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Sampling of Power Plant Stacks for Air Toxic Emissions: Final Report for Phases I and II

Contract No. DE-AC22-92PC90367

Prepared for:

U.S. Department of Energy
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April 28, 1995

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EXECUTIVE SUMMARY

1.0 Introduction

Under contract with the U.S. Department of Energy (DE-AC22-92PC90367), Pittsburgh Energy Technology Center, Radian Corporation has conducted a test program to collect and analyze size-fractionated stack gas particulate samples for selected inorganic hazardous air pollutants (HAPs). Specific goals of the program are 1) the collection of one-gram quantities of size-fractionated stack gas particulate matter for bulk (total) and surface chemical characterization, and 2) the determination of the relationship between particle size, bulk and surface (leachable) composition, and unit load.

The information obtained from this program identifies the effects of unit load, particle size, and wet FGD system operation on the relative toxicological effects of exposure to particulate emissions.

2.0 Schedule

Field testing was conducted in two phases. The Phase I field program was performed over the period of August 24 through September 20, 1992, at the Tennessee Valley Authority Widows Creek Unit 8 Power Station, located near Stevenson (Jackson County), Alabama, on the Tennessee River. Sampling activities for Phase II were conducted from September 11 through October 14, 1993. Widows Creek Unit 8 is a 575-megawatt plant that uses bituminous coal averaging 3.7% sulfur and 13% ash. Downstream of the boiler, a venturi wet scrubbing system is used for control of both sulfur dioxide and particulate emissions. There is no electrostatic precipitator (ESP) in this system. This system is atypical and represents only about 5% of the U.S. utility industry. However, this site was chosen for this study because of the lack of information available for this particulate emission control system.

3.0 Test Approach

In preparation for Phase I of this test program, an evaluation of various sample preparation and analytical techniques was performed. Several leaching agents were tested on standard reference fly ash samples to determine the relative leachability and availability of surface metals under conditions similar to those encountered in biological and ecological systems. Among the leaching agents tested were nitric acid, a simulated gastric fluid (primarily HCl), an acetic acid buffer solution, a simulated lung fluid, and a chelating agent. Tests were also conducted to determine the bulk, or total, composition of the fly ash for comparison. Instrumental neutron activation was selected as the primary technique for measuring the total trace element concentration.

The nitric acid digestion, gastric fluid leach, and acetic acid leach were the three surface characterization techniques chosen based on their performance criteria in Phase I. The three leaching methods provided minimal interferences and appeared to solubilize those metals at or near the surface of the particle, based on progressively lower concentrations of metals being leached from the ash material under progressively weaker leaching agents and conditions. The ICP-MS analytical technique was used to provide the lower detection limits and improved precision required to quantify the low levels of metals leached under these three conditions. The conventional ICP-AES and GFAAS techniques did not provide adequate sensitivity for these leachate samples.

The relevance of the three techniques to biological and ecological systems and their similarity to existing EPA protocols further supports the selection of these surface characterization techniques. The gastric fluid technique provides data estimating the availability of toxic metals to the body through ingestion and dissolution of fly ash by stomach acids. The buffered acetic acid approach provides a comparative test for evaluating the relative availability of toxic metals by a standard leachability procedure (i.e., the fluid is similar to that used in the TCLP test). By comparing the relative availability of elements determined by each leaching technique to the bulk composition, a more appropriate indication of the health risks associated with stack gas particulate emissions may be developed.

4.0 Results

During Phase I of this project, flue gas particulate samples were collected and fractionated into six aerodynamic size ranges using a series of five cyclone separators and a high-efficiency electrostatic precipitator. The six particle size fractions were >6.3 µm, 6.3-2.7 µm, 2.7-1.7 µm, 1.7-0.8 µm, 0.8-0.5 µm, and <0.5 µm. Particulate material collected over eight sampling runs was composited to produce a single sample (~1 gram total) in each size range. Where sufficient material was available, each composite sample was prepared and analyzed in triplicate for total and extractable trace element concentration. A statistical basis for comparing chemical composition as a function of particle size was obtained. Due to the variations in unit load and the relatively small amount of particulate collected during each sampling run, sufficient sample material reflecting a high- or low-load condition could not be obtained for characterization.

Source dilution sampling was also attempted during Phase I, however difficulties encountered as a result of the high humidity of the ambient dilution air and the high backpressure across the sample filters prohibited collection of adequate sample material.

Phase I results showed high concentrations of chromium, nickel, manganese, and cobalt in the samples from the two large particle size fractions. This suggested contamination from the cyclone sampling system or entrainment of process-duct corrosion products. High levels of arsenic, selenium, vanadium, and barium were also measured with element enrichments over 10 times the coal-ash concentrations observed for all of the target species. Samples of the FGD liquor were analyzed to determine if scrubber carryover could account for the high concentrations, but the results do not explain the enrichment of the particulate emissions. Extractable concentrations were proportional to the total concentration measured for each element and to the acidic strength of the leaching agent.

Results from Phase I led to numerous modifications to the test approach for Phase II. A statistical comparison of element concentration by particle sizes collected during Phase I revealed insignificant differences for most of the trace elements between adjacent size ranges. Based on these results, the Phase II approach was modified to provide particulate samples in three size fractions rather than six. The size fractions collected were >6.4 μm, 6.4-0.8 μm, and <0.8 μm.

In order to satisfy the project objective to determine the effects of unit load on concentration and particle size, two separate cyclone sampling systems were used in Phase II to permit isolated sample collection during both high- and low-load operating periods. The cyclones in both systems were also Teflon® coated to reduce the potential for contamination from the sampling system metallurgy. The division between the high- and low-load conditions was established at 375 MW after reviewing the load profiles from the Phase I testing. In Phase II, the average unit load during high- and low-load sample collection was 483 MW and 323 MW, respectively.

Additional process samples were collected during Phase II to assist in the interpretation and assessment of the data. Cascade impactor samples were collected at the stack during high- and low-load operation to define the particle size distribution within each of the three broad size fractions collected by the cyclone sampling system. Size-fractionated particulate samples were also collected from the economizer outlet (inlet to the FGD system) for comparison with the stack gas particulate, and composite samples of the FGD liquor and feed coal were collected to characterize sources of particulate emissions material.

In addition to these modifications in the sampling approach, the Widows Creek unit also experienced some changes. Prior to the Phase II testing, all of the ductwork into and out of the FGD system was replaced.

In spite of the numerous changes between test phases, Phase II results are similar to Phase I. Consistent with the hypothesis that volatile elements preferentially condense on smaller ash particles, the results from both test phases exhibit increasing trace element concentrations with decreasing particle size.

The particle-size distribution samples collected with the cascade impactor revealed a very narrow range of particles dominating the material in size fractions collected by the cyclone system. In the second size fraction (6.4-0.8 μm) the predominant particle size was <1.0 μm and in the <0.8 μm fraction, particle sizes were predominantly between 0.8 and 0.3 μm. Particle sizes in the >6.4 μm fraction appeared relatively even in distribution. The chemical characteristics of each broad sample size range are representative of the particle sizes actually collected and do not necessarily reflect the chemistry of an even distribution of particles across the entire size range.

Some of the more volatile elements become concentrated in the smaller particle sizes, and these smaller fractions (1-2 μm) generally represent the majority of the mass distribution in the stack emissions. Duplicated in Phase II in both high- and low-load samples were high enrichment factors apparent in Phase I. One explanation is that volatile trace elements may condense on a narrow particle-size range not effectively removed by the venturi scrubber. Two examples of trace element association with a specific and narrow particle size range are observed for cadmium and lead. In Phases I and II, nearly all of the cadmium and lead emissions were associated with the 1.7-0.8 μm fraction. From the data available, it could not be determined whether other trace elements exhibit a similar affinity for a specific particle size.

Unit load did not significantly affect the chemical characteristics of each particle size range; however, the particle removal efficiency of the FGD system was affected. Slight changes in the particle size distribution associated with each sample fraction produced some small changes in chemical composition. This was most evident in the large size fraction where greater penetration was observed during low-load operation. Changes in chemical composition were not observed in the two smaller size fractions; however, the greater predominance of fine particles penetrating the FGD system during high-load operation resulted in higher extractable concentrations for those sample fractions.

Extractable concentrations as a function of particle size were proportional to the total element concentration and to the relative strength of the leaching fluid. Compared to the fly ash material entering the FGD system, particulate emissions had higher relative extractable concentrations. Again, this was attributed to the selective removal of larger particles from each sample fraction and the effective increase in the surface area to mass ratio of the emitted particulate samples.

The potential toxicological effects due to inhalation and ingestion of these particles may increase slightly under high-load operating conditions. This is predominantly due to the slight increase in the gastric-fluid extractable percentage of trace elements associated with the respirable size fractions generated at high-load. Of all the particles collected in the >6.4 μm and 6.4-0.8 μm fractions, 88% and 67%, respectively are deposited in the nasopharyngeal and tracheobronchial region of the respiratory tract where the mucous lining is eventually expectorated or swallowed. Only about 16% of the particles in the smallest size fraction (<0.8 μm) are trapped in this part of the upper respiratory tract. Particles expected to reach the alveolar region of the lungs account for 10% to 20% of the smallest size fraction while the remaining percentages are exhaled.

It is difficult to extrapolate this data to emissions from ESPs. In several instances, it appears the FGD system has changed the chemical characteristics of the particulate. Determining the mechanism for how this occurs is beyond the scope of this study.

5.0 Recommendations

Emissions from other boiler types and emission control devices (specifically ESPs) should be studied as a function of multiple, narrower particle size ranges. Based on the high enrichment factors and the associations of selected trace elements (i.e., cadmium) on specific particle sizes, the question is raised whether the primary distribution of volatile trace elements are confined to a narrow particle size range. The objective should be collection of data enabling development of a correlation between particle size and trace element concentration.

If volatile trace elements are predominantly found in a narrow range of particle sizes, then the inorganic HAP emissions from various control devices may be predicted from the emitted particle size distributions and removal efficiencies. More importantly, process and operational changes may be possible to enhance the performance of control devices and increase removal of specific particle sizes. New technologies aimed at reducing emissions in the targeted size ranges may also be developed.

In addition, the emissions from various systems could be modeled using the extractable rather than total concentration data. Whether the apparent reduction in available trace element concentration affects the assessment of potential health risks remains to be seen.

Development of a standard leachability approach should also be considered for application to air-borne particulates from all sources. A standardized approach for determining bioavailability can be used to generate comparable data for various sources and potentially identify the source(s) of greatest impact on health effects.

1.0 INTRODUCTION

The Clean Air Act Amendments of 1990 (CAAA)[1] require that emissions of hazardous air pollutants (HAPs) from coal-fired power plants be evaluated for potential health risks. The 189 hazardous substances listed in the CAAA include numerous inorganic and organic species that are volatile under the conditions present in the boiler and entering flue gas emission control systems at coal-fired power plants. As the flue gas cools, it is hypothesized that many of these substances condense on the surface of the fine particulate matter that is often not removed by the control device.

Stack gas particulate emissions in the respirable size range of less than 10 microns are of particular interest in assessing health risks. The environmental and toxicological impacts resulting from these emissions are typically estimated on a "worst case" basis where the total composition of the emitted particulates is considered available to biological and ecological systems. More appropriately, the leachability of these toxic substances and their availability relative to the total composition should be considered when determining the health risks associated with particulate-borne HAPs.

Under contract with the U.S. Department of Energy (DE-AC22-92PC90367), Pittsburgh Energy Technology Center, Radian Corporation has conducted a test program to collect and analyze size-fractionated stack gas particulate samples for selected inorganic HAPs. Specific goals of the program are 1) the collection of one-gram quantities of size-fractionated stack gas particulate matter for bulk (total) and surface chemical characterization, and 2) the determination of the relationship between particle size, bulk and surface (leachable) composition, and unit load.

The primary objective of the field portion of this test program was to collect sufficient particulate matter from the stack effluent of a wet scrubber system for physical and chemical analysis. These samples, collected as a function of particle size, were characterized for both bulk and surface chemical composition. One-gram quantities were required so that multiple analyses could each be performed in triplicate enabling a statistical comparison of the data. Samples were collected during two different sampling periods, each period designed to represent two turbine load conditions.

The information obtained from this program identifies the effects of unit load, particle size, and wet FGD system operation on the environmental and bioavailability, and relative toxicological effects of exposure to particulate emissions. It may ultimately be used to provide insight into some questions relating to air toxics from coal fired power plants. For example:

- Is the total mass of certain emitted substances from a coal-fired power plant an appropriate basis for determining health risk?

- Are certain metals more or less bioavailable due to the particle size with which they are associated?
- Are certain metals more or less toxic due to their bioavailability?
- Is the distribution or availability of these metals affected by operating conditions of the power plant (i.e., changes due to load)?

The sample analyses that were performed in this test program were designed to answer these questions.

The program was conducted with three primary tasks:

- Analytical methods evaluation and selection;
- Field testing; and
- Data and toxicological assessment.

The analytical methods evaluation was performed first and the results have been presented at both AWMA and DOE sponsored conferences.[2] The results of this task are presented in Section 2.

The field testing was conducted in two phases. The Phase I field program was performed over the period of August 24 through September 20, 1992, at the Tennessee Valley Authority Widows Creek Unit 8 Power Station, located near Stevenson (Jackson County), Alabama, on the Tennessee River. Sampling activities for Phase II were conducted from September 11 through October 14, 1993. Widows Creek Unit 8 is a 575-megawatt plant that uses bituminous coal averaging 3.7% sulfur and 13% ash. Downstream of the boiler, a venturi wet scrubbing system is used for control of both sulfur dioxide and particulate emissions. There is no electrostatic precipitator (ESP) in this system.

During Phase I, in addition to collecting samples directly from the stack, particulate matter was collected using a source sampling dilution system to simulate the effects of dilution, cooling, and condensation in the ambient atmosphere. Dilution sampling was performed by Omni Environmental, Inc., under subcontract to Radian. During Phase II, samples were collected from the economizer outlet (inlet to the FGD system) as well in order to better characterize the system.

Based upon findings and experiences from the Phase I testing, several changes were made to the technical approach for Phase II. Consequently, all of the toxicological assessment and most of the data analysis has been limited to the Phase II results, as these samples more closely represent the overall program objectives.

This document has been formatted as follows. Rationale and procedures for the sample preparation and analytical methods selection are presented in Section 2. Details of test Phase I and test Phase II are presented in Sections 3 and 4, respectively. A discussion of the test results are presented in Section 5, and the toxicological evaluation is presented in Section 6.

1.1 References

1. Clean Air Act Amendments of 1990. PL 101-549, November 15, 1990.

2. Maxwell, David P., H. Benjamin Cox, and Hollis B. Flora. "Evaluation of Test Procedures to Determine Bulk and Surface Composition of Selected Metals on Fly Ash Particles," presented at the Air & Waste Management Association, 86th Annual Meeting & Exhibition. Air & Waste Management Association, Pittsburgh, PA, 1993.

2.0 ANALYTICAL TEST METHODS EVALUATION

The condensed metal species found predominantly on the surface of fly ash particles are more accessible to the environment than those species trapped within the alumina-silica matrix. However, one of the difficulties in characterizing these condensed or adsorbed species is that there are presently no standard, certified methods for determining the leachability of metals from the surface of micron-sized particles. In preparation for Phase 1 of this test program, an evaluation of various sample preparation and analysis techniques was performed. Several leaching agents were tested on standard reference fly ash samples to determine the relative leachability and availability of surface metals under conditions similar to those encountered in biological and ecological systems. Tests were also conducted to determine the bulk, or total, composition of the fly ash for comparison.

This section presents the analytical results of these tests and is the basis for selecting sample preparation and analysis techniques for application to size-fractionated fly ash samples collected at a coal-fired power plant. The bulk composition and the relative surface leachability of selected metals in a standard reference fly ash standard are reported. Selected metals include arsenic, barium, beryllium, cadmium, chromium, copper, cobalt, lead, manganese, mercury, molybdenum, nickel, selenium, and vanadium. These metals were chosen because of their known toxic properties, their presence on the CAAA list of hazardous substances, and their suspected occurrence in flue gas streams from coal-fired utility boilers.

2.1 Experimental

Several leaching and analytical procedures were evaluated to select three techniques for use in this program on size-fractionated fly ash samples collected both from hot stack gas and from cooled stack gas from a dilution sampler. An outline of the test matrix is presented in Figure 2-1. These sample preparation and analysis techniques were selected for their simplicity, their similarity to existing protocols, and their potential for meeting the program's objectives for relating leachability and availability under conditions similar to those encountered in biological and ecological systems. The surface composition was tested using five leaching agents and bulk composition was determined by two separate techniques. The basic criteria used in evaluating and selecting the preparatory and analytical techniques for use in the field test effort were:

- The reproducibility of results;
- The nature and reliability of the information obtained from the procedure (e.g., bulk composition, surface composition, depth profiling, or chemical speciation);

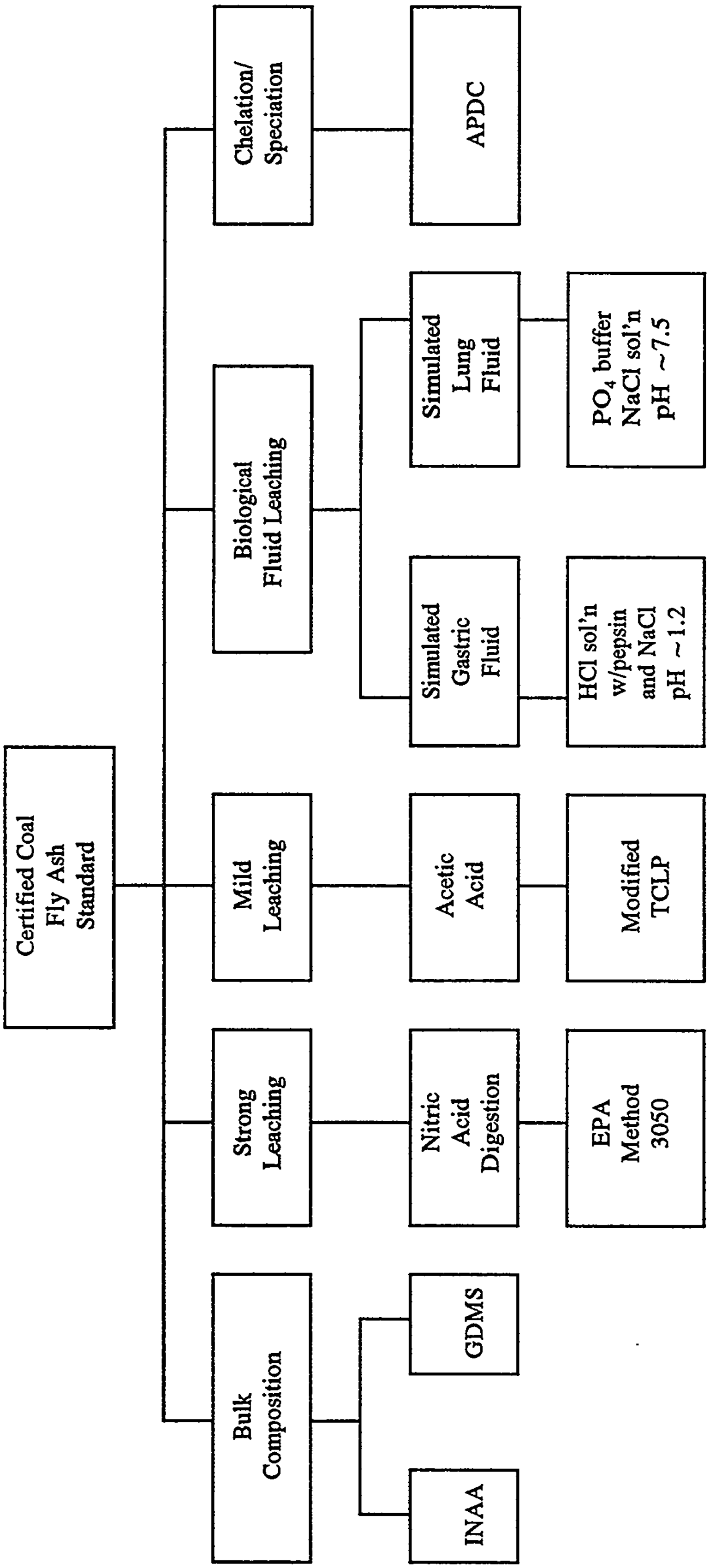

Figure 2-1
Test Methods Evaluation Plan

INAA = Instrumental neutron activation analysis.

GDMS = Glow discharge mass spectrometry.

TCLP = Toxicity characteristic leaching procedure.

APDC = Ammonium pyrrolidine-N-dithiocarbamate.

- Low method detection limits relative to sample size (i.e., sensitivity); and
- Minimal interferences.

To accurately evaluate these methods, a certified standard fly ash was needed. A certified coal fly ash available from Brammer Standard Co. was selected. The fly ash (IRNT 12-1-03) is certified for 29 trace metals (μg/g) and 8 major metals (wt.%), and is sieved instead of ground to produce a homogenous sample of ash particles less than 80 microns in size. This material was preferred over available NIST fly ash standards based on the number of certified metals provided.

2.1.1 Bulk Composition

Bulk composition analysis of the fly ash particles was performed using two different instrumental techniques, neutron activation and glow discharge mass spectrometry. These techniques require no dissolution or digestive preparation procedures prior to analysis. This eliminates the preparatory digestion step and the errors potentially introduced by the additional sample handling and incomplete recovery or volatilization of metals.

Instrumental Neutron Activation Analysis (INAA)

Instrumental neutron activation analysis (INAA)[1] is a nondestructive technique that measures the number and energy of gamma and x-rays emitted by the radioactive isotopes produced in the sample matrix by irradiation with thermal neutrons. The samples require no special preparation except for encapsulation in high-purity linear polyethylene vials prior to irradiation. Both samples and standards of the elements of interest are irradiated in a nuclear reactor. Each sample is then counted on a gamma ray detector to produce its characteristic gamma ray spectrum. Quantitation of elemental concentration is done by comparison with the energy spectra from those standards run simultaneously with the unknown samples. This technique is feasible for very small quantities of ash (100 mg). The method does not introduce any contaminating or interfering substances, and it provides a multi-element analysis. It is not applicable to those elements that either (1) have extremely short half-lives, or (2) do not produce gamma emitting isotopes, such as lead and beryllium.

