7	-0.629	2.0	-0.0095	-0.0093	-0.0095	-0.0096
NRT-SPLP-2-18	-0.660	0.8	-0.0099	-0.0100	-0.0099	-0.0098
032-SPLP-2-18	-0.655	1.1	-0.0098	-0.0097	-0.0099	-0.0099
0357-SPLP-2-18	-0.599	0.1	-0.0090	-0.0090	-0.0090	-0.0090
Standard-SPLP-2-	-0.662	0.8	-0.0099	-0.0100	-0.0099	-0.0099
AEP-SPLP-2-18	-0.656	0.3	-0.0098	-0.0098	-0.0099	-0.0098
Coal Creek-SPLP-2	-0.640	1.7	-0.0096	-0.0098	-0.0095	-0.0096

Standard 3	4800	4800	4800
Standard 4	10000	10000	10000
Standard 5	24000	24000	24000
Standard 6	48000	48000	48000
Standard 7	100000	100000	100000
standard tcl 1-18	16.8	25.3	36.0
nrt tc 1-18	51265	50942	50615
032 tc 1-18	16553	16563	16392
coal creek tc 1-18	1445	1429	1391
ae tc 1-18	1256	1253	1234
0357 tc 1-18	8743	8605	8481
nrt s 2-7	41851	40982	41184
ae s 2-7	7962	7990	7866
standard s 2-7	0.855uv	5.20uv	13.3
0357 s 2-7	5665	5580	5480
ccv	21879	21708	21557
032 s 2-7	37762	37069	37007
0357 s 1-7	217	204	202
ae s 1-7	6957	7002	6805
032 s 1-7	25827	25355	25266
nrt s 1-7	43443	42525	42520
coal creek s 2-18	615	611	597
032 s 2-18	55649	55988	54244
ae s 2-18	141	118	121
standard s 2-18	21.3	11.1	3.31uv
0357 s 2-18	37192	36816	35983
ccv	20361	20112	19524
nrt s 2-18	39804	39278	38006
coal creek s 2-7	624	601	595
coal creek 1-7	511	512	492
standard s 1-7	52.3	49.5	64.8
coal creek s 1-18	1692	1676	1584
032 s 1-18	48142	48313	45640
0357 s 1-18	64463	64951	61482
nrt s 1-18	38793	38464	36762
ae s 1-18	6559	6585	6213
standard s 1-18	26.4	26.0	12.2
ccv	19348	19607	18327
standard t 2-18	37.8	35.7	49.1
032 t 2-18	12067	12172	11321
0357 t 2-18	2411	2419	2242
032 t 1-7	1239	1178	1130
coal creek t 1-7	248	241	243
0357 t 2-7	4642	4642	4271
nrt t 2-7	3935	3979	3623