Glow Discharge Mass Spectrometry (GDMS)

Glow discharge mass spectrometry (GDMS) was selected to supplement the INAA data for determining the bulk composition of the size-fractionated fly ash samples. The sample is mixed with silver powder and pressed into the shape of a pin to serve as a conducting electrode in a low-pressure argon plasma ionization chamber. Sample atoms are sputtered into the plasma and then ionized. The plasma is a constant matrix in which the ionization efficiencies of the elements should remain constant. The ionization efficiencies, expressed as relative sensitivity factors (RSFs), are used to convert ion intensities to elemental concentrations. The preliminary application of this technique to fly ash particles suggests that fly ash matrix standards should be used to determine the RSFs for each target analyte. This technique is targeted for further study to determine its feasibility and the method's sensitivity relative to INAA.

2.1.2 Surface Composition

The primary focus of the methods evaluation plan was to determine methods that could leach or "peel" metals from the surface of a fly ash particle. The five methods studied were chosen on the basis of 1) selectivity for the metals of interest, 2) the method's similarity to chemical or biological processes, or 3) as modifications of an established method. For all five methods, 100 mg of Brammer certified fly ash was treated. For statistical purposes, six fly ash samples were leached, along with six reagent blanks and six reagent blank spikes per method. Each evaluated method consisted of 18 separate leaches. The five methods chosen ranged from a strong, near-complete digestion to progressively weaker leachings, two of which were simulated biological fluids. An organic chelating solution was also chosen to investigate the possibility of speciating metals whose oxidation state determines the toxic severity in solution. These procedures and leaching agents are listed below and are described in order from most to least aggressive.

Nitric Acid Digestion

The strongest, most aggressive sample leaching technique performed on each particulate sample was a nitric acid digestion using EPA Method 3050.[2] Samples, method blanks, and method spikes were digested, filtered through a 0.45 micron nitrocellulose membrane filter, and brought to a 100 mL final volume. This conventional procedure refluxes the sample in concentrated nitric acid and hydrogen peroxide. Metals present on the surface of the particle and those that may be loosely bound in the particle's matrix are digested. This technique does not totally digest the alumina-silica ash matrix and therefore may not account for the entire metal concentration determined by total composition techniques.

Simulated Gastric Fluid Leach

Simulated gastric fluid[3] is a solution of 85 mM hydrochloric acid, the enzyme pepsin, and sodium chloride. The pH of this solution is approximately 1.2. The leachability of metals in this matrix has a toxicological implication since some fly ash particles trapped in the mucous lining of the upper respiratory tract may be swallowed. The dissolution of fly ash in gastric fluid represents a likely ingestion mechanism for toxic metals into the body. Standard fly ash samples were leached at room temperature along with method blanks and matrix spikes. Each sample was placed in a covered beaker with 10 mL of the gastric fluid solution and stirred mechanically for a minimum of 18 hours. Using the same recovery procedure as the nitric acid digestates, the leachate was filtered and brought to a 100 mL final volume with DI water.

Acetic Acid Leach

Another leaching technique uses an acetic acid solution prepared according to the EPA's Toxicity Characteristic Leaching Procedure (TCLP).[4] The TCLP is the regulatory standard procedure used to determine the hazardous nature of solid wastes. The protocol requires leaching of the solid waste in a buffered acetic acid solution that is maintained at a pH of 4.93 throughout the test. The metal concentrations determined in the acetic acid leachate are compared to regulatory standards to determine whether the material is classified as hazardous or non-hazardous.

The TCLP is designed for leaching sample quantities much larger than 100 mg, and to scale down the volumes specified in the method to accommodate the small quantity of particulate sample available was impracticable. Consequently, 100 mg fly ash samples were simply placed in a covered beaker with 10 mL of the buffered acetic acid solution (pH 4.93) and stirred for a minimum of 18 hours. During this time, no additional pH adjustments were made to the acetic acid solution. Sample recovery was performed in the same manner as the gastric fluid leaching. The digestate was filtered and diluted to a 100 mL final volume before analysis.

Simulated Lung Fluid Leach[5]

Simulated lung fluid is a phosphate-bicarbonate saline solution with bovine serum and glucose buffered to a pH of 7. The purpose of leaching fly ash in this matrix is to determine the availability of surface-condensed or adsorbed metals within the lung fluid and mucous lining the respiratory tract. Standard fly ash samples were leached for an 18 hour period, then filtered and diluted to 100 mL with deionized water in a manner similar to the acetic acid and gastric fluid procedures.

Ammonium Pyrrolidine-N-dithiocarbamate (APDC)[6]

This chelating/complexing agent was evaluated for specific elements such as arsenic and chromium, whose differing toxic effects are related to their oxidation state. For this test, ammonium pyrrolidine-N-dithiocarbamate (APDC) was chosen since it selectively chelates specific elements at single oxidation states at various pHs. Standard fly ash samples (100 mg) were placed in 20 mL of a 5% APDC solution adjusted to a pH of 4.4 with acetate buffer. 10 mL of MIBK (methyl isobutyl ketone) was added and stirred for 18 hours. The leachate in the MIBK layer was separated, collected, and evaporated to dryness. The residue was then redissolved in 10 mL of 1:1 nitric acid and diluted to a final volume of 25 mL with deionized water.

2.1.3 Analytical Techniques

Three analytical techniques were used for the analysis of the leachate samples: inductively coupled argon plasma emission spectroscopy, graphite furnace atomic absorption spectrophotometry, and inductively coupled argon plasma mass spectrometry. These techniques were chosen since they are established analytical protocols.

Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES)

This is a conventional technique applicable to the simultaneous or sequential multi-element determination of trace elements in solution. The basis of the method is the measurement of atomic emission by an optical spectroscopic technique using a plasma torch for atomic excitation. This method's sensitivity varies from element to element; however, detection limits ranged from 0.3 ppb for beryllium to 8 ppb for copper. For some elements, greater sensitivity is obtained by atomic absorption techniques. The advantage to running this method is its ability to analyze elements simultaneously.

Graphite Furnace Atomic Absorption Spectroscopy (GFAAS)

This is also a conventional analytical technique. The basis for this method is atomic absorption rather than emission. A light beam from a hollow cathode lamp whose cathode is made of the element to be determined is directed through an atomized sample into a monochrometer and onto a detector that measures the amount of light actually transmitted (then calculated). A graphite furnace evaporates, chars, and atomizes an aqueous sample. The amount of light absorbed by the atomized vapor reduces the intensity of the light at the detector and is proportional to the concentration of the analyte in the sample. Detection limits for lead, arsenic, and selenium range from 3.0 to 5.0 ppb. The increased sensitivity is better than ICP-AES for these and most other elements.

ICP-Mass Spectrometry (ICP-MS)

Related to ICP-AES emission spectroscopy, ICP-MS is a relatively new technique with improved accuracy and sensitivity over conventional ICP-AES and GFAAS. ICP-MS introduces the sample through a nebulizer in the form of an aerosol to the plasma torch. The plasma acts as the ionization source by creating a high number density of positive ions. A portion of the ions is collected and detected by a quadrapole mass spectrometer.

ICP-MS has the advantage of being able to detect elements ranging from lithium to uranium (mass 7 to 238) with quantitation levels of 2.0 to 1000 ng/L. Detection limits for the 14 metals in this evaluation ranged from 2 to 130 ng/L. These detection limits are 10 to 100 times lower than those of ICP-AES or GFAAS. Though the quadrapole mass spectrometer gives mass to mass resolution for individual ions, it does not fully resolve ion pairs formed by oxides or those unique to the plasma torch. Arsenic (mass 74.9), for example, is interfered with by $ArCl^+$ (mass 75.4) that is produced in the argon plasma. Selenium has the same interference problems with Ar_2. The increased sensitivity causes an increased awareness of contamination in the leach or digestion reagents. For this reason six method blanks with deionized water were analyzed to correct for background contaminants.

2.2 Results

The data presented are the average values from the six fly ash samples analyzed per analysis and leaching technique. The standard deviation (SD) and the relative standard deviation (RSD) are also reported as measures of precision.

2.2.1 Bulk Composition Results

Table 2-1 lists the average recoveries, standard deviations (SDs), and relative standard deviations (RSDs) obtained by INAA. Acceptable recoveries, defined as 80% - 120% of the standard's certified value, were obtained for barium, cobalt, copper, manganese, and vanadium. Arsenic and chromium recoveries were only slightly outside this range at 127% and 124%, respectively. The reproducibility was acceptable (<20% RSD) for all the target elements except copper. Cadmium, beryllium, lead, and molybdenum were not detected by INAA. Results for the major elements were also reported to assess method accuracy. Acceptable recoveries for all major elements with certified values were achieved with the exception of calcium and potassium.

GDMS data are also presented in Table 2-1. For the target elements only chromium and copper had an acceptable recovery between 80-120%. The remaining target elements ranged from 17 to 77% recovery. The reproducibility was acceptable (<20% RSD) for all target analytes except molybdenum. Compared to INAA, GDMS detected 12 target elements, with cadmium being the only target element not detected. The precision and recovery were better for INAA than for GDMS; however, the GDMS technique appears to have better sensitivity at half the sample size. The relatively low bias in the elemental recovery may be a function of inappropriate RSFs for this matrix.

Table 2-1
Bulk Composition Analysis Results

Element	SRM Reported Value	Average	Std. Deviation	Relative Std. Deviation	% Recovery	Average	Std. Deviation	Relative Std. Deviation	% Recovery
Target Elements (μg/g)		INAA				GDMS			
Arsenic	79.1 C	100	3.5	4	127	47	4.3	9	59
Barium	1100 C	1200	48	4	109	190	24	13	17
Cadmium	2.94 I	<20	NA	NA	NA	<3.5	NA	NA	NA
Chromium	183 C	230	10	5	124	180	29	16	100
Cobalt	53.2 C	54	2.3	4	101	39	5.0	13	72
Copper	229 C	250	65	26	107	200	11	6	86
Lead	40.7 C	NA	NA	NA	NA	20	2.2	11	49
Manganese	440 C	450	26	6	102	270	15	6	61
Mercury	0.016 *	1.0	0.2	16	NC	0.26	0.052	20	NC
Molybdenum	14 *	<6	NA	NA	NA	8	2.8	36	NC
Nickel	108 I	76	NA	NA	70	61	5.7	9	57
Selenium	10 *	16	1.2	7	NC	4	1.0	24	NC
Vanadium	553 C	560	38	7	102	430	42	10	77
Major Elements (Wt. %)									
Aluminum	15.8 C	16	1.1	7	101	13	1.0	8	82
Calcium	1.68 I	3.7	0.14	4	221	1.0	0.09	8	62
Iron	5.16 C	5.8	0.24	4	112	4.4	0.38	9	85
Magnesium	0.580 I	0.5	0.03	7	85	0.49	0.032	6	85
Phosphorus	0.13 *	NA	NA	NA	NA	0.10	0.012	12	NC
Potassium	0.640 C	1.4	0.02	2	224	0.30	0.11	36	47
Silicon	22.9 I	NA	NA	NA	NA	28	0.9	3	122
Sodium	0.370 I	0.4	0.03	9	95	0.10	0.041	39	28
Strontium (ppm)	574 I	510	55	11	89	200	20	10	36
Sulfur (ppm)	420 *	NA	NA	NA	NA	520	150	29	NC
Titanium	3.68 C	3.4	0.22	7	92	3.9	0.43	11	107

C = Certified standard value based upon at least ten laboratory means.
I = Informational value based upon at least five laboratory means.
* = Unsubstantiated value. Single analysis result presented for information only.
NA = Not applicable or not analyzed.
NC = No certified value for comparison.

2.2.2 Surface Composition Results

The determination of surface metals focused on evaluating two separate analytical phases to meet the evaluation criteria. The first phase was the leach methods described previously. The second was a comparison of the analytical instrumentation between conventional ICP-AES and GFAAS to ICP-MS. From the perspective of instrument sensitivity, ICP-MS has lower detection limits than ICP-AES emission or GFAAS.

Table 2-2 contains the average concentrations, SDs, and RSDs for the certified fly ash samples from the nitric digestion analyzed by ICP-MS, ICP-AES, and GFAAS. The ICP-MS results presented in Table 2-2 were from samples diluted 1:100 prior to analysis, whereas the samples analyzed by ICP-AES and GFAAS were analyzed directly without dilution. In comparison, the relative standard deviation was best for the ICP-MS analysis. The increased sensitivity provided improved precision and reliability. Analysis by ICP-AES and GFAAS had poor precision because the levels analyzed were at or below the instrument detection limits. Arsenic analyzed by GFAAS had the best recovery and RSD since the levels measured were greater than 10 times the detection limit of 5 ppb. For ICP-MS the high arsenic and selenium recoveries are likely to be due to plasma interferences from $ArCl^+$ and Ar_2, respectively.

Table 2-3 presents the results from the gastric fluid leachate analyses by ICP-MS, ICP-AES, and GFAAS. As for the nitric acid digestate analyses, the better precision and reliability was obtained with ICP-MS analysis because of the increased sensitivity.

The gastric fluid leachate samples and reagent blanks began to form a white flocculent material that was removed by filtration prior to analysis. This flocculent material formed after two weeks and appeared to be mold. The flocculent material (mold) was not found in the spiked blank solutions. It is assumed that the 1 ppm levels of the toxic metals spiked in these solutions inhibited mold growth.

Similar results were obtained from the acetic acid and APDC leachates. These results are presented in Tables 2-4 and 2-5, respectively. As the amount of each element in solution decreased under less aggressive leaching conditions, the need for greater analytical sensitivity increased. Again, ICP-MS provided the best precision and sensitivity. For the acetic acid leachates, only arsenic was detected by GFAAS whereas 12 of the elements were detected by ICP-MS.

The APDC chelant did solubilize numerous elements that could be detected by all three instruments, but the RSD increased to over 100% for elements measured by ICP-AES or GFAAS and to more than 30% for ICP-MS. The APDC was used to chelate and speciate elements whose oxidation state determined their toxicity. Arsenic (As^{3+}) and chromium (Cr^{6+}) were the elements of interest in this

Table 2-2
Nitric Acid Digestion Results

Element	SRM Reported Value	ICP-MS				ICP-AES/GFAAS			
		Average	Std. Deviation	Relative Std. Deviation	% Extracted [a]	Average	Std. Deviation	Relative Std. Deviation	% Extracted
Target Elements (µg/g) (Blank Corrected - Dry Basis)									
Arsenic	79.1 C	120	7	6	152	70	0.7	1	89
Barium	1100 C	240	17	7	22	NA	0.24	7	NA
Beryllium	23.3 I	21	4.1	20	88	3.5	24	120	15
Cadmium	2.94 I	8	2.9	34	285	<9	20	27	11
Chromium	183 C	120	11	9	66	20	5.1	59	NA
Cobalt	53.2 C	22	1.1	5	41	NA	6.6	40	33
Copper	229 C	130	32	25	57	75	1.2	1900	21
Lead	40.7 C	40	14	36	99	9	8	5	NA
Manganese	440 C	300	29	10	68	NA			NA
Mercury	0.016 *	88	6.8	8	NC	NA			NA
Molybdenum	14 *	18	1.4	8	NC	NA			15
Nickel	108 I	100	12	12	93	16			NC
Selenium	10 *	1400	72	5	NC	0.06			29
Vanadium	553 C	280	9	3	51	160			

C = Certified standard value based upon at least ten laboratory means.

I = Informational value based upon at least five laboratory means.

* = Unsubstantiated value. Single analysis result presented for information only.

NA = Not analyzed.

NC = No certified value for comparison.

[a] Percent extracted is calculated by dividing the average measured value by the SRM value.

Table 2-3
Simulated Gastric Fluid Leach Results

Element	SRM Reported Value	ICP-MS Average	ICP-MS Std. Deviation	ICP-MS Relative Std. Deviation	ICP-MS % Extracted [a]	ICP-AES/GFAAS Average	ICP-AES/GFAAS Std. Deviation	ICP-AES/GFAAS Relative Std. Deviation	ICP-AES/GFAAS % Extracted
Target Elements (µg/g) (Blank Corrected - Dry Basis)									
Arsenic	79.1 C	46	19	41	58	56	23	42	71
Barium	1100 C	110	10	9.3	10	NA			NA
Beryllium	23.3 I	2.3	0.46	20	10	1.5	0.55	36	7
Cadmium	2.94 I	0.20	0.18	93	7	<17			
Chromium	183 C	2.5	0.88	35	1	<10			
Cobalt	53.2 C	3.6	0.78	22	7	NA			NA
Copper	229 C	33	10	30	14	<18			
Lead	40.7 C	4	2.0	50	10	5	3.4	75	11
Manganese	440 C	45	11	24	10	NA			NA
Mercury	0.016 *	0.49	0.15	31	NC	NA			NA
Molybdenum	14 *	7	1.3	20	NC	NA			NA
Nickel	108 I	8	1.8	22	8	<30			
Selenium	10 *	<18				<2			
Vanadium	553 C	110	35	32	20	83	13	16	15

C = Certified standard value based upon at least ten laboratory means.

I = Informational value based upon at least five laboratory means.

* = Unsubstantiated value. Single analysis result presented for information only.

NA = Not analyzed.

NC = No certified value for comparison.

[a] Percent extracted is calculated by dividing the average measured value by the SRM value.

Table 2-4
Acetic Acid Leach Results

Element	SRM Reported Value	ICP-MS				ICP-AES/GFAAS			
		Average	Std. Deviation	Relative Std. Deviation	% Extracted [a]	Average	Std. Deviation	Relative Std. Deviation	% Extracted [a]
Target Elements ($\mu g/g$) (Blank Corrected - Dry Basis)									
Arsenic	79.1 C	5	1.5	31	6	6.0	1.8	30	8
Barium	1100 C	23	3.1	14	2	NA			NA
Beryllium	23.3 I	0.06	0.056	98	0.2	NA			NA
Cadmium	2.94 I	0.23	0.11	50	8	<16			
Chromium	183 C	0.28	0.08	29	0.2	<3			
Cobalt	53.2 C	2.2	2.8	127	4	NA			NA
Copper	229 C	<22				NA			NA
Lead	40.7 C	<0.7				<4			
Manganese	440 C	12	3.7	31	3	NA			NA
Mercury	0.016 *	0.06	0.049	81	NC	NA			NA
Molybdenum	14 *	0.75	0.39	51	NC	NA			NA
Nickel	108 I	6	2.2	39	5	5.4	0.58	11	5
Selenium	10 *	<33				<1			
Vanadium	553 C	1.0	0.6	60	0.2	NA			NA

C = Certified standard value based upon at least ten laboratory means.

I = Informational value based upon at least five laboratory means.

* = Unsubstantiated value. Single analysis result presented for information only.

NA = Not analyzed.

NC = No certified value for comparison.

[a] Percent extracted is calculated by dividing the average measured value by the SRM value.

Table 2-5
APDC Chelant Leach Results

Element	SRM Reported Value	ICP-MS				ICP-AES/GFAAS			
		Average	Std. Deviation	Relative Std. Deviation	% Extracted [a]	Average	Std. Deviation	Relative Std. Deviation	% Extracted [a]
Target Elements ($\mu g/g$) (Blank Corrected - Dry Basis)									
Arsenic	79.1 C	1.1	0.41	37	1	0.3	0.39	140	0.3
Barium	1100 C	0.4	0.30	73	0.04	0.6	1.1	190	0.1
Beryllium	23.3 I	0.4	0.10	25	2	NA			NA
Cadmium	2.94 I	2.4	1.5	62	83	1.4	1.5	103	49
Chromium	183 C	4.2	0.57	14	2	<3			
Cobalt	53.2 C	1.2	0.42	36	2	0.5	0.58	118	0.9
Copper	229 C	47	9.3	20	20	3	14	481	1.2
Lead	40.7 C	22	10	44	55	12	12	100	29
Manganese	440 C	2.5	2.0	78	1	<4			
Mercury	0.016 *	6.0	3.9	66	NC	NA			NA
Molybdenum	14 *	0.8	0.71	88	NC	<1			
Nickel	108 I	5.9	6.1	104	5	<11			
Selenium	10 *	43	6.6	15	NC	NA			NA
Vanadium	553 C	2.3	2.1	89	0.4	1.2	2.6	218	0.2

C = Certified standard value based upon at least ten laboratory means.

I = Informational value based upon at least five laboratory means.

* = Unsubstantiated value. Single analysis result presented for information only.

NA = Not analyzed.

NC = No certified value for comparison.

[a] Percent extracted is calculated by dividing the average measured value by the SRM value.

set. Recoveries were low for both elements and the RSDs were 34% and 12% by ICP-MS. Both elements were at or below the detection limits for GFAAS (arsenic) and ICP-AES (chromium).

The simulated lung fluid matrix presented sample aspiration difficulties. The increased viscosity presented sample aspiration problems during attempts to analyze the lung fluids by ICP-AES. The neutral pH plus available nutrients also created a favorable medium for bacterial growth despite sample refrigeration. The fluids had a five-day holding time before bacterial growth began to cloud the solution.

Several attempts were made to analyze the simulated lung fluid by ICP-AES. Samples were diluted to try to reduce the viscosity; however, elemental concentrations were well below the detection limits once aspiration was achieved. The carbon content in the simulated lung fluid makes analysis by ICP-MS impractical, and since only three techniques were to be selected for the field test samples, further attempts to analyze these samples were not viewed as cost-effective. GFAAS analysis was not performed on the simulated lung fluids even though the viscosity and carbon content would not pose a problem with this technique.

The APDC solution formed a cloudy precipitate when the pH was adjusted to 4.4, which redissolved upon addition of MIBK and stirring. The precipitate also formed when the blank spikes were prepared again, from the decrease in pH caused by the spike matrix. The precipitate dissolved only partially when stirred with MIBK. Repeated solvent extraction did not remove the precipitate, which was filtered before analysis. This precipitate and the multiple extraction and filtration may have contributed to the poor spike recoveries for the spike blanks.

2.3 Discussion

Bulk composition analysis by GDMS failed to meet the method selection criteria for reliability and accuracy; however, the reproducibility was acceptable for 11 of the 13 target elements tested. The GDMS technique uses relative sensitivity factors to quantify the elemental concentrations from the mass spectrum's signal intensity. These RSFs are determined by the analysis of standard reference materials, typically metal alloys. The use of metal alloys for determining RSFs may explain the low bias in the technique's accuracy. The use of coal fly ash standards in lieu of metal alloys for determining RSFs for elemental quantification is recommended to simulate the ash sample matrix. This could take into account the possible difference in ionization potentials for elements present in a complex, oxidized form typical of fly ashes.