Analyte Element Concentration

Sample Label	Na 330.237	Na 330.298	Na 568.263	Na
	mg/L	mg/L	mg/L	
Blank	0.000	0.000	0.000	
Standard 1	8.00	8.00	-----e	
Standard 2	24.0	24.0	-----e	
Standard 3	48.0	48.0	48.0	
Standard 4	100	100	100	
Standard 5	240	240	240	
Standard 6	480	480	480	
Standard 7	1000	1000	1000	
standard tcl 1-18	1328x	1291x	1305x	
nrt tc 1-18	1266x	1222x	1232x	
032 tc 1-18	1301x	1261x	1231x	
coal creek tc 1-18	1289x	1249x	1211x	
ae tc 1-18	1274x	1228x	1176x	
0357 tc 1-18	1301x	1261x	1180x	
nrt s 2-7	10.6	10.5	-10.2uv	
ae s 2-7	3.96	3.94	-23.1uv	
standard s 2-7	1.34	1.39	-22.0uv	
0357 s 2-7	45.1	44.9	10.2	
ccv	227	229	169	
032 s 2-7	13.6	13.2	-15.3uv	
0357 s 1-7	52.3	52.0	14.1	
ae s 1-7	4.04	3.90	-28.8uv	
032 s 1-7	13.1	13.0	-20.9uv	
nrt s 1-7	10.1	9.92	-25.1uv	
coal creek s 2-18	16.5	15.9	-17.9uv	
032 s 2-18	14.3	14.1	-26.4uv	
ae s 2-18	3.81	3.75	-33.4uv	
standard s 2-18	1.84	1.51	-37.9uv	
0357 s 2-18	17.8	17.9	-25.9uv	
ccv	220	222	110	
nrt s 2-18	7.13	7.30	-50.2uv	
coal creek s 2-7	14.8	14.6	-38.1uv	
coal creek 1-7	14.9	14.9	-43.3uv	
standard s 1-7	1.19	0.825	-46.8uv	
coal creek s 1-18	15.1	15.1	-45.4uv	
032 s 1-18	13.7	14.0	-47.4uv	
0357 s 1-18	22.1	22.0	-35.0uv	
nrt s 1-18	7.01	7.28	-52.2uv	
ae s 1-18	3.86	4.05	-53.9uv	
standard s 1-18	2.12	1.81	-58.0uv	
ccv	219	220	91.0	

standard t 2-7	25.0	23.0	38.0
coal creek t 2-18	662	651	606
ae t 2-18	723	739	666
nrt t 2-18	43989	44431	41254
standard t 1-7	42.9	34.2	41.8
nrt t 1-7	25124	25290	23143
ae t 1-7	2026	2074	1837
0357 t 1-7	2287	2335	2074
1g s4	3417	3516	3350
1g s3	6859	7427	6411
ccv	17323	17883	15933
1g s2	3431	3574	3385
1g s1	1715	1753	1561
1g 30	1376	1425	1265
1g 5	1610	1652	1462

Sample Label	**Ca 183.944**	**Ca 210.324**	**Ca 211.276**	**Ca**
	mg/L	**mg/L**	**mg/L**	
Blank	-----e	0.000e	0.000	
Standard 1	10.0e	10.0	10.0	
Standard 2	30.0	30.0	30.0	
Standard 3	-----e	-----e	-----e	
Standard 4	125	125	125	
Standard 5	300	300	300	
Standard 6	600e	600	600	
Standard 7	1250e	1250	1250	
standard tcl 1-18	2.56c	2.37	2.42	
nrt tc 1-18	669c	663	662	
032 tc 1-18	591c	581	578	
coal creek tc 1-18	836c	871	866	
ae tc 1-18	176c	166	171	
0357 tc 1-18	653c	637	636	
nrt s 2-7	208c	202	208	
ae s 2-7	56.3c	53.9	54.1	
standard s 2-7	0.337c	0.305	0.324	
0357 s 2-7	335c	326	331	
ccv	298c	284	291	
032 s 2-7	205c	197	203	
0357 s 1-7	251c	241	244	
ae s 1-7	56.4c	53.5	53.6	
032 s 1-7	79.1c	74.2	74.5	
nrt s 1-7	208c	198	204	
coal creek s 2-18	260c	247	251	
032 s 2-18	185c	175	180	
ae s 2-18	57.1c	53.7	54.9	

coal creek s 2-7	257c	240	247
coal creek 1-7	251c	234	241
standard s 1-7	0.557c	0.509	0.516
coal creek s 1-18	260c	241	250
032 s 1-18	163c	150	157
0357 s 1-18	186c	170	177
nrt s 1-18	168c	154	161
ae s 1-18	53.3c	48.4	49.9
standard s 1-18	0.517c	0.460	0.485
ccv	298c	269	278
standard t 2-18	0.731c	0.601	0.658
032 t 2-18	557c	503	524
0357 t 2-18	593c	535	550
032 t 1-7	681c	648	660
coal creek t 1-7	817c	779	789
0357 t 2-7	523c	466	489
nrt t 2-7	586c	523	544
coal creek t 2-7	800c	755	765
032 t 2-7	669c	622	639
ae t 2-7	183c	158	166
ccv	300c	262	275
standard t 2-7	2.78c	2.32	2.44
coal creek t 2-18	773c	721	737
ae t 2-18	166c	142	150
nrt t 2-18	627c	549	568
standard t 1-7	2.06c	1.69	1.78
nrt t 1-7	577c	501	528
ae t 1-7	197c	167	177
0357 t 1-7	641c	557	574
lg s4	20.9c	17.8	18.8
lg s3	23.6c	20.1	21.2
ccv	305c	261	270
lg s2	26.4c	21.9	23.4
lg s1	39.3c	33.3	35.3
lg 30	42.2c	35.3	37.7
lg 5	32.5c	27.0	28.6

Sample Label	**Cr 205.560**	**Cr 267.716**	**Cs 459.311**
	ppb	**ppb**	**mg/L**
Blank	0.000	0.000	0.000
Standard 1	-----e	8.00	
Standard 2	24.0e	-----e	
Standard 3	-----e	-----e	
Standard 4	100	100	
Standard 5	240	240	

032 tc 1-18	108	106	0.000c
coal creek tc 1-18	377	362	0.000c
ae tc 1-18	102	97.7	0.000c
0357 tc 1-18	41.3	40.3	0.000c
nrt s 2-7	24.7	23.3	0.000c
ae s 2-7	133	123	0.000c
standard s 2-7	0.098uv	-0.074uv	0.000c
0357 s 2-7	0.360	0.505	0.000c
ccv	232	216	0.000c
032 s 2-7	5.03	4.44	0.000c
0357 s 1-7	0.589uv	0.409uv	0.000c
ae s 1-7	131	119	0.000c
032 s 1-7	9.29	7.92	0.000c
nrt s 1-7	33.0	31.4	0.000c
coal creek s 2-18	196	176	0.000c
032 s 2-18	13.3	12.2	0.000c
ae s 2-18	121	108	0.000c
standard s 2-18	-0.333uv	-0.915uv	0.000c
0357 s 2-18	27.0	23.2	0.000c
ccv	229	201	0.000c
nrt s 2-18	92.3	80.6	0.000c
coal creek s 2-7	235	203	0.000c
coal creek 1-7	250	217	0.000c
standard s 1-7	-0.048uv	-1.22uv	0.000c
coal creek s 1-18	207	178	0.000c
032 s 1-18	14.2	11.6	0.000c
0357 s 1-18	0.932	1.03	0.000c
nrt s 1-18	103	86.4	0.000c
ae s 1-18	113	95.9	0.000c
standard s 1-18	-0.461uv	-0.884uv	0.000c
ccv	227	190	0.000c
standard t 2-18	0.666	0.885	0.000c
032 t 2-18	118	97.4	0.000c
0357 t 2-18	59.6	48.7	0.000c
032 t 1-7	2.29	2.48	0.000c
coal creek t 1-7	456	370	0.000c
0357 t 2-7	0.142uv	0.479uv	0.000c
nrt t 2-7	17.4	16.1	0.000c
coal creek t 2-7	421	336	0.000c
032 t 2-7	4.74	4.94	0.000c
ae t 2-7	97.2	77.4	0.000c
ccv	226	179	0.000c
standard t 2-7	0.655	1.63	0.000c
coal creek t 2-18	327	256	0.000c
ae t 2-18	113	88.4	0.000c

0357 t 1-7	15.6	13.7	0.000c
1g s4	320	246	0.000c
1g s3	460	353	0.000c
ccv	225	170	0.000c
1g s2	457	343	0.000c
1g s1	76.7	58.5	0.000c
1g 30	80.4	60.2	0.000c
1g 5	61.0	46.3	0.000c