INAA was a more reliable technique with better reproducibility for determining the bulk composition of very small quantities of fly ash. However, this technique is unable to determine the concentrations of beryllium, lead, fluorine, and phosphorus. All of these can be determined by GDMS.

Based on the sensitivity of the ICP-MS technique, an additional consideration for determining the bulk composition of small quantities of fly ash would be a complete acid digestion of the ash solids followed by ICP-MS analysis. This technique could provide ample sensitivity for many of the target analytes although some consideration of the possible matrix effects from the digestion acids is necessary.

The nitric acid digestion, gastric fluid leach, and acetic acid leach are the three surface characterization techniques chosen based on their performance criteria when analyzed by ICP-MS. The three leaching methods provided minimal interferences and appeared to solubilize those metals at or near the surface of the particle. This is evidenced by progressively lower concentrations of metals being leached from the ash material under progressively weaker leaching agents and conditions. The ICP-MS analytical technique provided the lower detection limits and improved precision required to quantify the low levels of metals leached under these three conditions. The conventional ICP-AES emission and GFAAS techniques did not provide adequate sensitivity for these leachate samples.

The relevance of the three techniques to biological and ecological systems and their similarity to existing EPA protocols supports the selection of these surface characterization techniques. The gastric fluid technique provides data estimating the availability of toxic metals to the body through ingestion and dissolution of fly ash by stomach acids. The acetic acid/TCLP approach provides a comparative test for evaluating the relative availability of toxic metals by a standard leachability procedure. By comparing the relative availability of elements determined by each leaching technique to the bulk composition, a more appropriate indication of the health risks associated with stack gas particulate emissions may be developed.

Improved results are anticipated by reducing the analytical dilutions for the nitric digestions from 1:100 to 1:20. The higher analyte concentrations will increase the signal strengths, allowing the mass detector to differentiate these from plasma and other matrix interferences. The increased signal should also improve the precision and accuracy. However, since the lower dilution factor will cause major elements such as iron and titanium to blind the mass scale, the signals from these elements must be identified and skipped to remove them as a potential source of interference.

2.4 References

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3.0 PHASE I TESTING

The Phase I field program was performed from August 24 through September 20, 1992, and encompassed the collection of samples from the Unit 8 stack using in-stack and dilution sampler techniques.

The goal for the Phase I test program was the collection of sufficient quantities in six particle-size fractions (two fractions in the dilution system) such that detailed bulk and surface chemical characterization could be performed. Three samples were targeted for collection with each sample representing a unique but similar sampling period.

3.1 Sampling Methods

Sample collection for particulate matter was performed as a function of aerodynamic particle size using two separate procedures. The first procedure involved the collection of particles from the stack at process conditions using in-stack cyclone separators and a high-efficiency electrostatic precipitator (ESP). The second procedure employed a source dilution sampling system to simulate the effects of dilution and condensation in an ambient atmosphere. These sampling procedures are described below.

3.1.1 In-Stack Sampling

Particulate samples were collected and fractionated into six aerodynamic ranges using a series of five cyclone separators and a high-efficiency ESP. These devices were placed directly into the stack and samples were collected at stack conditions similar to EPA Reference Method 17. The cyclones were operated at a design flow rate of one cubic foot per minute.

All testing was performed in accordance with accepted procedures as referenced in 40 CFR 60, Appendix A. The selection of traverse points, determination of flow rate, gas molecular weight, and moisture content were made using EPA Methods 1-4, respectively. The following modifications to Method 17 were applied in order to meet the specific project goals:

- Samples were collected from a single point in the stack. Traversing of the stack was performed for velocity and volumetric flow rate measurements only.
- The in-stack filter assembly cited in EPA Reference Method 17 was replaced with an Andersen Cyclade followed by a high efficiency electrostatic precipitator for particle separation and collection.

- Once an initial isokinetic sampling rate was established, the rate was not adjusted to account for flue gas flow rate changes. A constant sampling rate was necessary to maintain constant cyclone cut-points.

The ESP was selected as an alternative to a final filter substrate to avoid large pressure drops at higher sampling rates and to provide fine particulate matter free from any filter substrate matrix. The ESP was designed to operate at a nominal maximum sampling rate of 6.5 cfm at 205° C and provide 95% collection of submicron particles. Figure 3-1 is a schematic illustrating the main features of the system. The collector is cylindrical with the collection electrodes arranged concentrically to allow a large surface area to be contained within a relatively short cylinder.

After the sample was collected, the collection plates were brushed to remove the fine particles. A schematic of the entire sampling system is shown in Figure 3-2.

Table 3-1 presents sampling data for each of the nine test runs performed during the Phase I test period. Run 5 was lost during recovery from condensate back-flowing from the impinger knockout into the cyclones and ESP. All of the test runs were collected from a single point in the stack under isokinetic conditions, with the exception of Run 7, which was sampled sub-isokinetically at 82 percent. Since the sampling was focused on the collection of fractionated the particulate matter and cyclonic cut points are not sharp (as compared to impactor sizing devices), the sub-isokinetic conditions of Run 7 are not considered to have an impact on sample integrity.

At the conclusion of each run, the cyclones and the ESP were disassembled and the collected material was recovered by brushing the particulate into a tared vial. Three of the ESP samples from Runs 2, 4, and 6 were wet upon disassembly of the unit, and these samples were rinsed from the ESP with deionized (DI) water. ESP samples from Runs 3 and 9 were not dry enough to recover completely without rinsing. The rinsed fractions and the dry fractions were collected separately. The samples were returned to Austin; the dry fractions were desiccated and reweighed. Table 3-2 presents the total recovered weight of the particulate catch on a size-fractionated basis for all recovered test runs. The sample sizes ranged from just over 0.5 grams to 1.6 grams, so the goal of collecting three samples with 1 gram quantities of each size fraction turned out to be impractical. This contributed to the modification of the approach to testing and analysis for Phase II.

3.1.2 Dilution Sampling

The second method of particulate matter collection was the extraction of sample gas using a source dilution sampling technique. The dilution sampler extracts particulate from the stack gas and dilutes it with ambient air to simulate the cooling and dilution effects on the effluent stream once in contact

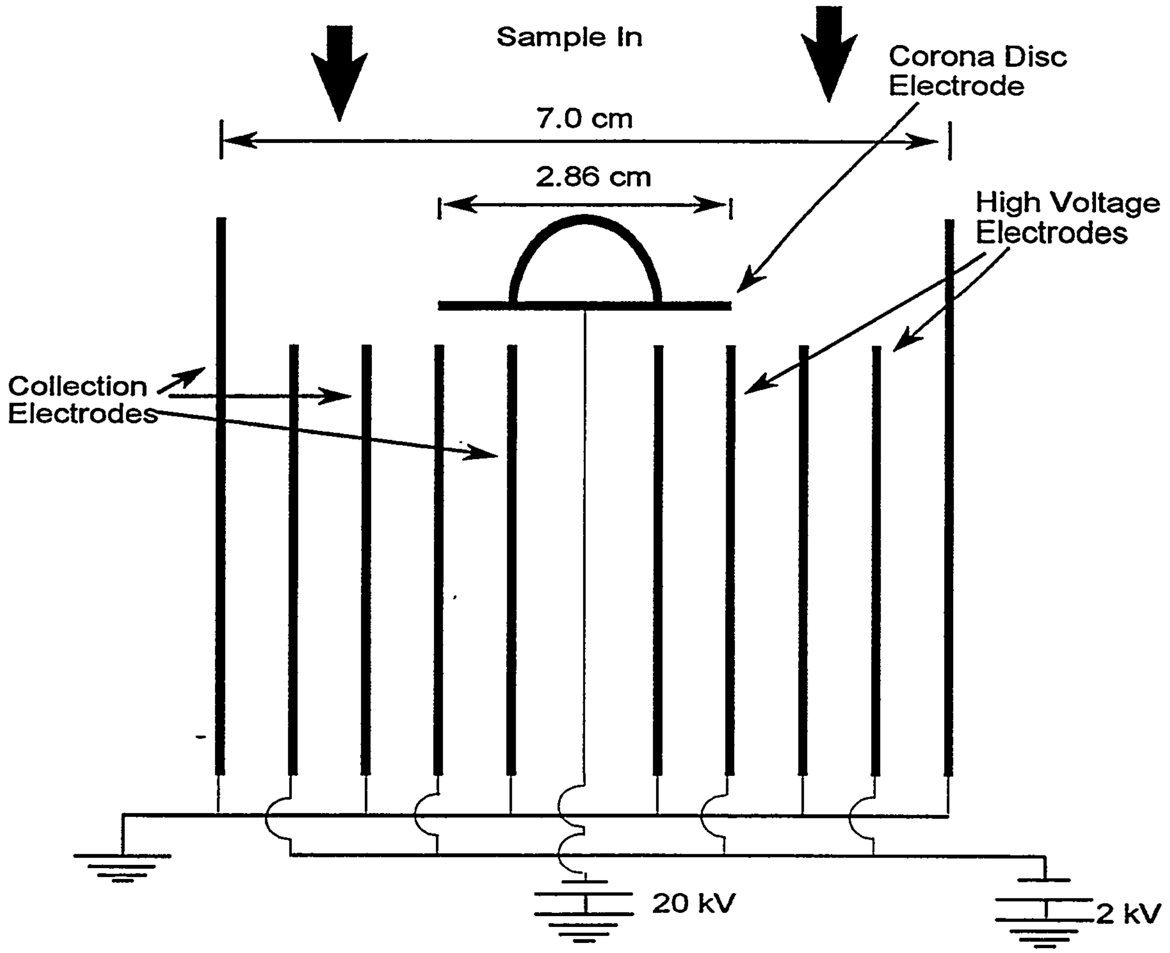
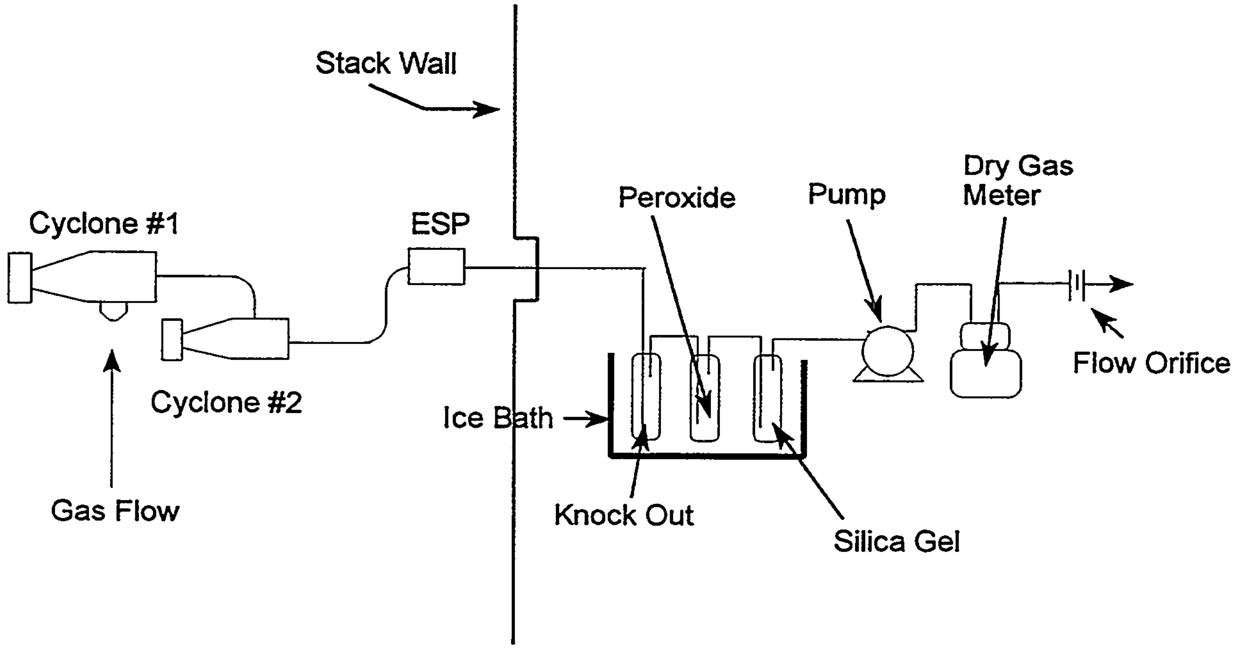


Figure 3-1
Schematic of High Efficiency ESP



Note: Cyclones #3, #4, and #5 were also used during Phase I.

Figure 3-2
In-Stack Sampling Train

Table 3-1
In-Stack Sampling Data

Run No.	Date	Start Time	Duration (Minutes)	Average Stack Temp °F	Average Flow Rate (dscfm)	Isokinetic Sampling Rate (%)
1	08/26/92	11:18	2,292	150	1,239,000	104
2	08/28/92	12:00	2,318	146	1,222,000	90
3	08/30/92	15:00	3,682	146	1,242,000	93
4	09/02/92	13:05	2,862	148	1,243,000	98
5[a]	09/09/92	09:20	1,290	148	1,243,000	97
6	09/10/92	15:10	3,247	146	1,244,000	97
7	09/14/92	14:45	2,340	146	1,245,000	81
8	09/16/92	16:00	2,330	148	1,242,000	101
9	09/18/92	16:30	2,180	146	1,245,000	98

[a] Lost during sample recovery.

Table 3-2
Particulate Weights by Size Fraction

Sample Composite	Particle Size Range	Total Mass Collected[a] (g)
Cyclone Stage 1	>6.3 µm	1.63
Cyclone Stage 2	6.3 - 2.7 µm	0.55
Cyclone Stage 3	2.7 - 1.7 µm	0.93
Cyclone Stage 4	1.7 - 0.8 µm	1.54
Cyclone Stage 5	0.8 - 0.5 µm	1.53
ESP Stage 6	<0.5 µm	1.79

[a] Samples were desiccated at room temperature and weighed to a constant weight per EPA Method 5 guidelines (variation between successive weights less than or equal to 0.5 mg).

with the atmosphere. The dilution sampling was conducted by OMNI Environmental from August 26 to August 31, 1992.

The dilution sampler was constructed such that two particle size fractions could be collected. The targeted size fractions for the source dilution sampling were in the range of greater than 2.5 microns for the first stage and less than 2.5 microns for the final stage. The first size fraction was collected using a cyclone separator downstream of the dilution chamber of the sampling system. The final size fraction was collected on two 8 x 10-inch filter substrates. A simplified drawing of the dilution system is shown in Figure 3-3.

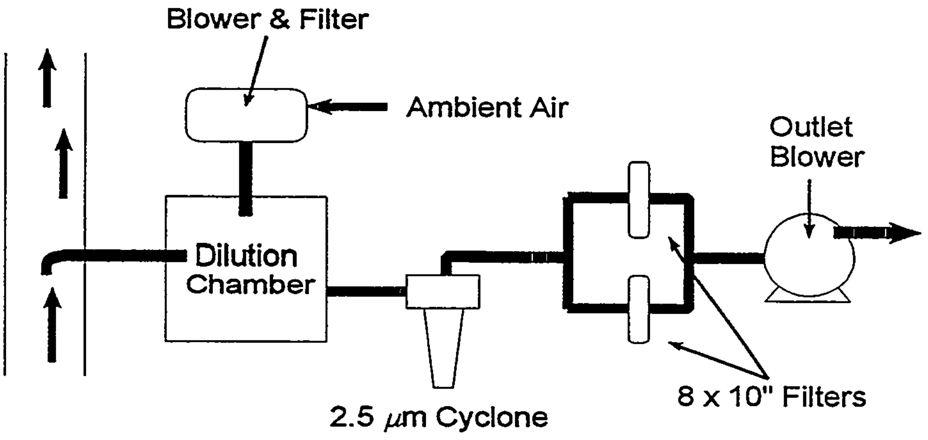


Figure 3-3
Dilution Sampling System

Based on the particulate loading of the source, it was estimated that sample runs in excess of 60 hours would be performed with the dilution sampler. Problems due to the high relative humidity of the dilution air and high pressure drops across the dilution sampler collection system significantly shortened the sample runs. OMNI obtained information from the National Weather Service for historical data on the relative humidity to determine a sampling "window" for periods of relative humidity of less than 80 percent. No sampling could be performed when the relative humidity approached 90% due to moisture/condensation in the dilution sampler and filtering assembly. In addition to the humidity problem, there was a rapid increase in the pressure drop across the final filters which prevented sampling at isokinetic rates. Due to these problems, OMNI could not sample for extended periods of time nor could the targeted sample mass of 1 gram be collected on a single set of filters.

Table 3-3 presents the sampling periods when the dilution sampler was operated. Sampling periods for the dilution sampling generally ranged from three to five hours. Five pairs of filters were collected by OMNI which represented sample periods between August 26 and August 31. The first four samples were collected on Teflon®-coated glass fiber filters. The sixth sample run utilized glass fiber filters in an attempt to reduce the pressure drop buildup across the filtering media. A longer sample time (14 hours) was achieved, but the nature of the glass fiber substrate also added to sample recovery problems in that the particles embedded themselves in the substrate material and a 'neat' sample could not be obtained. Table 3-4 provides the weight gain for each of the exposed filters used during the dilution sampling.

Table 3-3
Dilution Sampling Data

Run No.	Date	Start Time	Minutes Duration	Final Filter Type
1	08/26/92	12:45	198	Teflon®/glass fiber
2	08/28/92	13:50	318	Teflon®/glass fiber
3	08/28/92	19:15	285	Teflon®/glass fiber
4	08/29/92	10:00	240	Teflon®/glass fiber
5	08/29/92	19:30	300	None
6	08/30/92	10:00	840	Glass fiber
7	08/31/92	12:45	580	None

In addition to the glass fiber-based filter sets, cyclone catches were obtained from each sample run representing the particulate matter in the greater than 2.5 micron range. These cyclone catches were extremely small due to the shortened sample periods. In order to increase the operating time and increase the sample catch of the >2.5 micron fraction, the dilution sampler was also operated without final filters. The total mass collected in the cyclone separator during all seven runs was 50 mg, an insufficient amount for complete characterization.

Table 3-4
Dilution Sampler Particulate Catch

Dilution Sampler Run Number	Filter I.D.[a]	Particulate Mass[b] (g)	Total Filtered Mass Collected[b] (g)	> 2.5μm Cyclone Catch
1	80136-1 80136-2	0.2272 0.2281	0.4553	Trace
2	80136-3 80136-4	0.2528 0.2526	0.5054	Trace
3	80136-5 80136-6	0.2014 0.2005	0.4019	Trace
4	80136-7 80136-8	0.1825 0.1786	0.3611	Trace
5	None	--	--	50 mg
6	--	--	--	
7	None	--	--	

[a] 8" x 10" Teflon®-coated glass fiber filters (2 filters per run).

[b] Samples were weighed five times under desiccation at room temperature (relative standard deviation for all weights is less than 0.05%).

3.2 Process Data

The plant output in megawatts was the primary parameter used to evaluate unit operation. Load profiles for each of the periods are graphically presented in Figure 3-4. Table 3-5 presents the tabulated plant output in megawatts for eight of the nine test periods (Run 5 was lost during recovery). Included with the table are the average, maximum, and minimum loads for each test run.