Sample Label	**Cu 324.754**	**Cu 327.395**	**Fe 238.204**
	ppb	**ppb**	**ppb**
Blank	0.000	0.000	0.000
Standard 1	8.00e	8.00	800
Standard 2	24.0e	24.0	2400
Standard 3	-----e	-----e	4800
Standard 4	100e	100e	10000
Standard 5	240e	240	24000
Standard 6	480	480	48000
Standard 7	-----e	-----e	-----e
standard tcl 1-18	2.28	-2.56uv	12.1
nrt tc 1-18	-2.63uv	-1.99uv	0.244
032 tc 1-18	-1.88uv	-2.97uv	2.73
coal creek tc 1-18	-2.74uv	-2.83uv	0.847
ae tc 1-18	58.9	48.1	15.1
0357 tc 1-18	-2.88uv	-1.80uv	2.43
nrt s 2-7	0.711uv	-0.983uv	2.41
ae s 2-7	1.60	-0.420uv	1.53
standard s 2-7	2.73	-0.548uv	0.355uv
0357 s 2-7	0.181uv	-1.05uv	-0.086uv
ccv	210	207	21735
032 s 2-7	0.262	-0.838uv	2.58
0357 s 1-7	1.62	-0.871uv	0.896
ae s 1-7	1.13	-0.249uv	1.24
032 s 1-7	1.87	-0.944uv	3.23
nrt s 1-7	0.945	-0.217uv	1.04
coal creek s 2-18	-0.027uv	-1.31uv	1.14
032 s 2-18	1.22	-1.08uv	0.621
ae s 2-18	2.58	-0.716uv	0.063uv
standard s 2-18	3.50	-0.159uv	0.016uv
0357 s 2-18	2.10	-0.649uv	2.00
ccv	188	182	20393
nrt s 2-18	2.57	-1.17uv	4.42
coal creek s 2-7	1.46	-1.14uv	0.698
coal creek 1-7	2.03	-1.00uv	0.341uv
standard s 1-7	4.28	-0.375uv	0.460

ae s 1-18	3.10	-1.17uv	0.787
standard s 1-18	5.17	-0.237uv	0.207uv
ccv	181	170	19867
standard t 2-18	6.98	-2.57uv	5.75
032 t 2-18	0.398uv	-0.728uv	2.45
0357 t 2-18	1.02uv	-2.17uv	0.577
032 t 1-7	2.41	-2.17uv	0.037uv
coal creek t 1-7	0.002uv	-0.547uv	0.547
0357 t 2-7	2.13	-0.753uv	1.01
nrt t 2-7	3.34	-1.42uv	0.913
coal creek t 2-7	1.41	-0.669uv	0.924
032 t 2-7	1.99	-3.76uv	0.881
ae t 2-7	60.8	44.8	31.5
ccv	171	158	18975
standard t 2-7	6.48	-1.40uv	10.4
coal creek t 2-18	-0.106uv	-3.81uv	0.651
ae t 2-18	40.4	25.8	7.44
nrt t 2-18	2.47	-2.92uv	9.42
standard t 1-7	7.17	-0.489uv	7.90
nrt t 1-7	1.63	-0.001uv	3.97
ae t 1-7	65.7	49.5	28.4
0357 t 1-7	3.46	-3.58uv	0.429
lg s4	144	129	8408
lg s3	203	186	12808
ccv	163	144	18404
lg s2	210	191	11441
lg s1	77.9	65.5	2338
lg 30	73.5	61.7	2184
lg 5	62.0	49.6	2062

Sample Label	**K 769.897**	**Mn 257.610**	**Mn 293.931**
	mg/L	**ppb**	**ppb**
Blank	0.000	0.000	0.000
Standard 1		20.0	20.0
Standard 2		60.0	60.0
Standard 3		-----e	120
Standard 4		250	250
Standard 5		600e	600
Standard 6		1200	1200
Standard 7		2500	-----e
standard tcl 1-18	0.000c	0.459	1.55
nrt tc 1-18	0.000c	-0.171uv	-0.351uv
032 tc 1-18	0.000c	-0.272uv	0.779
coal creek tc 1-18	0.000c	-0.355uv	4.09