3.3 Analytical Approach

Since sufficient material could not be collected during any single run period, the first task was to determine how the material collected over the nine runs would be composited to form three samples. A fairly wide variation in plant load was encountered during each run and, since the average load varied from run to run, a statistical evaluation of the load data was performed. This evaluation isolated two runs representative of high- and low-load operation. The remaining runs could be statistically segregated into two or three overlapping groups. Based upon the sample quantities

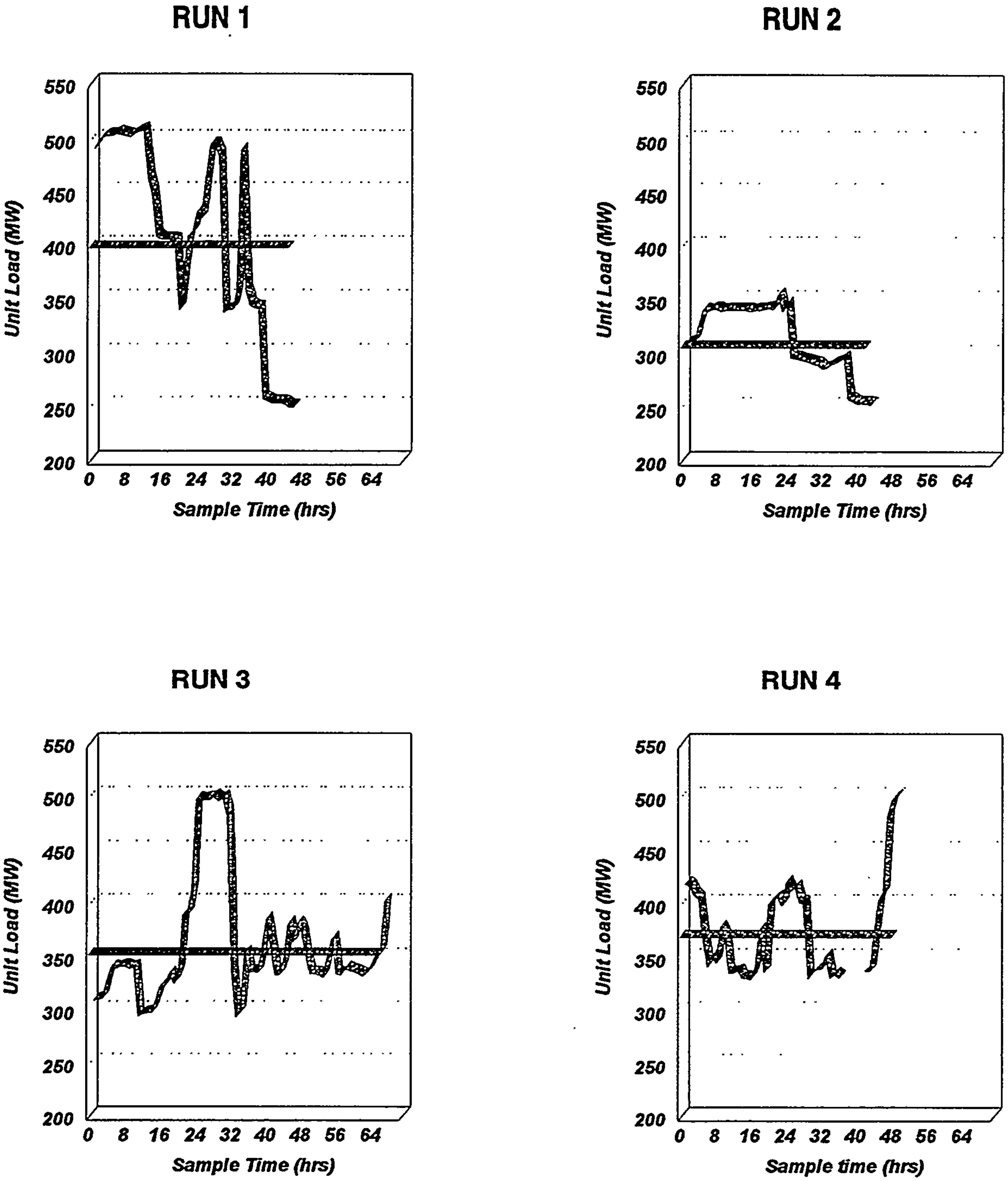
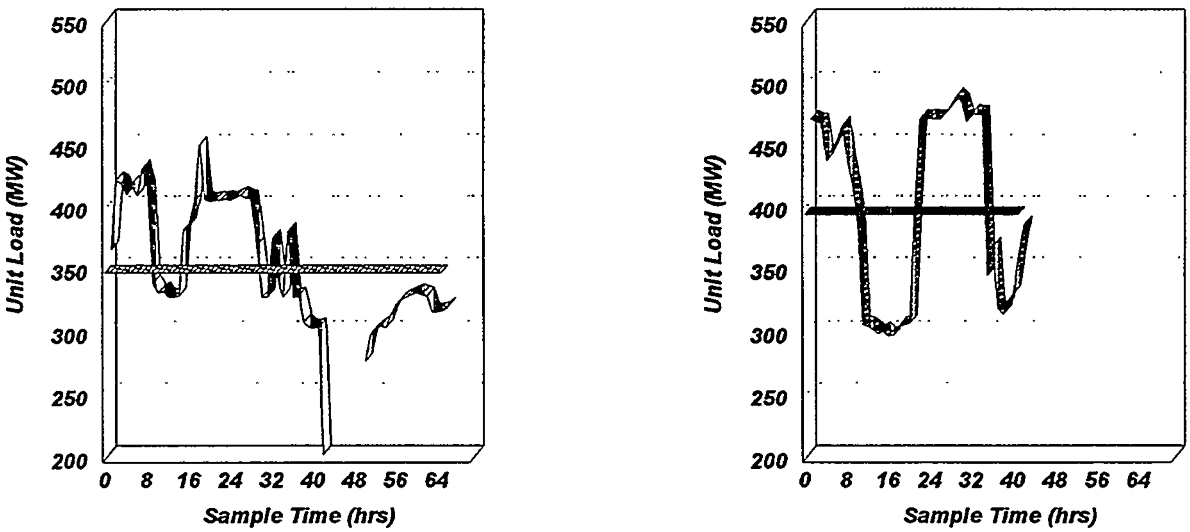
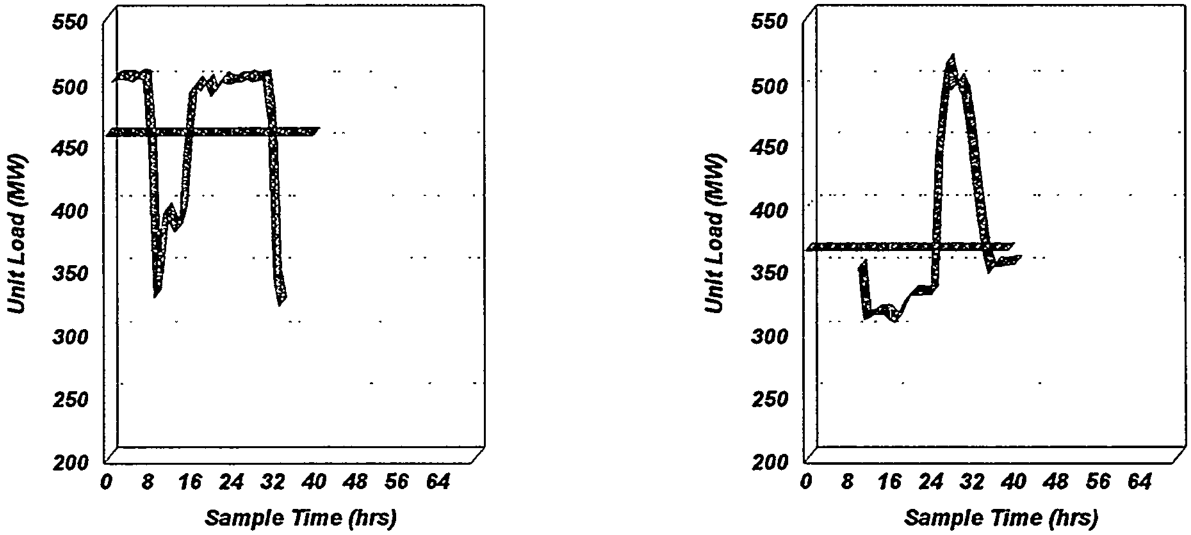


Figure 3-4
Phase I Load Profile



RUN 6

RUN 7



RUN 8

RUN 9

Figure 3-4 (Continued)

Table 3-5
Power Output Summary

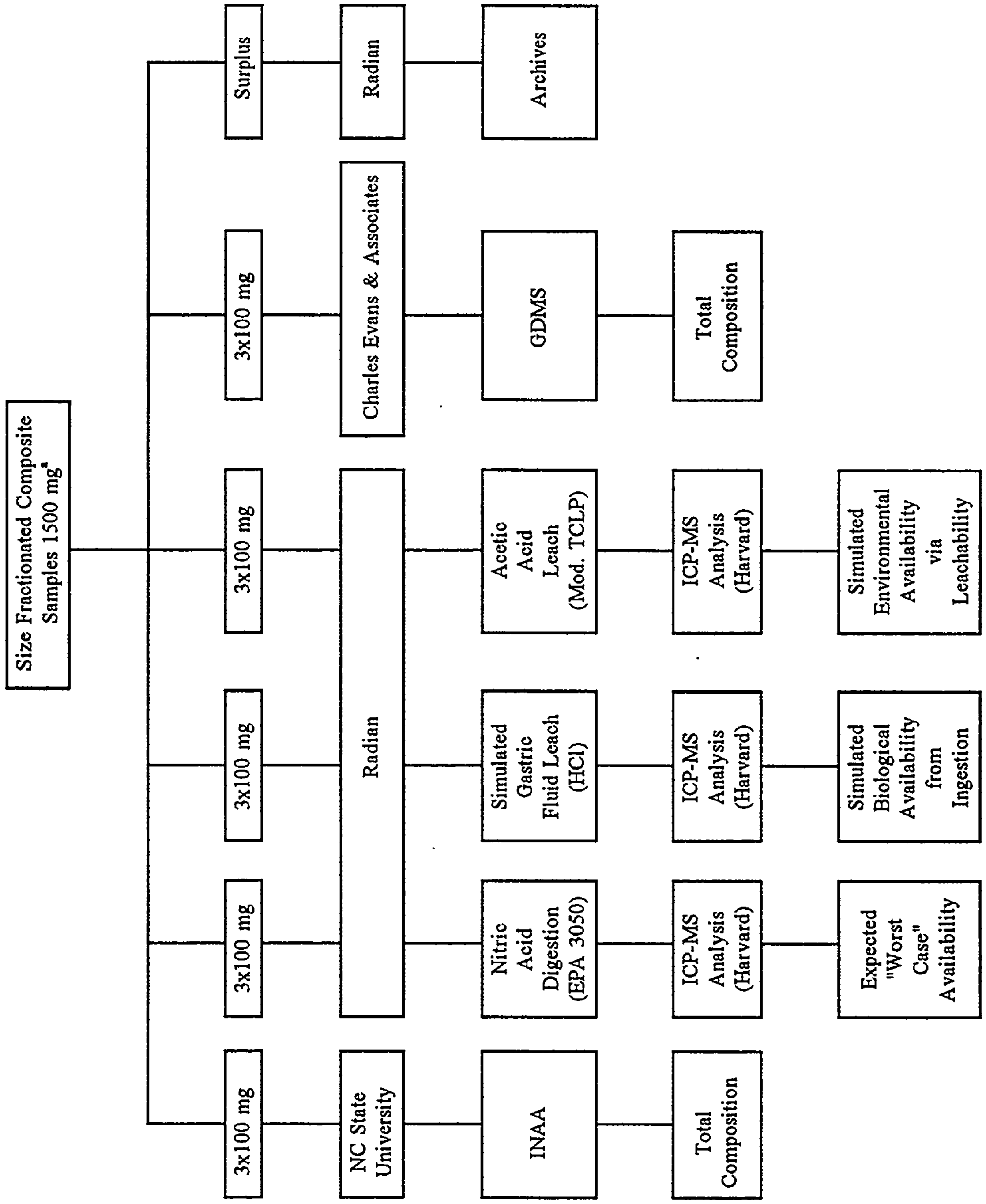
Test Period	Average Load[a]	Maximum Load[a]	Minimum Load[a]
1	403	507	248
2	310	353	251
3	358	498	292
4	375	498	328
6	351	448	181
7	398	487	295
8	461	502	319
9	369	513	306

[a] Megawatts.

available, only two composites could be reasonably considered for providing high- versus low-load data comparisons. The drawback to this high- vs. low-load composite evaluation is that only one data point (sample analysis) would be obtained under each load condition for each size fraction. This did not fully satisfy the program objectives for comparing particle composition against particle size or load with a statistical basis for comparison.

With concurrence of the DOE project manager, an alternative approach was selected that satisfied the program's objectives more completely. All eight samples were combined and mixed (on a size-fraction basis) to produce a total composite sample for each size range. These composites were split into three separate subsamples. These three samples provided the basis for replicate analyses to generate the statistical information necessary to support comparisons between composition and particle size. The issue of composition versus load was deferred to Phase II. Statistical data from this first test phase was used in determining the Phase II sampling approach to completely address the program objectives.

Figure 3-5 represents the overall analytical scheme for the size-fractionated samples. Sample preparation and analysis details for each technique are described below. These samples were analyzed according to the analytical matrices presented in Tables 3-6 through 3-10. These tables provide detailed information as a function of each analytical technique that was performed. They also show QA/QC samples in the form of laboratory check samples (LCSs) and matrix spike samples, as well



[a] Stages 1, 4, 5, and 6 will follow this matrix. Stages 2 and 3 followed a similar but reduced matrix due to sample size limitations.

Figure 3-5
Analytical Matrix Overview

Table 3-6
Neutron Activation Analytical Matrix

Sample I.D.	Run 1	Run 2	Run 3
LCS[a]	X	X	X
Cyclone Stage 1	X	X	X
Cyclone Stage 2[b]	X		
Cyclone Stage 3	X	X	X
Cyclone Stage 4	X	X	X
Cyclone Stage 5	X	X	X
Cyclone Stage 6	X	X	X
Filter Blanks	X[c]	X	X
Filtered Particulate	X	X	X

[a] LCS = Laboratory check sample. A standard fly ash material was submitted to the laboratory as a blind sample to assess analytical accuracy.

[b] A sufficient amount of material was not collected in the second cyclone of the sampling system to provide three 100-mg samples for analysis.

[c] A laboratory check sample (standard fly ash) was added to a blank filter from the Dilution Sampler.

[d] Particulate samples on filters from dilution sampler.

Table 3-7
Glow Discharge Mass Spectrometry Analytical Matrix

Sample I.D.	Run 1	Run 2	Run 3
LCS[a]	2X	2X	2X
Stage 1	X	X	X
Stage 2[b]			
Stage 3[b]			
Stage 4	X	X	X
Stage 5	X	X	X
Stage 6	X	X	X

[a] LCS = Laboratory check sample. Two different standard fly ash standards were submitted to the laboratory as blind samples to assess analytical accuracy.

[b] A sufficient amount of material was not available for analysis by this technique.

Table 3-8
Nitric Acid Digestion Matrix

Sample I.D.	Run 1	Run 2	Run 3[a]	Matrix Spike[b]
Digestion Blank	X	X	X	2X[c]
Cyclone Stage 1	X	X	X	X
Cyclone Stage 2	X	X	X	X
Cyclone Stage 3	X	X	X	X
Cyclone Stage 4	X	X	X	X
Cyclone Stage 5	X	X	X	X
Cyclone Stage 6	X	X	X	X
Filter Blanks	X	X	X	X
Filtered Particulate	X	X	X	X
Standard Fly Ash[e]	X	X	X	X

[a] Analytical duplicates were run on the third split of each size fraction sample to assess analytical variability.

[b] Matrix spikes were performed on the third sample splits after sample digestion (post-digestion spikes) to assess matrix interferences rather than digestion recovery. Spike levels of 50 ppb have been selected based upon the expected sample concentration ranges of 1 to 10 ppb for the target analytes.

[c] An aqueous standard (predigestion blank spike) was run in conjunction with the post-digestion blank spike to assess sample recovery through the digestion and sample transfer procedure.

[d] Particulate samples on filters from dilution sampler.

[e] Brammer fly ash standard used during methods evaluation test phase.

Table 3-9
Simulated Gastric Fluid Leaching Matrix

Sample I.D.	Run 1	Run 2	Run 3[a]	Matrix Spike[b]
Digestion Blank	X	X	X	2X[c]
Cyclone Stage 1	X	X	X	X
Cyclone Stage 2[d]	X			
Cyclone Stage 3	X	X	X	X
Cyclone Stage 4	X	X	X	X
Cyclone Stage 5	X	X	X	X
Cyclone Stage 6	X	X	X	X
Filter Blanks	X	X	X	X
Filtered Particulate[e]	X	X	X	X
Standard Fly Ash[f]	X	X	X	X

[a] Analytical duplicates were run on the third split of each size fraction sample to assess analytical variability.

[b] Matrix spikes were performed on the third sample splits after sample digestion (post-digestion spikes) to assess matrix interferences rather than digestion recovery. Spike levels of 70 ppb were selected based upon the expected sample concentration ranges of 1 to 10 ppb for the target analytes.

[c] An aqueous standard (predigestion blank spike) was run in conjunction with the post-digestion blank spike to assess sample recovery through the digestion and sample transfer procedure.

[d] A sufficient amount of material was not available for triplicate analysis by this technique.

[e] Particulate samples on filters from dilution sampler.

[f] Brammer fly ash standard used during methods evaluation test phase.

Table 3-10
Acetic Acid Leaching Matrix

Sample I.D.	Run 1	Run 2	Run 3[a]	Matrix Spike[b]
Digestion Blank	X	X	X	2X[c]
Cyclone Stage 1	X	X	X	X
Cyclone Stage 2[d]				
Cyclone Stage 3[d]				
Cyclone Stage 4	X	X	X	X
Cyclone Stage 5	X	X	X	X
Cyclone Stage 6	X	X	X	X
Filter Blanks	X	X	X	X
Filtered Particulate[e]	X	X	X	X
Standard Fly Ash[f]	X	X	X	X

[a] Analytical duplicates were run on the third split of each size fraction sample to assess analytical variability.

[b] Matrix spikes were performed on the third sample splits after sample digestion (post-digestion spikes) to assess matrix interferences rather than digestion recovery. Spike levels of 70 ppb were selected based upon the expected sample concentration ranges of 1 to 10 ppb for the target analytes.

[c] An aqueous standard (predigestion blank spike) was run in conjunction with the post-digestion blank spike to assess sample recovery through the digestion and sample transfer procedure.

[d] A sufficient amount of material was not available for analysis by this technique.

[e] Particulate samples on filters from dilution sampler.

[f] Brammer fly ash standard used during methods evaluation test phase.

as indicate where sufficient sample material (for cyclone stages two and three) was not available for analysis. These tables also indicate the analyses to be performed on the filtered particulate from the dilution sampling system. ESP fractions which were recovered by rinsing with DI water were composited, filtered, and the filtrate split into three fractions for analysis of total dissolved solids (TDS), sulfate, and metals. The filers were weighed to determine the particulate fraction. This analytical approach is depicted in Figure 3-6.

3.3.1 Total Composition

Total compositional analyses of the fly ash particles were performed using INAA and GDMS. These methods, described in Section 2.1.1, do not require any dissolution or digestive preparation procedures prior to analysis. There were no changes to the INAA procedure described in Section 2; however, fly ash matrix standards were used to determine RSFs for GDMS.

3.3.2 Surface Composition Available by Nitric Acid Digestion

All particulate composite samples were prepared by EPA Method 3050, described in Section 2.1.2. Three 100 mg samples of each size-fraction were digested, filtered through a 0.45 micron nitrocellulose membrane filter, and brought to a 100 mL final volume. Prior to analysis by ICP-MS, 1:20 dilutions were made to bring the sample into the linear range of the mass detector. To assess potential matrix interferences, one of the three samples generated for each size fraction was selected as the source for a matrix spike. The sample selected was split to provide a sample for spiking, and the remaining sample was identified for duplicate analysis. The spike was prepared using a SPEX® multi-element ICP-MS calibration solution. Spike levels in the analyzed digestate were 50 ppb for all elements except molybdenum, which was not present in the calibration solution. This spiking level was based on previous results obtained from this procedure applied to standard reference fly ash samples. Average concentrations in those prepared samples ranged from 1 to 15 ppb. At these concentration levels, ICP-MS was selected as the analytical technique over atomic emission and graphite furnace-atomic absorption spectrophotometry. These spectrophotometric techniques cannot provide the sensitivity required to accurately detect the target elements in this low concentration range.

3.3.3 Surface Composition Leachable in Simulated Gastric Fluid

Three separate 100 mg particulate samples were taken from each size-fractionated composite sample and leached at room temperature. Each sample was placed in a covered beaker with 10 mL of the gastric fluid solution and stirred mechanically for a minimum of 18 hours. Using the same recovery procedure as the nitric acid digestates, the leachate was filtered and brought to a 100 mL final volume

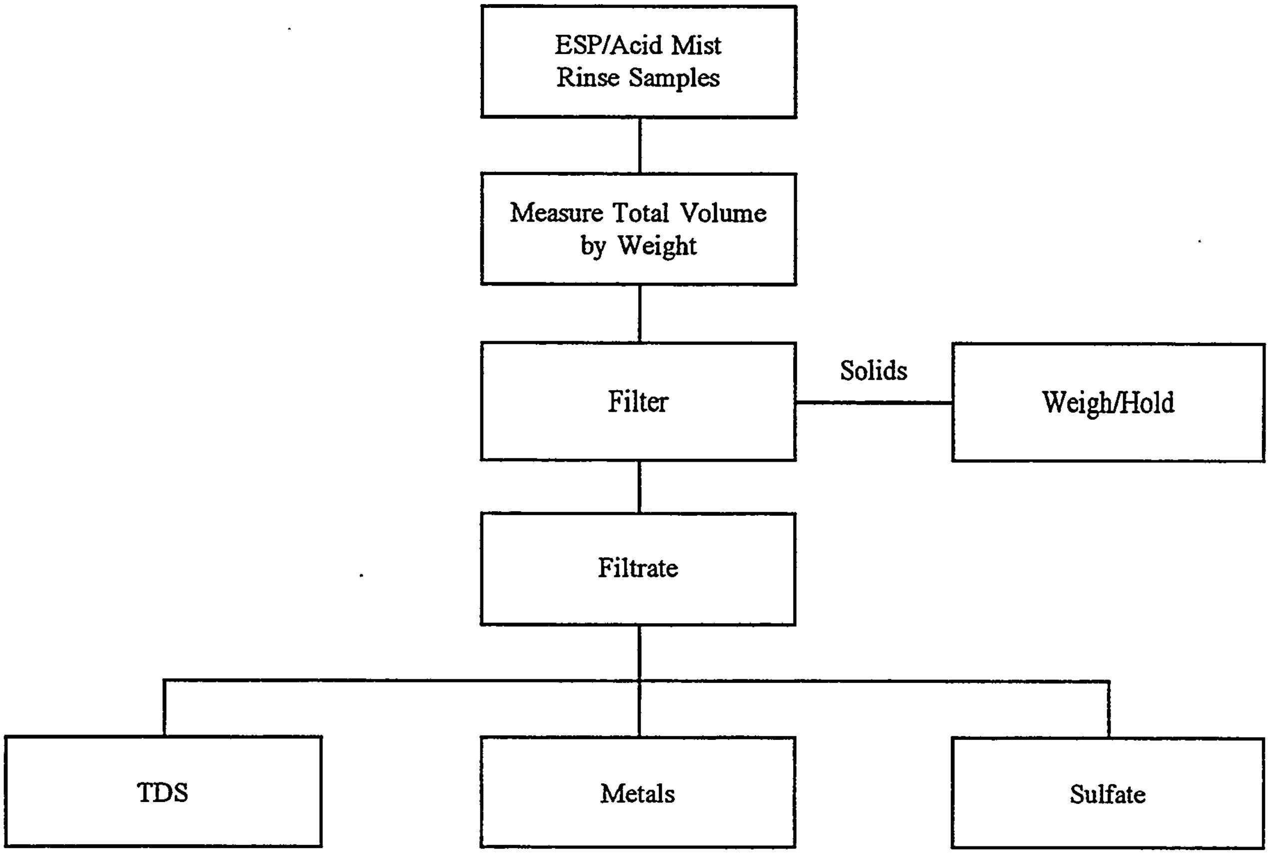


Figure 3-6
Analytical Matrix for ESP Rinse Samples

with DI water. Undiluted aliquots were analyzed by ICP-MS. In addition, matrix spikes were prepared using one of the three samples generated for each size fraction and those samples selected for spiking were identified for duplicate analyses. Gastric fluid matrix spikes were also prepared using the SPEX® ICP-MS calibrating solution and were prepared at 69 ppb for each of the target analytes except molybdenum. This spiking level was based on previous results obtained from this procedure applied to standard reference fly ash samples. Average concentrations in those prepared samples ranged from 0.2 to 110 ppb.

Because of the adverse matrix effects chloride poses for a number of the target elements when analyzed by ICP-MS, calibration standards were prepared from the gastric fluid matrix to provide calibration curves with the same potential bias present in the samples. Arsenic is one of the key elements that is susceptible to mass detection interferences. Argon and chlorine, with atomic weights of 39.95 and 35.45, respectively, tend to form the polyatomic $ArCl^+$ ion with a mass of 75.4 amu. The high chloride levels in the gastric fluid, coupled with argon as the source of the plasma, generate a signal from $ArCl^+$ that can overwhelm the arsenic signal at 74.9 amu.