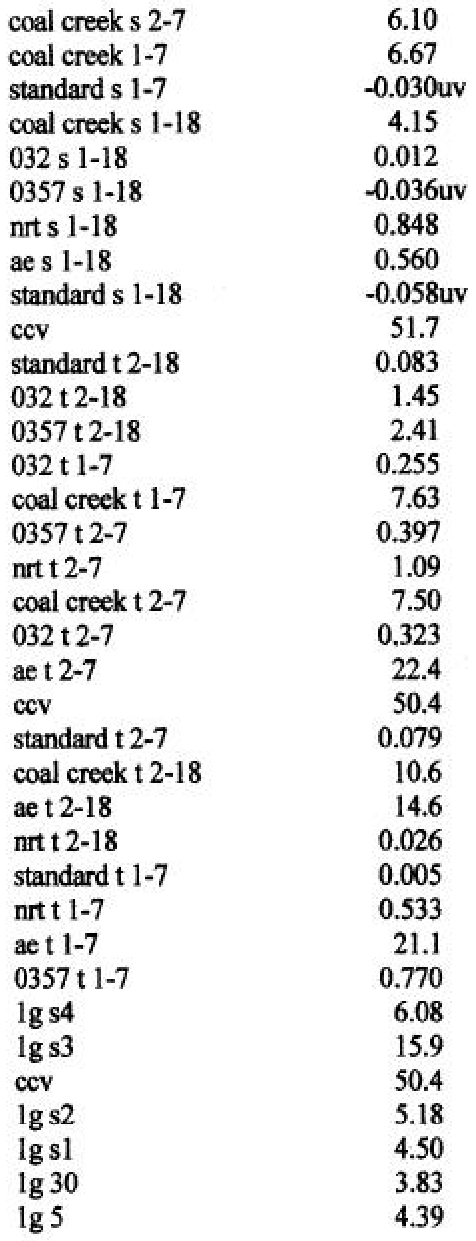
0357 s 2-7	0.000c	-0.129uv	-0.211uv
ccv	0.000c	531	522
032 s 2-7	0.000c	-0.142uv	-0.714uv
0357 s 1-7	0.000c	0.037uv	-0.354uv
ae s 1-7	0.000c	-0.443uv	0.575
032 s 1-7	0.000c	-0.234uv	-0.655uv
nrt s 1-7	0.000c	0.076uv	-0.642uv
coal creek s 2-18	0.000c	-0.396uv	3.09
032 s 2-18	0.000c	-0.440uv	-0.970uv
ae s 2-18	0.000c	-0.058uv	-0.226uv
standard s 2-18	0.000c	-0.215uv	0.450
0357 s 2-18	0.000c	-0.165uv	-0.153uv
ccv	0.000c	469	460
nrt s 2-18	0.000c	-0.154uv	-0.614uv
coal creek s 2-7	0.000c	-0.283uv	3.61
coal creek 1-7	0.000c	-0.438uv	4.79
standard s 1-7	0.000c	-0.192uv	0.630
coal creek s 1-18	0.000c	-0.386uv	3.10
032 s 1-18	0.000c	-0.466uv	0.771
0357 s 1-18	0.000c	-0.420uv	-0.318uv
nrt s 1-18	0.000c	-0.183uv	-0.137uv
ae s 1-18	0.000c	-0.372uv	0.406
standard s 1-18	0.000c	-0.238uv	0.410uv
ccv	0.000c	449	434
standard t 2-18	0.000c	0.070	0.624
032 t 2-18	0.000c	-0.406uv	-0.353uv
0357 t 2-18	0.000c	-0.445uv	0.630uv
032 t 1-7	0.000c	-0.291uv	-0.318uv
coal creek t 1-7	0.000c	-0.422uv	6.00
0357 t 2-7	0.000c	-0.298uv	-0.425uv
nrt t 2-7	0.000c	-0.276uv	0.169uv
coal creek t 2-7	0.000c	-0.413uv	3.57
032 t 2-7	0.000c	-0.334uv	-0.603uv
ae t 2-7	0.000c	338	305
ccv	0.000c	412	402
standard t 2-7	0.000c	0.098	1.52
coal creek t 2-18	0.000c	-0.380uv	5.16
ae t 2-18	0.000c	243	217
nrt t 2-18	0.000c	-0.095uv	-0.562uv
standard t 1-7	0.000c	0.031uv	0.412uv
nrt t 1-7	0.000c	-0.126uv	-0.455uv
ae t 1-7	0.000c	319	287
0357 t 1-7	0.000c	-0.257uv	1.15
lg s4	0.000c	114	100.0
lg s3	0.000c	158	144