3.3.4 Surface Composition Leachable in Acetic Acid

Particulate samples (100 mg) were placed in a covered beaker with 10 mL of the buffered acetic acid solution (pH 4.93) and stirred for a minimum of 18 hours. During this time, no additional pH adjustments were made to the acetic acid solution. Sample recovery and spiking was performed in the same manner as the gastric fluid leaching. The digestate was filtered and diluted to a 100 mL final volume before analysis by ICP-MS, and the same matrix spike and duplicate analysis scheme was used. With the exception of cyclone stages 2 and 3, three 100 mg samples were prepared for each size fraction. Cyclone stages 2 and 3, which represented the 6.3-1.7 micron particle size range, yielded insufficient sample to satisfy all of the sample analysis requirements. The 69 ppb spiking level was also based on previous results obtained from this procedure when applied to standard reference fly ash samples. Average concentrations in those prepared samples ranged from 0.7 to 224 ppb.

3.3.5 Surface Composition Available in Condensed Sulfuric Acid Mist

Not all of the solids collected by the high efficiency ESP were dry. Some of the sampling runs conducted when the average unit load was below 375 MW produced wet samples from excess sulfuric acid mist. Sample recovery was accomplished by rinsing with deionized water. These ESP sample fractions were composited and filtered through a 0.45 micron nitrocellulose membrane filter. The filtrate was split into three fractions for gravimetric analysis of total dissolved solids (TDS), sulfate analysis by ion chromatography, and soluble metals by ICP-MS. The filters and filtered solids were desiccated and weighed to determine the mass of the particulate fraction recovered. This approach is similar to the previous leaching procedures in that it addresses the availability of toxic metals associated with fly ash in the presence of condensed sulfuric or sulfurous acid mist.

3.3.6 Dilution Sampler Filter Preparation and Analysis

The Teflon®-coated glass fiber filters collected from the dilution sampler were also prepared and analyzed by the preceding techniques with the exception of GDMS and water leaching. Of the two filters arranged in parallel during each run, approximately 0.2 gram had accumulated on each before the excessive pressure drop across the filters forced an end to the run. Each filter was desiccated and weighed to determine the particulate loading. Each filter was then cut in half to produce a 100 mg sample of particulate for INAA, digestate, and leachate analyses. For the digestion and leaching procedures each filter half was cut into smaller pieces that would fit at the bottom of a 100 mL beaker prior to adding the leaching solutions. The filter halves prepared for neutron activation analysis were folded and rolled up for insertion in small polyethylene vials. Three blank filter halves from the same lot were also processed and analyzed by each technique to provide background corrections attributed to the filter matrix.

3.4 Results

The analytical results for each sample set are presented in Tables 3-11 through 3-14. Bulk composition, and surface composition as determined by nitric acid digestion, gastric fluid leaching, and acetic acid leaching, are given for each element and particle size range. Table 3-15 presents a comparison of the bulk and surface composition of the dry particulate matter collected in the ESP and the surface composition associated with the sulfuric acid mist collected in the ESP water rinses. All of the surface composition results have been blank-corrected and reported as the available analyte concentration in the particulate sample, as received. Coal and FGD slurry sample results are presented in Table 3-16.

Data flags are indicated where matrix spike recoveries did not meet the project-specified data quality objectives of 75-125% recovery of matrix spikes. The prevalence of data flags indicating poor spike recoveries is primarily a result of inadequate spiking levels for the concentrations present in the digestate and leachate samples. Based on previous leachate studies performed using standard reference fly ash material, prepared analyte concentrations were expected in the 0.2 to 250 ppb range. The concentrations for nearly all of the target analytes in the prepared solutions using the collected stack gas particulate from this site were substantially higher than expected, over two orders of magnitude higher in many cases. Sample dilutions had to be performed on the gastric fluid and acetic acid

Table 3-11
Bulk Composition of Stack Gas Particulates vs. Particle Size

Analysis	Cyclone Stage 1	Cyclone Stage 2[a]	Cyclone Stage 3	Cyclone Stage 4	Cyclone Stage 5	ESP Stage 6
Size Range (µm)	>6.3	6.3-2.7	2.7-1.7	1.7-0.8	0.8-0.5	<0.5
Target Elements (µg/g)[b]						
Arsenic	670 ± 290	1200	1700 ± 100	1900 ± 100	2300 ± 200	1900 ± 160
Barium	3800 ± 900	5600	8700 ± 2300	9200 ± 230	11000 ± 1400	14400 ± 1400
Beryllium (GDMS)	20 ± 9	NA	NA	76 ± 13	82 ± 11	80 ± 20
Cadmium	70 ± 100	100	240 ± 30	1480 ± 150	300 ± 20	90 ± 40
Chlorine	1100 ± 230	980	1500 ± 140	1050 ± 160	180 ± 40	150 ± 40
Chromium	33000 ± 11000	36000	5500 ± 300	7400 ± 800	3000 ± 400	1500 ± 150
Cobalt	370 ± 250	500	45 ± 5	80 ± 18	34 ± 3	22 ± 2
Copper	830 ± 140	800	820 ± 100	950 ± 90	1100 ± 300	840 ± 40
Fluorine (GDMS)	70 ± 140	NA	NA	24 ± 22	25 ± 4	5 ± 8
Lead (GDMS)	120 ± 50	NA	NA	3500 ± 5000	170 ± 110	180 ± 80
Manganese	2100 ± 240	2200	910 ± 70	1290 ± 60	530 ± 50	170 ± 20
Mercury	7 ± 4	<8	<7	<8	<8	<7
Molybdenum	150 ± 200	180	380 ± 220	330 ± 20	310 ± 9	400 ± 280
Nickel	14000 ± 11000	19000	2200 ± 300	3400 ± 800	1300 ± 100	670 ± 90
Phosphorus (GDMS)	850 ± 300	NA	NA	3000 ± 500	2500 ± 1500	3600 ± 1300
Selenium	300 ± 150	490	610 ± 90	720 ± 190	720 ± 30	780 ± 20
Vanadium	4800 ± 600	5700	8300 ± 200	9500 ± 400	10900 ± 1100	1800 ± 300
Major Elements (%)[b]						
Aluminum	42 ± 5.0	38	58 ± 13	47 ± 1.9	42 ± 3.7	2.7 ± 0.7
Calcium	4 ± 2.7	4	4 ± 4.4	19 ± 7.4	8 ± 2.8	6.0 ± 0.9
Iron	14 ± 5.4	13	6.1 ± 0.6	6.2 ± 0.3	4.3 ± 0.3	3.4 ± 0.2
Magnesium	0.8 ± 0.16	0.7	1.2 ± 0.2	0.80 ± 0.24	0.97 ± 0.08	0.08 ± 0.01
Potassium	1.0 ± 0.2	1.0	1.0 ± 0.4	1.0 ± 0.4	0.7 ± 0.17	0.9 ± 0.22
Sodium	0.16 ± 0.06	0.19	0.22 ± 0.02	0.15 ± 0.01	0.13 ± 0.02	0.10 ± 0.01
Strontium	0.10 ± 0.05	0.10	0.07 ± 0.03	0.07 ± 0.06	0.07 ± 0.08	0.040 ± 0.004
Titanium	1.0 ± 0.2	1.0	1.5 ± 0.2	1.3 ± 0.4	1.1 ± 0.3	1.1 ± 0.1

[a] Particulate mass collected in Cyclone Stage 2 permitted single analysis only.
[b] Average results expressed with uncertainty range at a 90% confidence interval.
NA = Not available; insufficient sample for analysis.

Table 3-12
Nitric Acid Leachable Composition of Stack Gas Particulates vs. Particle Size

Analysis	Cyclone Stage 1	Cyclone Stage 2	Cyclone Stage 3	Cyclone Stage 4	Cyclone Stage 5	ESP Stage 6
Size Range (µm)	>6.3	6.3-2.7	2.7-1.7	1.7-0.8	0.8-0.5	<0.5
Target Elements (µg/g)[a]						
Arsenic	550 ± 80	1000 ± 220	1200 ± 110[b]	1400 ± 150[b]	1600 ± 70[b]	2000 ± 140[b]
Barium	3400 ± 380	5300 ± 1300[b]	5400 ± 2200[b]	2100 ± 290[b]	2200 ± 530[b]	2500 ± 3600[b]
Beryllium	8 ± 1[c]	12 ± 4	19 ± 1[c]	10 ± 6	15 ± 4	26 ± 1
Cadmium	50 ± 19	80 ± 15	160 ± 70	830 ± 190	140 ± 50	110 ± 40
Chromium	13000 ± 600[d]	980 ± 220[d]	3900 ± 700[b]	4500 ± 50[b]	2200 ± 120[b]	1400 ± 40[b]
Cobalt	310 ± 8	150 ± 130	40 ± 9	70 ± 6	31 ± 2	25 ± 5
Copper	380 ± 60	300 ± 90	350 ± 60[b]	330 ± 70	320 ± 100	1600 ± 680[b]
Lead	80 ± 9	80 ± 20	100 ± 10	720 ± 900[a,b]	400 ± 410[b]	100 ± 220
Manganese	1300 ± 300[d]	880 ± 250	640 ± 160[b]	890 ± 60	340 ± 30	260 ± 20
Mercury	<0.44	<0.44	<0.44	2 ± 5[d]	<0.44[d]	<0.44[c]
Molybdenum	340 ± 30	300 ± 40	380 ± 40	410 ± 24	380 ± 10	530 ± 150
Nickel	12000 ± 260[d]	5300 ± 4900[b]	1900 ± 360[b]	2800 ± 300[b]	990 ± 100[b]	1300 ± 230[b]
Selenium	370 ± 20[d]	620 ± 100	710 ± 60[b]	870 ± 50[b]	950 ± 40[b]	1000 ± 250[b]
Vanadium	660 ± 100[d]	920 ± 320	1200 ± 130	1700 ± 80[b]	1700 ± 260[b]	1700 ± 170[b]

[a] Average results expressed with uncertainty range at a 90% confidence interval.

[b] Matrix spike recovery is below data quality objective range (75-125% recovery).

[c] Duplicate analysis results did not meet data quality objective (20% RPD).

[d] Matrix spike recovery exceeds data quality objective range (75-125% recovery).

Table 3-13
Gastric Fluid Leachable Composition of Stack Gas Particulates vs. Particle Size

Analysis	Cyclone Stage 1	Cyclone Stage 2[a]	Cyclone Stage 3	Cyclone Stage 4	Cyclone Stage 5	ESP Stage 6
Size Range (μm)	>6.3	6.3-2.7	2.7-1.7	1.7-0.8	0.8-0.5	<0.5
Target Elements (μg/g)[b]						
Arsenic	1800 ± 300[c]	1500	1900 ± 400[c]	1100 ± 200[c]	1300 ± 100[c]	1200 ± 1900[d]
Barium	160 ± 50[c]	280	270 ± 210[c]	330 ± 380[c]	320 ± 220[c]	140 ± 90[c]
Beryllium (GDMS)	8 ± 1[c]	7	15 ± 1[c]	16 ± 2[c]	17 ± 1[c]	12 ± 11[c]
Cadmium	40 ± 10[c]	510	160 ± 20[c]	1100 ± 310[c]	100 ± 20[c]	75 ± 30[c]
Chromium	5800 ± 1200[c]	6100	1700 ± 30[c]	2100 ± 240[c]	1600 ± 300[c]	640 ± 550[c]
Cobalt	200 ± 50[c]	210	28 ± 0.2[c]	60 ± 40[c]	30 ± 14[c]	10 ± 9[c]
Copper	430 ± 30[c]	1400	360 ± 10[c]	290 ± 20[c]	280 ± 20[c]	250 ± 210[c]
Lead (GDMS)	16 ± 5	670	12 ± 3	580 ± 390[c]	100 ± 14[c]	3 ± 3
Manganese	1100 ± 90[c]	1100	560 ± 40[c]	640 ± 10[c]	330 ± 60[c]	140 ± 120[c]
Mercury	8 ± 2[c]	7	7 ± 1[c]	3 ± 0.2	3 ± 1	3 ± 2
Molybdenum	150 ± 20	120	410 ± 20	460 ± 10	540 ± 70[c]	570 ± 420
Nickel	8400 ± 1800[c]	8900	1300 ± 30[c]	1900 ± 50[c]	900 ± 220[c]	570 ± 470[c]
Selenium	130 ± 10[c]	120[e]	340 ± 80[c]	310 ± 110[c]	480 ± 90[c]	530 ± 540[d]
Vanadium	1900 ± 270[c]	1600	2500 ± 90[c]	1900 ± 40[c]	2000 ± 100[c]	1500 ± 1300[c]

[a] Particulate mass collected in Cyclone Stage 2 permitted single analysis only.

[b] Average results expressed with uncertainty range at a 90% confidence interval.

[c] Matrix spike recovery is below data quality objective range (75-125% recovery).

[d] Matrix spike recovery exceeds data quality objective range (75-125% recovery).

[e] Duplicate analysis results did not meet data quality objective (20% RPD).

Table 3-14
Acetic Acid Leachable Composition of Stack Gas Particulates vs. Particle Size

Analysis	Cyclone Stage 1	Cyclone Stage 2	Cyclone Stage 3	Cyclone Stage 4	Cyclone Stage 5	ESP Stage 6
Size Range (µm)	>6.3	6.3-2.7	2.7-1.7	1.7-0.8	0.8-0.5	<0.5
Target Elements (µg/g)[a]						
Arsenic	10 ± 6^b	NA	NA	8 ± 7^b	90 ± 30^b	120 ± 150^b
Barium	220 ± 120	NA	NA	150 ± 75^b	130 ± 40	110 ± 40
Beryllium	5 ± 2^c	NA	NA	17 ± 0.4	20 ± 1	18 ± 3
Cadmium	40 ± 10	NA	NA	1100 ± 600^b	110 ± 4	90 ± 10
Chromium	2000 ± 100^b	NA	NA	1700 ± 150^b	1200 ± 210^b	760 ± 20^b
Cobalt	280 ± 50	NA	NA	80 ± 50	34 ± 10	22 ± 2
Copper	190 ± 30^d	NA	NA	300 ± 40^d	300 ± 70^d	370 ± 120^d
Lead	2 ± 2^e	NA	NA	500 ± 800^b	7 ± 10	3 ± 1
Manganese	1200 ± 50^b	NA	NA	850 ± 80	370 ± 46^b	240 ± 20
Mercury	4 ± 1^d	NA	NA	6 ± 1^c	4 ± 0.5	4 ± 0.4
Molybdenum	1 ± 0.4^c	NA	NA	3 ± 2^c	15 ± 9	20 ± 12
Nickel	4800 ± 6100^b	NA	NA	2500 ± 180^d	1300 ± 140^d	1300 ± 150^d
Selenium	25 ± 14	NA	NA	25 ± 9^{b,c}	42 ± 15^b	66 ± 14^b
Vanadium	10 ± 10^b	NA	NA	12 ± 10^{b,c}	140 ± 100^b	240 ± 180^b

[a] Average results expressed with uncertainty range at a 90% confidence interval.

[b] Matrix spike recovery exceeds data quality objective range (75-125% recovery).

[c] Duplicate analysis results did not meet data quality objective (20% RPD).

[d] Matrix spike recovery is below data quality objective range (75-125% recovery).

[e] Flags average result calculated from less than three data points. Outlying data point omitted.

NA = Not available; insufficient sample for analysis.

Table 3-15

Bulk and Extractable Composition of Particles in the less than 0.5 Micron Size Range

Element (µg/g)	Bulk Composition	Leachable by Nitric Acid	Leachable by Gastric Fluid	Leachable by Acetic Acid	Sulfuric Acid Mist Components in Water[a]
Arsenic	1900 ± 160	2000 ± 140	1200 ± 190	120 ± 150	750 ± 30
Barium	14400 ± 1400	2500 ± 3600	140 ± 90	110 ± 40	350 ± 10
Beryllium	80 ± 20	26 ± 1	12 ± 11	18 ± 3	87 ± 3
Cadmium	90 ± 40	110 ± 40	75 ± 30	90 ± 10	560 ± 10
Chlorine	150 ± 40	NA	NA	NA	NA
Chromium	1500 ± 150	1400 ± 40	640 ± 550	760 ± 20	11000 ± 200
Cobalt	22 ± 2	25 ± 5	10 ± 9	22 ± 2	220 ± 15
Copper	840 ± 40	1600 ± 680	250 ± 210	370 ± 120	290 ± 200
Fluorine	5 ± 8	NA	NA	NA	NA
Lead	180 ± 80	100 ± 220	3 ± 3	3 ± 1	22 ± 0.4
Manganese	170 ± 20	260 ± 20	140 ± 120	240 ± 20	2900 ± 200
Mercury	<7	<0.44	3 ± 2	4 ± 0.4	40 ± 20
Molybdenum	400 ± 280	530 ± 150	570 ± 420	20 ± 12	1400 ± 100
Nickel	670 ± 90	1300 ± 230	570 ± 470	1300 ± 150	15000 ± 1000
Phosphorus	3600 ± 1300	NA	NA	NA	NA
Selenium	780 ± 20	1000 ± 250	530 ± 540	66 ± 14	1200 ± 100
Vanadium	1800 ± 300	1700 ± 170	1500 ± 1300	240 ± 180	6700 ± 300

[a] Concentration reported in mg of element leached per kg of suspended solids recovered from ESP rinse samples.

Table 3-16
Elemental Composition of Coal and FGD Slurry Components

Analysis	Coal	FGD Scrubber Solids	FGD Scrubber Liquor[a]
Loss on Ignition (dry Wt.%)	87.37	--	--
Total Dissolved Solids (mg/L)	--	--	4300
Target Elements (µg/g)			
Arsenic	5	9.7	23
Barium	70	56	77
Beryllium	0.9	0.61	0.51
Cadmium	<0.1	1.0	0.30
Chlorine	2160	NA	NA
Chromium	17	14	0.79
Cobalt	2	1.8	4.0
Copper	13	13	<5
Fluorine	70	NA	NA
Lead	8	<4	<12
Manganese	26	42	326
Mercury	0.05	0.12	<0.04
Molybdenum	<3	2.6	256
Nickel	12	6.1	19
Phosphorus	100	NA	NA
Selenium	2	14	93
Vanadium	44	24	11
Major Elements (%)			
Aluminum	1.6	0.33	0.005
Calcium	0.25	20	17
Iron	1.33	0.60	0.01
Magnesium	0.06	0.41	3.0
Potassium	0.28	0.06	0.35
Sodium	0.06	0.01	0.40
Strontium	0.004	0.03	0.08
Titanium	0.08	NA	NA

[a] Element concentrations expressed in terms of µg/g of TDS.

NA = Not analyzed.

leachate samples in order to bring concentrations into the linear range of the mass detector. These factors significantly impacted the ability to measure the relatively low spiking levels in these samples.

In spite of the problems associated with the matrix spike recoveries, the bulk and leachable surface composition results for any given analyte, when plotted by particle size, are consistent. These plots are provided in Appendix A. As one would expect, the bulk composition analysis should produce the highest values relative to the acid leachate analyses. Correspondingly, the analytical results for the nitric acid digestate, the gastric fluid leachate, and the acetic acid leachate would be progressively lower based on the relative pH and less aggressive acidic attack inherent in these techniques. Although this appears to be the case for most of these analytes in each particle size range, what is surprising is the similarity in the available concentrations by each technique, including the water rinses of the ESP catch. This suggests that the stack gas particulates collected at this site have a high degree of solubility, and are unlike characteristic fly ashes with relatively insoluble alumina-silica matrices.

Also apparent from concentration versus particle size plots are trends that indicate some metals are present at higher concentrations in the smaller size fractions. Among the elements exhibiting this trend are arsenic, selenium, and vanadium.

The level of chromium and nickel in the larger size fractions collected indicates probable contamination of the sample from either the stainless steel cyclone sampling system, or corrosion products accumulating in the scrubber system or process ductwork.

3.5 Conclusions

Based on the data obtained in this test phase, it is apparent that the stack gas particulate emissions downstream of the wet scrubber at Widows Creek are atypical of coal fly ash. The toxic metals associated with these particulate emissions exhibit a higher degree of solubility in even the weaker leaching solutions used to simulate gastric fluid and the toxicity characteristic leaching procedure. Due to the relatively high levels of chromium and nickel found in the particulate samples, corrosion products from either the stainless steel sampling system or the process piping and ductwork are evident. Concentration effects in the smaller size fractions are also found for some of the more volatile metal species such as arsenic, and selenium.

4.0 PHASE II TESTING

Sampling activities for the Phase II sampling program were performed September 11, 1993 through October 14, 1993. Based on the testing and analytical results obtained during Phase I and plant modifications that were made to the scrubber and duct work on Unit 8, several changes were made to the technical approach for Phase II. These changes are summarized below:

- The dilution sampling approach was dropped due to the extremely short sampling periods that were obtainable.
- Samples were collected as a function of plant load by using two identical sampling systems. One was used exclusively during high-load operation, the other during low load operation.
- The number of particle size ranges collected was reduced from six to three.
- A full particle-size distribution was performed on the stack gas (cascade impactor).
- Size-fractionated bulk particulate was collected from the economizer outlet.
- Composite samples of the scrubber slurry were obtained.
- Sampling cyclones were Teflon® coated to minimize the potential for contamination from the sampling system's metallurgy.

In addition to these modifications to the sampling approach, the Widows Creek Power Plant also underwent some modifications. During Phase I severe corrosion of the ductwork was noticed. It was theorized that corrosion products from the duct could be a possible source of contamination for some of the metals. Prior to the Phase II effort, all of the ductwork into and out of the FGD unit was replaced. Also, the duct reheat line for this unit was removed.

The Phase II test plan was revised so that results from both a high- and low-load condition can be obtained during a single test effort, thereby addressing one of the primary objectives of the program; the effect of load on the surface composition of fine particles. Criteria for the selection of high- and low-load ranges involved an evaluation of the load pattern from the first test effort. This showed that the unit tended to operate in two general load ranges. During low-load conditions, the unit load varied generally between 250 and 350 MW. High-load conditions ranged from 400 to 500 MW. Therefore, 375 MW was selected as the dividing line between high- and low-load conditions. Unit loads greater than 375 MW were sampled with one sampling train, and loads less than 375 MW were sampled with the other sampling train. The two sampling trains were maintained in a ready mode, so that one sampling system could be kept running at all times. Also, in order to minimize any potential contamination from the sampling system itself, the cyclones were Teflon® coated.

Six size fractions were collected during the Phase I testing. An evaluation of the data generally indicated no statistical difference between the chemical characteristics of particles in any two to three adjoining stages. The number of cut-points was reduced from six to three in order to collect sufficient sample quantities under two separate load conditions. The same equipment was used to collect the samples; however, only the first and fourth cyclones were used prior to the ESP. This provided particle cut-points of nominally >6.4, 6.4-0.8, and <0.8 µm. The 6.4 micrometer cut-point is collected with the first cyclone in the set that was used previously. Since most of the particulate is expected to be smaller than 6.4 µm, this cut-point was kept to provide consistency between the two test phases. It is hypothesized that particles in the 2-5 µm size range are more likely to be permanently entrained in the lungs and, therefore, pose the greatest potential health risk. Particles larger than 5 µm in diameter tend to be trapped in the mucous lining of the upper respiratory tract where they are more easily expelled. Similarly, extremely fine particles (<1 µm) tend to remain suspended and are exhaled. The three cut-points selected for the Phase II test closely reflect these pertinent size ranges given the desire to produce size fraction data comparable to that obtained during Phase I.

The relative mass of particles recovered in each of the six size fractions collected during Phase I suggests that most of the particles in this second size fraction (6.4-0.8 µm) are in the 2.5-3.7 µm range. To accurately identify the particle size and mass distribution across this relatively broad size range, three particle size distribution (PSD) samples were collected at the stack using a University of Washington impactor. This additional PSD data are beneficial not only for identifying the predominant particle sizes in each of the three cut-points, but also for estimating the emission rates of each size fraction. Since there was no statistical difference in surface and bulk composition between the particles in the three adjacent size ranges comprising this second cut-point, determining the predominant size fraction and relative emission rate can be significant from a toxicological perspective in estimating potential health risks.

Additional process samples were collected during Phase II so that questionable data could be more fully qualified. In addition to the high- and low-load size fractionated and particle size distribution samples from the stack, size-fractionated particulate samples were also collected from the inlet to the FGD system. Testing was performed using a modification of EPA Method 17 for in-stack particulate collection. Sampling was performed in a similar manner as the stack with the exception of using a high-capacity Anderson cascade impactor for particle separation and collection. Particulate matter was collected from a single point in the inlet duct. Due to physical constraints, the cascade impactor assemble could not be inserted into the duct, so a long probe and nozzle were inserted into the duct for extraction of the particulate material. Therefore, although the size fractionation from this sampling assembly is considered representative, the absolute mass obtained for each size fraction is not suitable for any type of mass flow calculations as there were considerable losses in the extended nozzle and probe. The high-capacity Andersen cascade impactor separates the particles into four fractions using a combination of impaction and cyclonic separation. Samples of the FGD scrubber liquor and inlet feed coal were also collected. These samples provide additional information for the overall data evaluation.

4.1 Sampling

Table 4-1 presents the test periods for each of the sample trains used during this program. Economizer outlet samples were collected during the beginning of the program. These samples were collected for comparison only and were related to the high-load conditions.

4.1.1 Unit Load

Size-fractionated particulate samples were collected from the stack during two distinct load conditions. The average unit load during collection of the high-load samples was 483 MW. Average unit load during low-load sample collection was 323 MW. The coefficients of variation (CVs = 100 x standard deviation/mean) and load ranges are presented in Table 4-2. Based on data collected during both test phases, these load ranges appear consistent with typical high- and low-load operation of this unit.

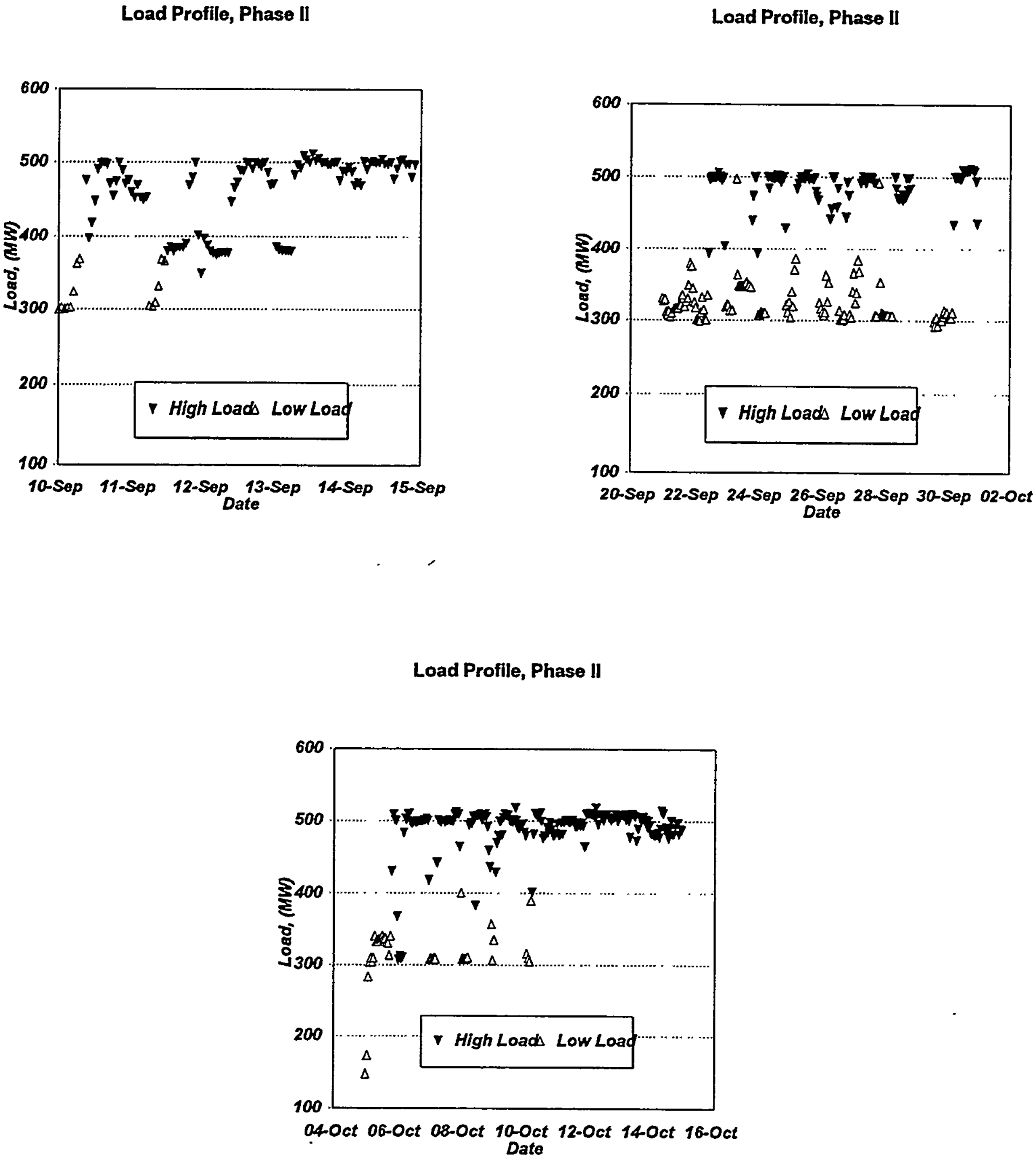
A 375-MW limit was specified for separating high- and low-load sampling conditions based on the unit load data collected during test Phase I. During high-load sample collection in Phase II, the unit load dipped below 375 MW for four consecutive hours. During low-load sample collection, two separate hourly data points were recorded above 375 MW. Neither of these out-of-limit conditions is expected to affect the sample representation for either load range since this represents less than 2% of the total sample collection time. The unit load data have been plotted for the entire sample collection period and are presented in Figure 4-1.

4.1.2 Particle Sample Size Ranges

The average size ranges for the size-fractionated particulate samples are shown in Table 4-3 along with the total amount of material collected for each particle size range. These particle sizes are presented as aerodynamic particle diameters rather than physical diameters. Aerodynamic diameters assume a spherical particle shape with a density of 1 g/cc. The total sample mass collected in each size fraction from the stack and the economizer outlet are also presented.

Table 4-1
Widows Creek Unit 8—Phase II Test Times

Train	Location	Load Condition	Run No.	Date	Time
High-Capacity Anderson	Economizer Outlet	High	1	09-10-93	0824-1050
		High	2	09-10-93	1139-1420
		High	3	09-11-93	0848-1254
		High	4	09-11-93	1343-1753
		High	5	09-12-93	0818-1438
U of W Impactor - (PSD)	Stack	High	1	09-12-93	0830-1330
		High	2	09-26-93	1300-1433
		Low	3	09-27-93	1300-1823
Cyclade - ESP	Stack	Low	1	09-11-93	0952-1710
		High	1	09-11-93	2205-1805
		High	2	09-12-93	1830-1925
		High	3	09-13-93	1955-2130
		Low	2	09-20-93	1040-2105
		High	4	09-21-93	2150-2327
		Low	3	09-23-93	0005-0655
		Low	4	09-23-93	1240-2015
		High	5	09-24-94	0940-2218
		Low	5	09-24-93	2238-0600
		High	6	09-25-93	0616-2334
		Low	7	09-25-93	2342-0650
		High	7	09-26-93	0712-2210
		Low	8	09-26-93	2315-0600
		High	8	09-27-93	0605-1635
		Low	9	09-27-93	1720-0625
		High	9	09-28-93	0640-1625
		Low	10	09-30-93	1200-0638
		High	10	10-01-93	0655-0550
		High	11	10-02-93	0700-0940
		Low	11	10-05-93	1000-1800
		High	12	10-06-93	1010-0052
		Low	12	10-07-93	0104-0530
		High	13	10-07-93	0600-0030
		Low	13	10-08-93	0040-0545
		High	14	10-08-93	0620-2310
		Low	14	10-08-93	2325-0517
		High	15	10-10-93	0100-1510
		High	16	10-11-93	1152-1252
		High	17	10-12-93	1300-2108
		High	18	10-13-93	2133-1750


Load Profile, Phase II

Load Profile, Phase II

Load Profile, Phase II

Figure 4-1
Phase II Load Profiles

Table 4-2
Unit Load

Sampling Condition	Average	CV	Max.	Min.
High Load	483 MW	7.7	519	308
Low Load	323 MW	10.9	498	149

Table 4-3
Size-Fractionated Particulate Samples

	Stage 1	Stage 2	Stage 3
Stack (Cyclone/ESP)			
Particle-Size Range, μm	>6.4	6.4 - 0.8	<0.8
Collected Mass (High Load), grams	0.5522	0.6580	4.9670
Collected Mass (Low Load), grams	0.6914	0.1979	1.6668
Economizer Outlet (H C Andersen)			
Particle-Size Range, μm	>7.5	7.5-1	<1
Collected Mass (High Load), grams	60.7	18.7	9.4

These size ranges are consistent with the particle sizes obtained during Phase I testing. The Stage 1 fraction is unchanged between test Phases I and II (Phase I = >6.3 μm); however, three cyclone stages from Phase I were combined in Phase II through elimination of two cyclones. The size fractions collected in stages 2, 3, and 4 during Phase I (6.3-2.7, 2.7-1.7, and 1.7-0.8 μm) are reflected in the Stage 2 sample collected during Phase II (6.4 - 0.8 μm). The last two stages from Phase I (0.8-0.5 and <0.5 μm) were effectively combined by elimination of the final cyclone stage during Phase II sampling. Stage 3 samples were collected by the high efficiency ESP and represent particles less than 0.8 μm in size. The consistency between the Phase I and Phase II size range data enables direct comparisons of chemical composition data from the two test phases since they represent the same particle ranges when combined.

Since the particle size ranges collected by the cyclone/ESP are very broad, additional samples were collected at the stack with a University of Washington (U of W) cascade impactor to determine a more detailed particle size distribution.

4.1.3 Particle-Size Distribution (PSD)

Three PSD samples were collected during Phase II using a U of W cascade impactor. Two samples were obtained during high-load conditions and 1 sample under low load conditions. The U of W impactor was configured with ten impactor stages and a final filter to provide eleven size fractions ranging from >10 μm to <0.10 μm. These PSD measurements identify the predominant particle sizes represented by each of the three cyclone stages. Figure 4-2 presents the differential mass concentration plots of the U of W PSD data for high- and low-load conditions with the cyclone/ESP system stages identified for comparison.

Figure 4-2 illustrates the predominance of particles collected in the ESP stage (<0.8 μm fraction) are between 0.8 and 0.3 μm. The broad size range of cyclone Stage 2 (6.3 - 0.8 μm fraction) is primarily represented by particles in the 0.8 to 2 μm size range. The particle size distribution within the broad size ranges collected by the Cyclade/ESP system is an important consideration when correlating the enrichment of trace elements with smaller particles. The chemical characteristics of each broad sample size range are representative of the particle sizes actually collected and do not necessarily reflect the chemistry of an even distribution of particles across the entire size range of any given stage.

4.1.4 Particulate Loading

Particulate loading (and mass emission rates) were not an original program objective. However, upon analysis of the data and the results of other (DOE) studies performed during the duration of this project, particulate loading has been estimated for the calculation of comparative mass emission rates. The total particulate mass collected with each U of W impactor, cyclone/ESP sample, and high-capacity Anderson impactor run was used to estimate particulate loading at the inlet and outlet of the venturi scrubber system. Wall losses through each of these sampling devices tend to bias the particulate loading results low when compared to standard EPA Method 5 measurements. These mass loadings are used to calculate emission factors for each particle size range to serve as an indicator of relative exposure when compared to the emission factors for other particulate control devices associated with coal-fired utility boilers.

Table 4-4 presents the flue gas particulate loadings determined from the U of W impactor, the cyclone/ESP system, and the high-capacity Andersen impactor data. The particulate loading of the stack gas (scrubber outlet) by size fraction is also presented for both high- and low-load conditions. Emission factors and particulate removal efficiency are discussed in Section 5.

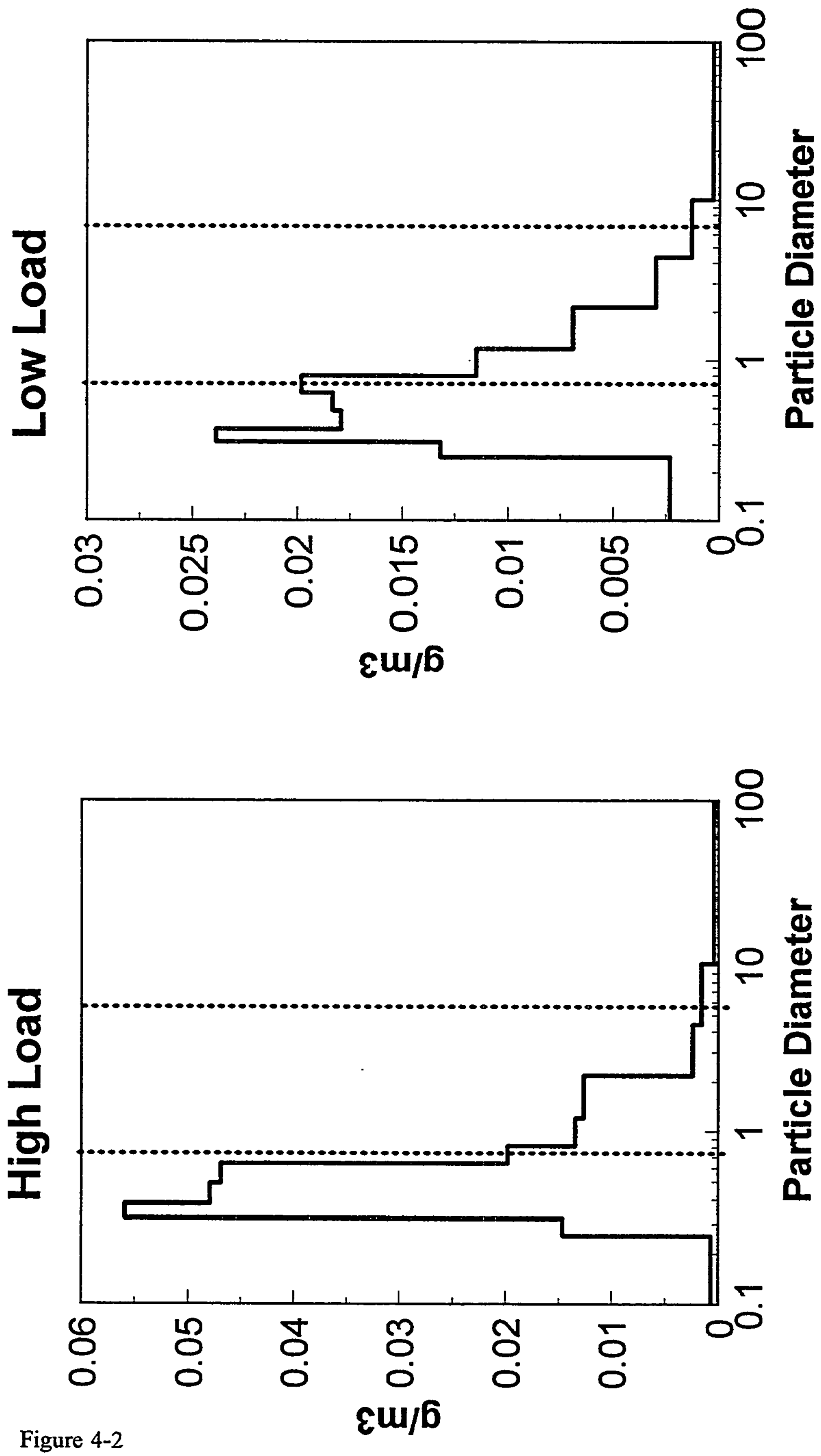


Figure 4-2
University of Washington Differential Mass Concentration Plots

Table 4-4
Particulate Loading

	Cyclone/ESP	U of W Impactor	H C Andersen
Estimated Particulate Loading [a]			
Stack (High Load)	16	29	--
Stack (Low Load)	15	16	--
Economizer outlet (High Load)	--	--	1,400
Particulate Loading by Size Fraction [a]			
Stack (High Load) Stage 1	1.4 (8.7%)		
Stack (High Load) Stage 2	1.6 (10.1%)		
Stack (High Load) Stage 3	13 (81.2%)		
Stack (Low Load) Stage 1	3.9 (26.6%)		
Stack (Low Load) Stage 2	1.1 (7.8%)		
Stack (Low Load) Stage 3	9.6 (65.6%)		

[a] All values mg/Nm^3.

4.2 Analytical Approach

Composite gas particulate samples were prepared and analyzed for metals by numerous techniques to provide a bulk sample concentration and three different extractable concentrations. The bulk concentration analysis accounts for the total elemental concentration of the sample, whereas the extractable concentration relates to the metal concentration available under different acidic leaching environments. In addition to the gas particulate samples, coal and FGD slurry samples were also analyzed to help qualify the gas particulate results and provide data for metal source identification. This section describes the preparation and analysis of these gas particulate, coal, and FGD slurry samples. Included at the end of this section is a summary of the analytical quality control activities. Detailed tables showing the sample analyses performed for each matrix are presented in Tables 4-5 through 4-8.

4.2.1 Gas Particulate Samples

Samples representing the economizer outlet flue gas particulate matter, and the particulate matter emitted from the stack under high- and low-load operation, were collected in three separate size fractions for analysis. Each sample was prepared and analyzed simultaneously for bulk and extractable metal concentrations. Bulk concentrations were determined by instrumental neutron activation (INAA)[1] and glow discharge mass spectrometry (GDMS)[2]. Inductively coupled plasma-atomic emission spectrometry (ICP-AES)[3] and cold vapor atomic absorption spectrophotometry (CVAAS)[4] were also used following complete acid dissolution to provide data for metals that were undetected or determined unreliably by INAA and GDMS. Samples prepared for extractable metal concentrations were leached using three different solutions. In order of the most to least aggressive are: 1) a nitric acid digestion, 2) an 18-hour leaching in simulated gastric fluid, and 3) an 18-hour leach in a buffered acetic acid solution. Analysis of the nitric acid digestates was used to represent the highest degree of availability for metals not bound in the alumina-silica fly ash matrix. The simulated gastric fluid and the buffered acetic acid leachates were analyzed to reflect the availability of metals due to ingestion and ground water leaching, respectively. The digestates/leachates were analyzed by inductively coupled plasma mass spectrometry (ICP-MS)[5], ICP-AES, graphite furnace atomic absorption spectrophotometry (GFAAS)[6], and CVAAS. An overview of the sample preparation and analysis plan for the size-fractionated particulate samples is presented in Figure 4-3.

Bulk Concentration Analysis

Bulk analyses of the flue gas particulate matter were performed using two direct instrumental analysis techniques: neutron activation and glow discharge mass spectrometry. After these results were evaluated, samples were digested and analyzed by ICP-AES and CVAAS as supplemental analytical

Table 4-5
Phase II Bulk Concentration Analytical Matrix

Sample I.D.	INAA	GDMS	ICP-AES
Fly Ash Standard 1[a]	3X	3X	--
Fly Ash Standard 2[a]	3X	3X	--
Stack-High Load Cyclone Stage 1	2X[b]	3X	X
Stack-High Load Cyclone Stage 2	3X	3X	X
Stack-High Load ESP	3X	3X	X[c]
Stack-Low Load Cyclone Stage 1	3X	3X	X
Stack-Low Load Cyclone Stage 2[b]	X	X	X
Stack-Low Load ESP	3X	3X	X
Economizer Outlet Stage 1	X	--	X
Economizer Outlet Stage 2	X	--	X
Economizer Outlet Stage 3	X	--	X

[a] Standard 1 = Brammer fly ash standard IRNT-12-1-02; Standard 2 = NIST 1632a fly ash standard.

[b] A sufficient amount of material was not available to provide three 100-mg samples for analysis.

[c] Matrix spike/matrix spike duplicate analyses performed to assess analytical bias and precision.

Table 4-6
Phase II Nitric Acid Digestate Analytical Matrix

Sample I.D.	ICP-MS	GFAAS (As,Se)	CVAAS (Hg)	ICP-AES
Digestion Blank	3X[a]	3X	3X	X
Stack-High Load Cyclone Stage 1	3X[a]	3X	3X	X
Stack-High Load Cyclone Stage 2	3X[a]	3X	3X[b]	X[b]
Stack-High Load ESP	3X[a]	3X	3X	X
Stack-Low Load Cyclone Stage 1	3X[a]	3X	3X	X
Stack-Low Load Cyclone Stage 2[c]	X	X	X	X
Stack-Low Load ESP	3X[a]	3X	3X	X
Economizer Outlet Stage 1[d]	X	X	X[b]	X
Economizer Outlet Stage 2[d]	X	X	X	X
Economizer Outlet Stage 3[d]	X[a]	X	X	X
Fly Ash Standard 1[e]	3X[a]	3X[b]	3X	X
Fly Ash Standard 2[e]	3X[a]	3X	3X	X

[a] Matrix spikes and analytical duplicates were run by ICP-MS on one of each size fraction sample to assess analytical bias and precision.