Standard 3	-----e	19200	-----e
Standard 4	100e	40000	250e
Standard 5	240e	96000	600
Standard 6	480	192000	1200
Standard 7	-----e	400000	2500
standard tcl 1-18	66.2	20.4uv	1.08uv
nrt tc 1-18	81.6	114	34.8
032 tc 1-18	83.4	11499	52.2
coal creek tc 1-18	71.8	204283	270
ae tc 1-18	89.2	52158	114
0357 tc 1-18	75.1	83666	227
nrt s 2-7	0.657	2035	28.7
ae s 2-7	-5.02uv	35458	277
standard s 2-7	0.745uv	363	-17.3uv
0357 s 2-7	20.5	-21.8uv	9.97
ccv	210	93497	576
032 s 2-7	-3.05uv	73.7	19.1
0357 s 1-7	21.0	35.1	-6.20uv
ae s 1-7	-3.95uv	34759	256
032 s 1-7	18.8	159	-0.326uv
nrt s 1-7	-0.978uv	2089	29.2
coal creek s 2-18	2.00uv	72755	90.2
032 s 2-18	0.232uv	481	12.5
ae s 2-18	-3.98uv	35502	149
standard s 2-18	-3.39uv	360	-18.0uv
0357 s 2-18	19.5	4181	16.8
ccv	205	93115	571
nrt s 2-18	19.1	9209	26.8
coal creek s 2-7	2.94	49080	53.8
coal creek 1-7	4.15	43269	52.1
standard s 1-7	-7.28uv	402	-3.85uv
coal creek s 1-18	8.23	68579	75.3
032 s 1-18	25.6	573	13.3
0357 s 1-18	-2.19uv	248	10.2uv
nrt s 1-18	7.03	10957	19.5
ae s 1-18	-1.51uv	33075	214
standard s 1-18	-3.83uv	426	-7.27uv
ccv	193	95037	559
standard t 2-18	62.3	-34.0uv	3.02uv
032 t 2-18	66.0	16059	38.1
0357 t 2-18	63.1	97872	272
032 t 1-7	90.4	38.2	49.0
coal creek t 1-7	71.7	189554	122
0357 t 2-7	90.6	259	29.6
nrt t 2-7	104	961	33.5

standard t 2-7	56.4	71.3	-13.4uv
coal creek t 2-18	73.7	190440	264
ae t 2-18	63.7	49823	111
nrt t 2-18	69.6	789	39.9
standard t 1-7	53.0	-9.36uv	-9.95uv
nrt t 1-7	59.3	1594	31.0
ae t 1-7	64.1	54076	94.8
0357 t 1-7	95.3	485	30.7
1g s4	272	921	3.61uv
1g s3	487	1610	5.29
ccv	179	95901	575
1g s2	447	3813	-7.11uv
1g s1	45.4	31301	6.06uv
1g 30	40.8	30821	19.5
1g 5	36.4	29770	10.9uv

Sample Label	**Si 251.611**
	mg/L
Blank	0.000e
Standard 1	-----e
Standard 2	-----e
Standard 3	-----e
Standard 4	-----e
Standard 5	60.0
Standard 6	120
Standard 7	250
standard tcl 1-18	0.504
nrt tc 1-18	0.128
032 tc 1-18	1.56
coal creek tc 1-18	7.25
ae tc 1-18	16.7
0357 tc 1-18	2.47
nrt s 2-7	0.443
ae s 2-7	0.787
standard s 2-7	-0.019uv
0357 s 2-7	0.162
ccv	55.5
032 s 2-7	0.290
0357 s 1-7	0.281
ae s 1-7	0.792
032 s 1-7	0.102
nrt s 1-7	0.405
coal creek s 2-18	3.22
032 s 2-18	0.076
ae s 2-18	0.148

coal creek s 2-18	15.9c	0.000c	0.260
032 s 2-18	13.8c	0.000c	-0.511uv
ae s 2-18	3.36c	0.000c	0.478
standard s 2-18	1.27c	0.000c	1.61uv
0357 s 2-18	16.5c	0.000c	0.125uv
ccv	168c	0.000c	221
nrt s 2-18	6.33c	0.000c	0.380uv
coal creek s 2-7	13.3c	0.000c	1.29uv
coal creek 1-7	13.4c	0.000c	-0.488uv
standard s 1-7	0.782c	0.000c	1.40
coal creek s 1-18	13.3c	0.000c	0.221uv
032 s 1-18	12.1c	0.000c	0.017uv
0357 s 1-18	19.9c	0.000c	-0.513uv
nrt s 1-18	5.90c	0.000c	0.374uv
ae s 1-18	3.05c	0.000c	0.769
standard s 1-18	1.44c	0.000c	2.29
ccv	155c	0.000c	215
standard t 2-18	684c	0.000c	1.31
032 t 2-18	640c	0.000c	0.025uv
0357 t 2-18	680c	0.000c	-0.201uv
032 t 1-7	663c	0.000c	2.77
coal creek t 1-7	647c	0.000c	-0.351uv
0357 t 2-7	641c	0.000c	3.38
nrt t 2-7	616c	0.000c	4.85
coal creek t 2-7	597c	0.000c	1.04uv
032 t 2-7	561c	0.000c	2.06
ae t 2-7	568c	0.000c	69.7
ccv	138c	0.000c	208
standard t 2-7	580c	0.000c	1.15
coal creek t 2-18	527c	0.000c	0.643
ae t 2-18	541c	0.000c	49.6
nrt t 2-18	496c	0.000c	1.99
standard t 1-7	489c	0.000c	1.21uv
nrt t 1-7	537c	0.000c	0.865
ae t 1-7	493c	0.000c	72.3
0357 t 1-7	488c	0.000c	3.85
lg s4	0.151c	0.000c	30.4
lg s3	0.152c	0.000c	40.5
ccv	124c	0.000c	203
lg s2	0.337c	0.000c	42.5
lg s1	2.47c	0.000c	17.8
lg 30	2.43c	0.000c	19.1
lg 5	2.31c	0.000c	14.4



coal creek s 2-7	6.10
coal creek 1-7	6.67
standard s 1-7	-0.030uv
coal creek s 1-18	4.15
032 s 1-18	0.012
0357 s 1-18	-0.036uv
nrt s 1-18	0.848
ae s 1-18	0.560
standard s 1-18	-0.058uv
ccv	51.7
standard t 2-18	0.083
032 t 2-18	1.45
0357 t 2-18	2.41
032 t 1-7	0.255
coal creek t 1-7	7.63
0357 t 2-7	0.397
nrt t 2-7	1.09
coal creek t 2-7	7.50
032 t 2-7	0.323
ae t 2-7	22.4
ccv	50.4
standard t 2-7	0.079
coal creek t 2-18	10.6
ae t 2-18	14.6
nrt t 2-18	0.026
standard t 1-7	0.005
nrt t 1-7	0.533
ae t 1-7	21.1
0357 t 1-7	0.770
1g s4	6.08
1g s3	15.9
ccv	50.4
1g s2	5.18
1g s1	4.50
1g 30	3.83
1g 5	4.39