[b] Matrix spike/matrix spike duplicate analyses performed to assess analytical bias and precision.

[c] A sufficient amount of material was not available for triplicate analysis by this technique.

[d] Particulate samples from the high-capacity Andersen impactor.

[e] Standard 1 = Brammer fly ash standard IRNT-12-1-02; Standard 2 = NIST 1632a fly ash standard.

Table 4-7
Phase II Gastric Fluid Leachate Analytical Matrix

Sample I.D.	ICP-MS	GFAAS (As,Se)	CVAAS (Hg)	ICP-AES
Digestion Blank	3X[a]	3X	3X	X
Stack-High Load Cyclone Stage 1	3X[a]	3X[b]	3X	X
Stack-High Load Cyclone Stage 2	3X[a]	3X	3X	X
Stack-High Load ESP	3X[a]	3X	3X[b]	X
Stack-Low Load Cyclone Stage 1	3X[a]	3X	3X	X
Stack-Low Load Cyclone Stage 2[c]	X	X	X[b]	X
Stack-Low Load ESP	3X[a]	3X	3X	X
Economizer Outlet Stage 1[d]	X	X	X	X
Economizer Outlet Stage 2[d]	X	X[b]	X	X[b]
Economizer Outlet Stage 3[d]	X[a]	X	X	X
Fly Ash Standard 1[e]	3X[a]	3X[b]	3X	X
Fly Ash Standard 2[e]	3X[a]	3X	3X	X

[a] Matrix spikes and analytical duplicates were run by ICP-MS on one of each size fraction sample to assess analytical bias and precision.

[b] Matrix spike/matrix spike duplicate analyses performed to assess analytical bias and precision.

[c] A sufficient amount of material was not available for triplicate analysis by this technique.

[d] Particulate samples from the high-capacity Andersen impactor.

[e] Standard 1 = Brammer fly ash standard IRNT-12-1-02; Standard 2 = NIST 1632a fly ash standard.

Table 4-8
Phase II Acetic Acid Leachate Analytical Matrix

Sample I.D.	ICP-MS	GFAAS (As,Se)	CVAAS (Hg)	ICP-AES
Digestion Blank	3X[a]	3X	3X	X
Stack-High Load Cyclone Stage 1	3X[a]	3X	3X	X
Stack-High Load Cyclone Stage 2	3X[a]	3X[b]	3X	X[b]
Stack-High Load ESP	3X[a]	3X	3X[b]	X
Stack-Low Load Cyclone Stage 1	3X[a]	3X[b]	3X	X
Stack-Low Load Cyclone Stage 2[c]	X	X	X	X
Stack-Low Load ESP	3X[a]	3X	3X	X
Economizer Outlet Stage 1[d]	X	X	X[b]	X
Economizer Outlet Stage 2[d]	X	X	X	X
Economizer Outlet Stage 3[d]	X[a]	X[b]	X	X
Fly Ash Standard 1[e]	3X[a]	3X[b]	3X	X
Fly Ash Standard 2[e]	3X[a]	3X[b]	3X	X

[a] Matrix spikes and analytical duplicates were run by ICP-MS on one of each size fraction sample to assess analytical bias and precision.

[b] Matrix spike/matrix spike duplicate analyses performed to assess analytical bias and precision.

[c] A sufficient amount of material was not available for triplicate analysis by this technique.

[d] Particulate samples from the high-capacity Andersen impactor.

[e] Standard 1 = Brammer fly ash standard IRNT-12-1-02; Standard 2 = NIST 1632a fly ash standard.

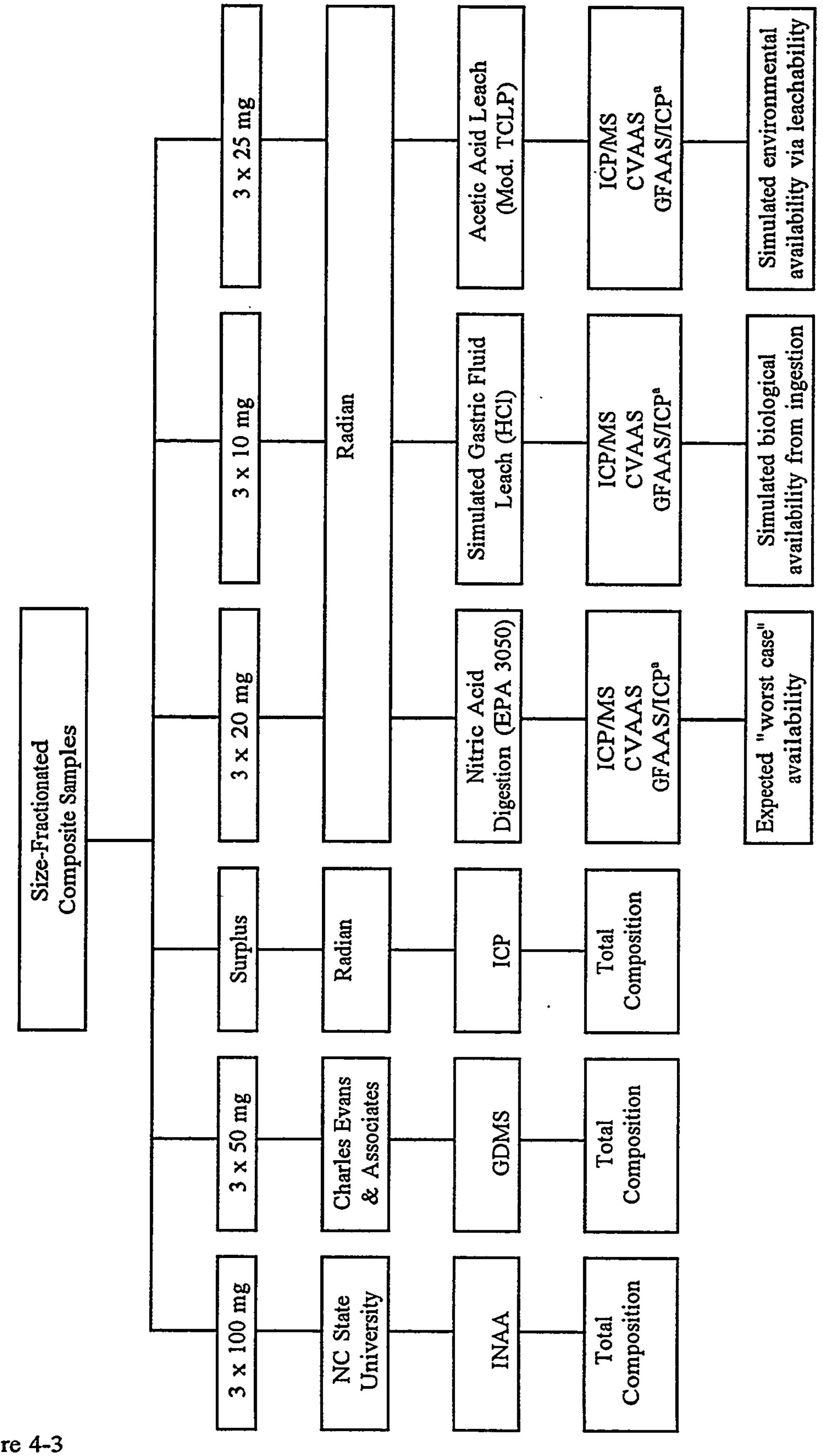


Figure 4-3
Sample Distribution and Analysis Plan—Phase II

[a] ICP analysis on one sample only.

techniques. ICP-AES was used for bulk concentration data for beryllium, lead, copper, nickel, and calcium. Mercury was also analyzed by CVAAS since it was not detected by INAA. Additional elements reported by this technique include manganese, potassium, and zinc. Samples were prepared by a mixed-acid digestion in a closed microwave oven digestion vessel to prevent potential losses of volatile trace elements during digestion.

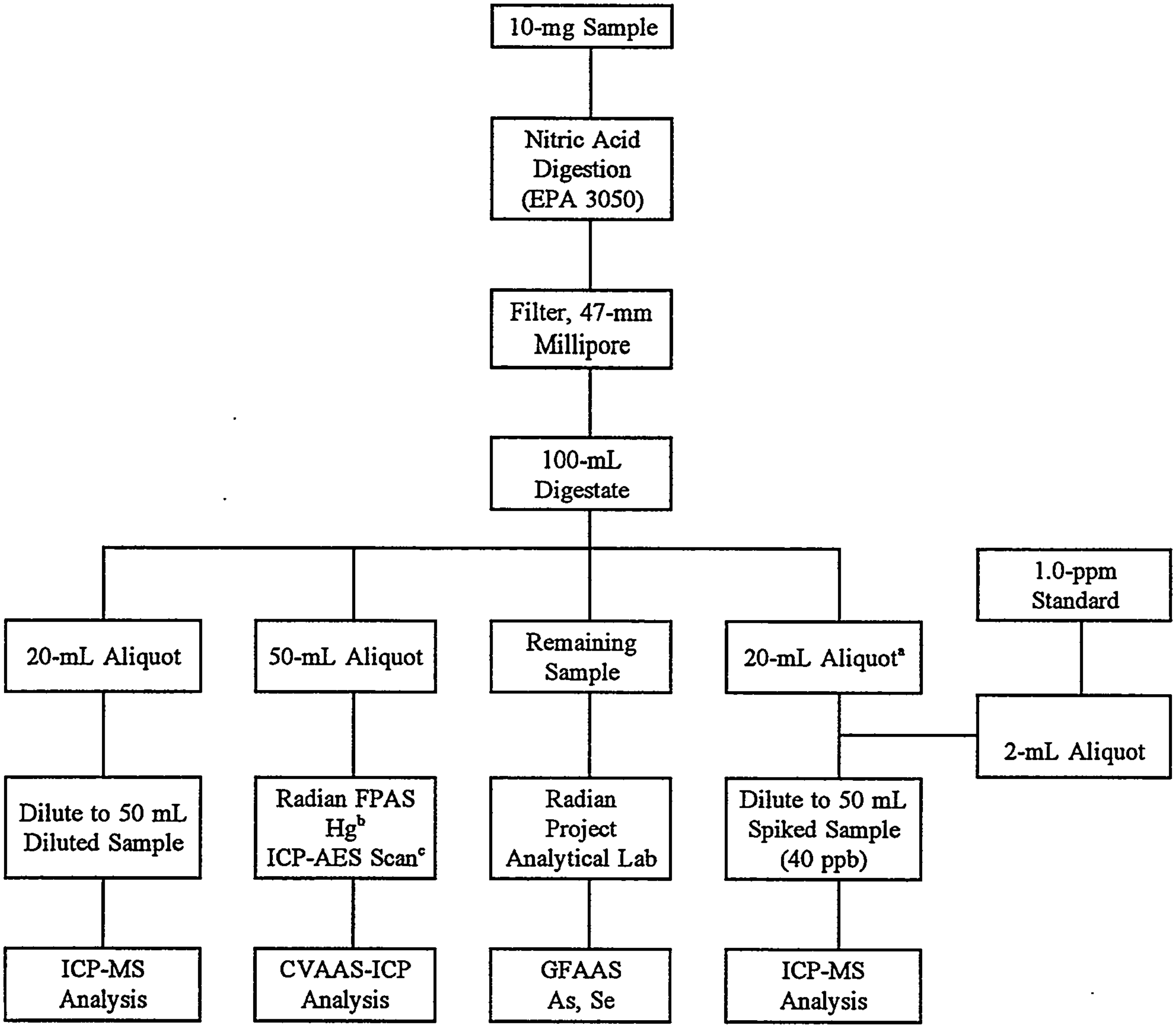
The apparent density of three gas particulate samples was also performed following a thorough evaluation of the concentration data. The analyzed samples were the Stage 3 (ESP) samples collected from the stack under both high- and low-load conditions and the Stage 2 samples collected at the economizer outlet. These were the only samples with sufficient material remaining to perform this test. Apparent density measurements were made by measuring the volume displacement of methanol by a known mass of solid sample[7].

Extractable Concentration by Nitric Acid Digestion

All particulate composite samples were digested by EPA Method 3050[8]. A 10-mg sample of each size-fraction was digested, filtered through a 0.45-micron nitrocellulose membrane filter, and brought to a 100-mL final volume. Triplicate sample preparations were made for all stack gas samples except the micron-size range collected during low load where the collected sample mass allowed the preparation of only a single sample. Single samples of the economizer outlet samples were prepared. To determine potential matrix interferences, one of the three samples generated for each size fraction was selected as the source for a matrix spike. The sample selected for spiking was also identified for duplicate analysis to determine analytical precision. The digestates were analyzed by ICP-MS for all of the target elements and also by GFAAS for arsenic and selenium, and CVAAS for mercury. One of the three prepared samples was also analyzed by ICP-AES for determining the major ash constituents and to provide comparative data with the ICP-MS results. Figure 4-4 presents a detailed sample preparation and analysis flow diagram for the nitric acid digestates.

Extractable Concentration Leachable in Simulated Gastric Fluid

A 10-mg particulate sample was taken from each size-fractionated composite sample and leached at room temperature. Stack gas samples were prepared in triplicate again except for the micron-size range collected during low load. Each sample was placed in a covered beaker with 10 mL of the gastric fluid solution and stirred mechanically for a minimum of 18 hours. Using the same recovery and analysis procedure as the nitric acid digestates, the leachate was filtered and brought to a 100-mL final volume with DI water.



[a] Matrix spike performed on one of the three triplicate samples only.

[b] All samples analyzed for Hg by CVAAS.

[c] One sample split for ICP-AES multi-element scan.

Figure 4-4
Nitric Acid Digestion Sample Preparation and Analysis

Samples were analyzed by ICP-MS, ICP-AES, CVAAS (Hg), and GFAAS (As and Se). In addition, matrix spikes were prepared using one of the three samples generated for each size fraction and those samples selected for spiking were identified for duplicate analyses. Figure 4-5 summarizes the gastric fluid leachate sample preparation and analysis.

Surface Composition Leachable in Acetic Acid

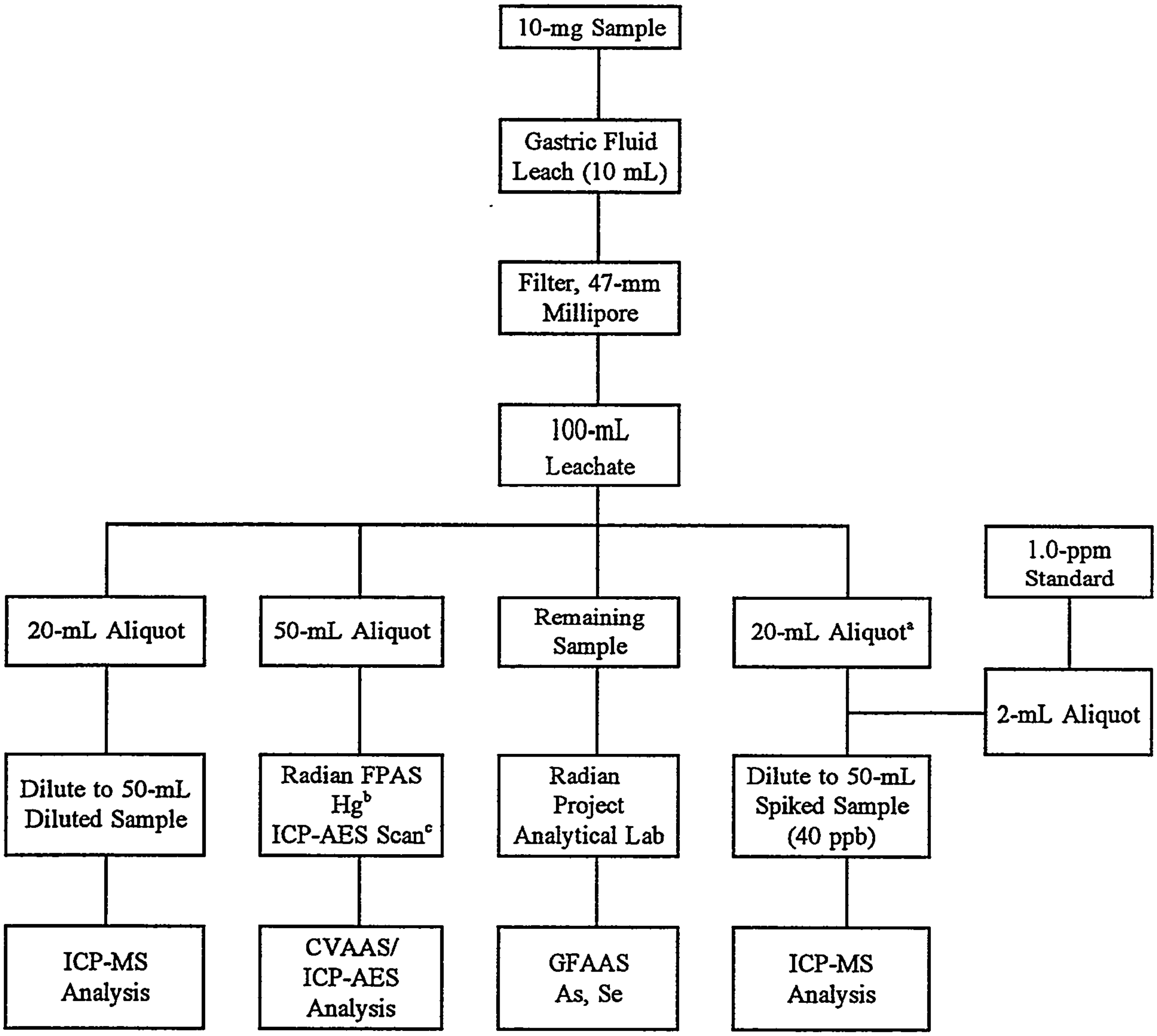
Particulate samples (25 mg) were placed in a covered beaker with 10 mL of the buffered acetic acid solution (pH 4.93) and stirred for a minimum of 18 hours. During this time, no additional pH adjustments were made to the acetic acid solution. Sample recovery and spiking were performed in the same manner as the gastric fluid leaching. The digestate was filtered and diluted to a 100 mL final volume before analysis by ICP-MS, ICP-AES, CVAAS (Hg), and GFAAS (As and Se). The same matrix spike and duplicate analysis scheme was used as described previously for the nitric acid and gastric fluid samples. Triplicate samples were prepared for all samples except the economizer outlet samples and the low load sample representing the micron particle size range. Figure 4-6 presents the acetic acid leachate sample preparation and analysis activity.

4.2.2 Coal Analysis

A single coal composite sample was sent to Commercial Testing and Engineering Company for metals and ash analysis. The coal sample was prepared according to standard ASTM Methods and analyzed by the techniques summarized in Table 4-9.

4.2.3 FGD Slurry Analysis

Individual FGD slurry samples were composited to form a single sample. The composite sample was filtered to separate the solid and aqueous phases, which were both submitted for analysis. The FGD solids were prepared by a mixed acid digestion in a closed microwave digestion vessel and analyzed by ICP-AES and GFAAS (As, Cd, Pb, Se). Mercury was prepared and analyzed separately by CVAAS by EPA Method 7471. The aqueous-phase sample was prepared for analysis by acid digestion according to EPA Method 3020[9]. The aqueous digestate was also analyzed by ICP-AES and GFAAS. A separate undigested aliquot was prepared and analyzed for mercury by CVAAS by EPA Method 7470[10].

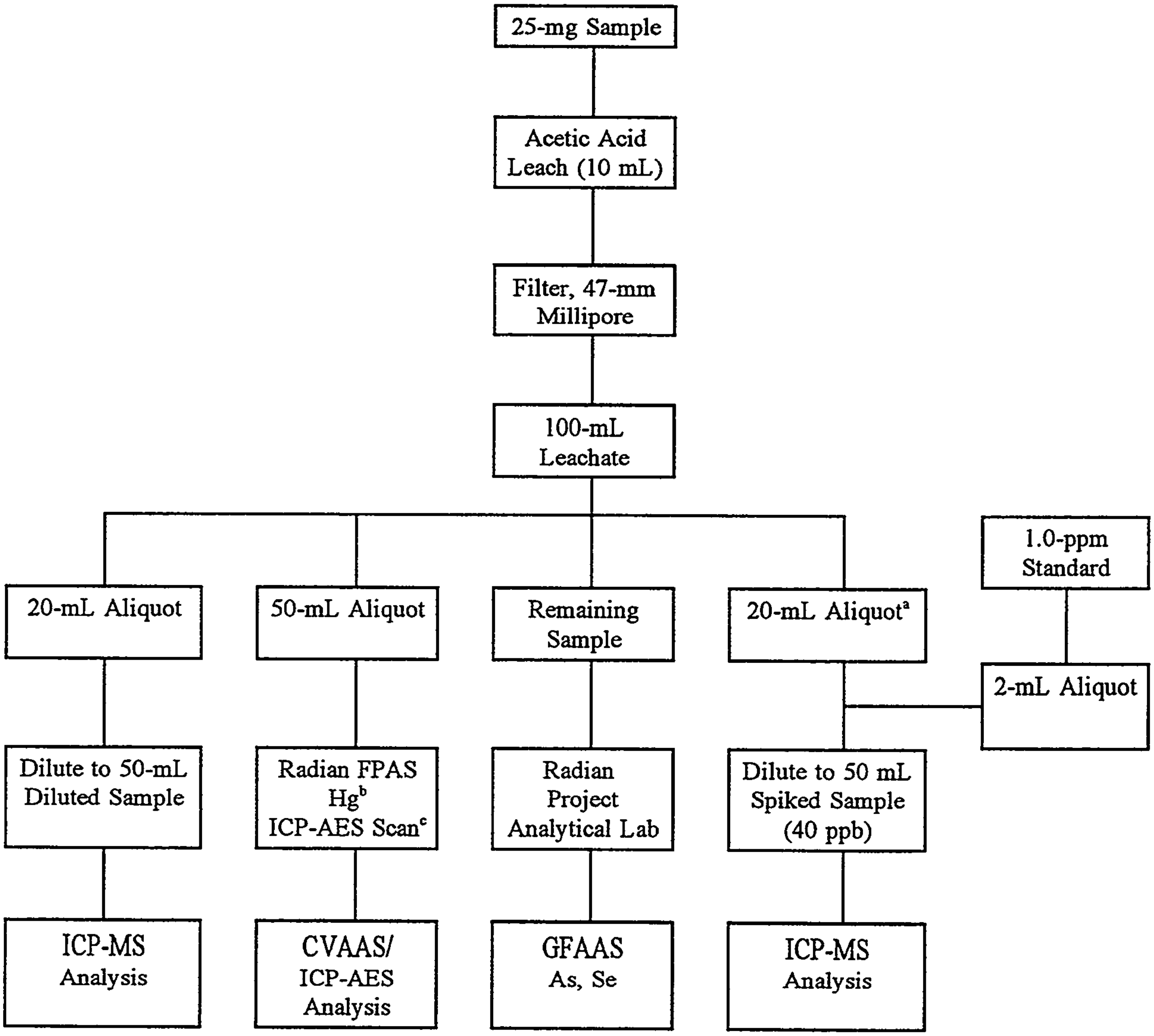


[a] Matrix spike performed on one of the three triplicate samples only.

[b] All samples analyzed for Hg by CVAAS.

[c] One sample split for ICP-AES multi-element scan.

Figure 4-5
Gastric Fluid Leachate Sample Preparation and Analysis



[a] Matrix spike performed on one of the three triplicate samples only.

[b] All samples analyzed for Hg by CVAAS.

[c] One sample split for ICP-AES multi-element scan.

Figure 4-6
Acetic Acid Leachate Sample Preparation and Analysis

Table 4-9
Coal Analysis Summary

Analyte	Sample Preparation	Analysis
Ash	ASTM D3174[11]	Gravimetric
Ash Minerals[a]	ASTM D4326[12]	XRF[b]
Trace Elements[c]	ASTM D3683[13]	ICP-AES
As, Cd, Pb, Se	ASTM D3683/D3684[14]	GFAAS
Hg	Dbl. gold amalgamation[15]	CVAAS
Chloride	ASTM D4208[16]	SIE[d]
Fluoride	ASTM D3761[17]	SIE

[a] Ash minerals: Al_2O_3, CaO, Fe_2O_3, MgO, K_2O, Na_2O, SiO_2, SrO, and TiO_2.
[b] X-ray fluorescence.
[c] Trace elements by ICP-AES: Ba, Be, Cr, Co, Cu, Mn, Mo, Ni, P, and V.
[d] Specific ion electrode.

4.3 Quality Control

The objectives of this program to identify differences in elemental concentrations as a function of unit load and particle size requires multiple analyses to provide a statistical basis for comparison and sufficient quality control (QC) to qualify those analytical results. Blanks, matrix spikes, matrix spike and analytical duplicates, and standard reference materials (SRM) were prepared and analyzed to determine the precision and bias of the preparatory and analytical techniques. Tables 4-5 through 4-8 present the sample preparation and analysis matrix for each of the preparation techniques. Digestion blanks and SRM samples are identified in these tables and selected samples are footnoted where matrix spikes and duplicate analyses were performed.

At the onset of the program, data quality objectives were established to serve as benchmarks for qualifying each analytical technique's performance with the various samples. These objectives for SRM and spike recovery, and the relative percent difference between the duplicate analyses, are summarized in Table 4-10. The quality control results are listed in Appendix B, and those QC sample results that do not meet the data quality objectives are flagged.

The quality control sample results for analytical bias play an important role in the selection of the final data set. Although ICP-MS and INAA are the primary analytical techniques, matrix spike and SRM recovery results were used to identify elements and matrices susceptible to interferences and quantification errors. The results from alternate methods (ICP-AES/GFAAS) were selected if the

Table 4-10
Data Quality Objectives

Analysis	Methods	Quality Control Measurement		Data Quality Objectives	
		Bias	**Precision**	**Bias**	**Precision**
Bulk Concentration	INAA, GDMS	SRM[a]	Triplicate Analysis	75-125%	20% RSD[b]
	ICP-AES	SRM, MS[c]	MSD[d]	75-125%	20% RPD[e]
Extractable Concentration	ICP-MS	MS	Duplicate Analysis	75-125%	20% RPD
	GFAA	MS	Duplicate Analysis	75-125%	20% RPD
	ICP-AES	MS	MSD	75-125%	20% RPD

[a] SRM = Standard reference material.
[b] RSD = Relative standard deviation.
[c] MS = Matrix spike.
[d] MSD = Matrix spike duplicate.
[e] RPD = Relative percent difference.

method-specific QC results were within the DQOs or were consistent with supporting data from other size fractions or leachate concentrations. The selected results for each component are identified in Appendix B.

4.4 Chemical Composition Results

The analytical results for the target trace elements and selected major ash mineral elements are summarized in Tables 4-11 through 4-13. Detailed analytical results for each sample are presented in Appendix C. These results represent the total, or bulk sample concentration, the nitric acid digestible concentration, gastric fluid extractable and acetic acid extractable concentrations for each size fraction of particles collected from the economizer outlet, and stack.

To illustrate the relationship between total and extractable concentration and particle size, these data are presented graphically in Appendix D. The results from the Phase I test are also provided in Appendix A. Trends in the relationships between total and particle size, extractable concentrations, and total concentration are evident from these graphical representations. Similarities in the data plots from both test phases are also apparent. The test results from Phase II are discussed in more detail in Section 5.

Table 4-11
Trace Element Concentration in Particles from the Economizer Outlet (µg/g)

		Total Concentration		Nitric Acid Extractable			Simulated Gastric Fluid Leach			TCLP-Acetic Acid Leach		
Size Range	Element	Average	95% CI	Average	95% CI	% Extract.	Average	95% CI	% Extract.	Average	95% CI	% Extract.
> 6.4 µm	Antimony	7.6	0.82	0.88	0.2	12	0.72	0.15	9.5	0.87	0.15	11
> 6.4 µm	Arsenic	73	5.5	77	15	110	55	10	75	2.9	0.57	4
> 6.4 µm	Barium	1,700	160	880	140	51	410	130	24	40	14	2.3
> 6.4 µm	Beryllium	19	ND	8.4	3.2	45	1.5	0.71	7.8	0.35	0.07	1.8
> 6.4 µm	Cadmium	74	14	4.3	1.8	5.8	1.2	0.98	1.7	0.97	0.46	1.3
> 6.4 µm	Chromium	200	22	97	ND	49	39	ND	20	26	ND	13
> 6.4 µm	Cobalt	68	7.1	31	7.1	45	5	1.2	7.4	0.94	0.42	1.4
> 6.4 µm	Copper	210	ND	65	29	31	41	10	20	29	9	14
> 6.4 µm	Lead	120	ND	120	80	100	19	28	16	0.82	0.71	0.7
> 6.4 µm	Manganese	170	30	110	36	63	19	8.5	11	14	3.1	8
> 6.4 µm	Mercury	0.23	ND	<0.09	0.22	<41	<0.1	0.16	<42	<0.05	ND	<22
> 6.4 µm	Molybdenum	49	5	37	6	76	16	3.1	32	5.2	3.7	11
> 6.4 µm	Nickel	130	ND	77	21	58	11	2.6	7.9	15	7.5	11
> 6.4 µm	Selenium	27	1.7	20	3.2	76	5.8	0.92	22	<1.9	0.32	<7.0
> 6.4 µm	Vanadium	350	23	190	27	54	96	ND	27	<2.3	ND	<0.66
6.4-0.8 µm	Antimony	23	2.5	2.7	0.63	12	1	0.21	4.3	2.3	0.4	9.9
6.4-0.8 µm	Arsenic	230	17	240	46	110	190	35	83	2.8	0.55	1.2
6.4-0.8 µm	Barium	2,400	220	1,800	290	75	590	180	25	120	43	5.1
6.4-0.8 µm	Beryllium	28	ND	22	8.3	77	3.5	1.7	12	0.88	0.19	3.1
6.4-0.8 µm	Cadmium	110	21	10	4.3	9.3	4.7	3.8	4.2	2.5	1.2	2.2
6.4-0.8 µm	Chromium	410	44	300	ND	73	160	ND	39	21	ND	5.2
6.4-0.8 µm	Cobalt	120	13	87	20	72	12	2.8	9.8	5.6	2.5	4.7
6.4-0.8 µm	Copper	390	ND	300	130	76	72	18	18	46	14	12
6.4-0.8 µm	Lead	320	ND	250	170	77	58	88	18	1.3	1.2	0.41

Table 4-11 (Continued)

Size Range	Element	Total Concentration		Nitric Acid Extractable			Simulated Gastric Fluid Leach			TCLP-Acetic Acid Leach		
		Average	95% CI	Average	95% CI	% Extract.	Average	95% CI	% Extract.	Average	95% CI	% Extract.
6.4-0.8 µm	Manganese	270	47	200	64	73	30	13	11	23	5.2	8.6
6.4-0.8 µm	Mercury	1.1	ND	0.1	0.24	9	0.12	0.2	11	<0.05	ND	<4.5
6.4-0.8 µm	Molybdenum	130	13	85	14	68	39	7.6	31	12	8.5	9.6
6.4-0.8 µm	Nickel	320	ND	210	58	65	63	16	20	55	28	17
6.4-0.8 µm	Selenium	52	3.4	23	3.7	45	13	2.1	25	<1.9	0.32	<3.7
6.4-0.8 µm	Vanadium	590	40	460	67	78	240	ND	40	3.3	ND	0.55
< 0.8 µm	Antimony	24	2.6	2.8	0.64	12	1.8	0.37	7.5	1.2	0.2	4.9
< 0.8 µm	Arsenic	210	16	200	39	96	170	32	81	1.3	0.25	0.61
< 0.8 µm	Barium	2,300	210	1,200	200	55	540	170	24	110	39	4.9
< 0.8 µm	Beryllium	30	ND	18	6.8	61	4.2	2	14	0.82	0.18	2.8
< 0.8 µm	Cadmium	140	26	11	4.4	7.8	5.5	4.4	4	3.3	1.6	2.4
< 0.8 µm	Chromium	950	110	760	ND	80	540	ND	56	48	ND	5.1
< 0.8 µm	Cobalt	130	14	74	17	57	18	4.2	14	11	4.7	8.2
< 0.8 µm	Copper	320	ND	260	120	80	73	19	23	39	12	12
< 0.8 µm	Lead	320	ND	210	140	67	61	93	19	0.55	0.48	0.17
< 0.8 µm	Manganese	310	54	250	81	81	90	40	29	93	21	30
< 0.8 µm	Mercury	1.1	ND	0.08	0.2	7.3	<0.09	0.16	<8.6	0.02	ND	1.8
< 0.8 µm	Molybdenum	170	17	100	16	60	45	8.8	27	3.7	2.6	2.2
< 0.8 µm	Nickel	350	ND	250	71	72	100	25	29	91	45	26
< 0.8 µm	Selenium	58	3.7	53	8.4	91	18	2.8	30	<1.9	0.32	<3.3
< 0.8 µm	Vanadium	580	39	440	63	75	250	ND	44	4.3	ND	0.74

Shaded confidence intervals are calculated using average confidence intervals determined from multiple results by the same analysis technique.

ND = Not determined--insufficient data.

NA = Not applicable to results reported less than the detection limit.

Table 4-12
Trace Element Concentration in Stack Gas Particles Under High Load (µg/g)

Size Range	Element	Total Concentration		Nitric Acid Digestion			Simulated Gastric Fluid Leach			TCLP-Acetic Acid Leach		
		Average	95% CI	Average	95% CI	% Extract.	Average	95% CI	% Extract.	Average	95% CI	% Extract.
> 6.4 µm	Antimony	140	39	75	23	53	27	4.3	19	24	6.4	17
> 6.4 µm	Arsenic	1,800	450	1,700	260	91	1,400	38	76	650	39	35
> 6.4 µm	Barium	7,000	240	5,700	1,000	81	24	740	34	940	300	13
> 6.4 µm	Beryllium	17	ND	17	10	100	12	4.6	72	16	6.2	96
> 6.4 µm	Cadmium	270	8.6	81	7.9	30	180	380	65	82	22	30
> 6.4 µm	Chromium	4,300	2,600	3,600	940	82	780	360	18	800	1,000	18
> 6.4 µm	Cobalt	91	50	73	11	80	33	12	36	77	66	85
> 6.4 µm	Copper	440	ND	410	38	93	190	26	43	360	120	82
> 6.4 µm	Lead	250	ND	180	16	73	750	2,900	300	47	32	19
> 6.4 µm	Manganese	700	ND	620	350	89	150	46	21	400	160	57
> 6.4 µm	Mercury	2.1	ND	<0.82	NA	<38	1.4	4	65	<0.2	NA	<9.4
> 6.4 µm	Molybdenum	540	29	470	21	87	250	75	47	93	66	17
> 6.4 µm	Nickel	4,500	ND	2,600	830	57	880	620	19	2,400	3,100	52
> 6.4 µm	Selenium	1,000	190	1,100	260	100	840	100	81	390	72	38
> 6.4 µm	Vanadium	2,100	290	1,700	230	81	2,000	ND	97	760	170	36
6.4-0.8 µm	Antimony	160	26	66	13	41	40	13	25	29	9.2	18
6.4-0.8 µm	Arsenic	2,200	170	1,700	200	78	18	240	79	640	84	28
6.4-0.8 µm	Barium	8,400	1,300	6,800	1,600	81	3,200	700	38	940	230	11
6.4-0.8 µm	Beryllium	21	ND	17	4.4	84	16	3	78	19	4.7	91
6.4-0.8 µm	Cadmium	1,700	390	1,300	1,800	78	1,200	1,000	72	1,600	2,500	92
6.4-0.8 µm	Chromium	850	64	600	150	70	610	500	72	420	52	49
6.4-0.8 µm	Cobalt	58	2.2	37	11	64	28	21	49	32	1.7	55
6.4-0.8 µm	Copper	250	ND	270	20	110	200	35	77	260	50	100
6.4-0.8 µm	Lead	170	ND	2,700	5,700	1,600	3,000	9,100	1,800	1,200	3,400	710

Table 4-12 (Continued)

Size Range	Element	Total Concentration		Nitric Acid Digestion			Simulated Gastric Fluid Leach			TCLP-Acetic Acid Leach		
		Average	95% CI	Average	95% CI	% Extract.	Average	95% CI	% Extract.	Average	95% CI	% Extract.
6.4-0.8 µm	Manganese	220	ND	230	82	100	110	99	50	200	5.6	90
6.4-0.8 µm	Mercury	0.39	ND	1.3	3.7	340	<0.92	NA	<240	<0.2	NA	<50
6.4-0.8 µm	Molybdenum	540	32	40	12	75	270	84	50	130	47	25
6.4-0.8 µm	Nickel	710	ND	430	58	60	500	160	70	420	260	58
6.4-0.8 µm	Selenium	800	30	750	220	94	770	150	97	280	74	36
6.4-0.8 µm	Vanadium	2,500	93	1,900	110	74	2,600	ND	100	900	250	36
< 0.8 µm	Antimony	230	8.2	120	39	53	48	10	21	25	4.9	11
< 0.8 µm	Arsenic	3,000	95	2,400	330	79	2,200	160	74	500	230	17
< 0.8 µm	Barium	12,000	800	10,000	2,300	88	2,100	500	18	670	220	5.8
< 0.8 µm	Beryllium	25	ND	24	9.1	96	16	5.1	65	21	5.1	87
< 0.8 µm	Cadmium	300	37	110	14	37	120	22	38	110	12	36
< 0.8 µm	Chromium	1,700	80	1,400	260	82	1,300	22	76	940	120	57
< 0.8 µm	Cobalt	39	4.9	34	12	88	23	5.1	59	29	9.2	75
< 0.8 µm	Copper	290	ND	310	170	110	190	30	66	310	110	110
< 0.8 µm	Lead	160	ND	170	36	100	84	43	52	17	9	11
< 0.8 µm	Manganese	240	ND	220	15	90	130	61	54	220	59	90
< 0.8 µm	Mercury	0.18	ND	<0.96	NA	<540	1.5	3.2	840	<0.2	NA	<110
< 0.8 µm	Molybdenum	1,000	78	820	63	81	720	63	71	280	100	28
< 0.8 µm	Nickel	1,300	ND	920	110	72	1,000	37	80	1,100	260	82
< 0.8 µm	Selenium	810	39	770	240	95	760	36	94	230	85	28
< 0.8 µm	Vanadium	2,900	290	2,300	130	78	3,100	ND	110	690	400	24

Shaded confidence intervals are calculated using average confidence intervals determined from multiple results by the same analytical technique.
ND = Not determined—insufficient data.
NA = Not applicable to results reported less than the detection limit.

Table 4-13
Trace Element Concentration in Stack Gas Particles Under Low Load (µg/g)

		Total Concentration		Nitric Acid Digestion			Simulated Gastric Fluid Leach			TCLP-Acetic Acid Leach		
Size Range	Element	Average	95% CI	Average	95% CI	% Extract.	Average	95% CI	% Extract.	Average	95% CI	% Extract.
> 6.4 µm	Antimony	65	6.10	23	23	35	10	1.7	15	5	3.7	7.6
> 6.4 µm	Arsenic	860	86	670	310	77	440	250	51	150	120	18
> 6.4 µm	Barium	3,800	790	2,700	700	70	1,800	500	47	720	180	19
> 6.4 µm	Beryllium	5.4	ND	5.8	2.6	110	2.2	3.1	40	3.5	0.96	64
> 6.4 µm	Cadmium	140	41	30	10	22	22	17	16	22	8.5	16
> 6.4 µm	Chromium	53,000	9,000	35,000	17,000	67	26,000	ND	49	5,500	5,100	10
> 6.4 µm	Cobalt	630	110	340	170	54	250	53	40	290	150	46
> 6.4 µm	Copper	420	ND	600	860	140	260	180	62	280	180	67
> 6.4 µm	Lead	190	ND	120	90	61	42	1.6	22	8.3	5.1	4.4
> 6.4 µm	Manganese	1,000	ND	950	540	91	900	360	86	770	380	74
> 6.4 µm	Mercury	7.5	ND	1.1	2.1	14	1.7	2.6	22	<0.2	NA	<2.7
> 6.4 µm	Molybdenum	350	80	320	190	92	120	120	34	41	75	12
> 6.4 µm	Nickel	23,000	ND	20,000	13,000	87	12,000	1,500	55	13,000	5,200	58
> 6.4 µm	Selenium	920	86	740	250	81	470	170	51	140	150	16
> 6.4 µm	Vanadium	790	61	620	290	79	440	ND	55	92	100	12
6.4-0.8 µm	Antimony	120	13	38	8.8	32	24	4.9	20	18	3.1	15
6.4-0.8 µm	Arsenic	1,800	130	1,500	289	85	1,300	240	74	330	65	19
6.4-0.8 µm	Barium	8,700	810	6,400	1,000	74	4,900	1,500	56	950	340	11
6.4-0.8 µm	Beryllium	42	ND	19	7.2	46	13	6.4	32	11	2.3	26
6.4-0.8 µm	Cadmium	230	44	120	48	51	320	260	140	110	53	48
6.4-0.8 µm	Chromium	8,500	930	8,800	2,200	100	4,600	ND	54	2,200	ND	26
6.4-0.8 µm	Cobalt	140	14	150	36	110	740	180	540	85	37	62
6.4-0.8 µm	Copper	510	ND	330	150	66	250	64	50	250	76	48
6.4-0.8 µm	Lead	<3.75	ND	270	180	ND	290	440	ND	45	39	ND

Table 4-13 (Continued)

Size Range	Element	Total Concentration		Nitric Acid Digestion			Simulated Gastric Fluid Leach			TCLP-Acetic Acid Leach		
		Average	95% CI	Average	95% CI	% Extract.	Average	95% CI	% Extract.	Average	95% CI	% Extract.
6.4-0.8 µm	Manganese	1,000	ND	440	140	43	390	170	38	330	74	32
6.4-0.8 µm	Mercury	4.8	ND	2.2	5.3	45	<0.96	1.6	<20	<0.2	ND	<4.2
6.4-0.8 µm	Molybdenum	370	38	330	53	88	170	34	47	48	34	13
6.4-0.8 µm	Nickel	19,000	ND	7,100	2.000	37	3,200	810	17	3,500	1,700	18
6.4-0.8 µm	Selenium	120	7.6	1,100	280	910	920	150	790	320	53	270
6.4-0.8 µm	Vanadium	1,800	120	1,500	210	85	1,600	ND	93	340	ND	19
< 0.8 µm	Antimony	240	42	83	16	34	51	6.3	21	23	5.6	9.5
< 0.8 µm	Arsenic	3,300	340	2,900	190	86	2,700	260	80	620	150	19
< 0.8 µm	Barium	19,000	610	16,000	2,100	88	2,900	1,400	15	700	440	3.7
< 0.8 µm	Beryllium	29	ND	29	12	99	17	2	58	20	2.8	68
< 0.8 µm	Cadmium	350	100	120	18	35	120	14	34	100	29	29
< 0.8 µm	Chromium	2,200	200	2,000	600	90	2,000	ND	93	1,000	160	46
< 0.8 µm	Cobalt	57	2.4	45	14	79	32	5.7	57	95	260	170
< 0.8 µm	Copper	500	ND	380	32	84	290	33	64	380	100	83
< 0.8 µm	Lead	150	ND	150	29	99	34	21	22	12	1.2	7.9
< 0.8 µm	Manganese	270	ND	240	13	90	100	13	37	190	24	71
< 0.8 µm	Mercury	0.2	ND	<0.95	NA	<470	2.1	5.4	1,000	<0.2	NA	<97
< 0.8 µm	Molybdenum	780	110	760	53	98	520	91	67	190	53	25
< 0.8 µm	Nickel	1,700	ND	1,500	250	88	1,100	69	62	1,100	150	63
< 0.8 µm	Selenium	1,700	160	1,800	220	100	1,700	88	94	540	63	31
< 0.8 µm	Vanadium	2,200	180	2,000	14	88	2,400	ND	100	510	85	23

Shaded confidence intervals are calculated using average confidence intervals determined from multiple results by the same analysis technique.
ND = Not determined—insufficient data.
NA = Not applicable to results reported less than the detection limit.

4.5 Extractable Composition Results

In addition to measuring the total elemental composition of the size-fractionated particulate material, the trace element concentration available under 1 digestive procedure and 2 leaching environments was determined. A nitric acid digestion (EPA Method 3050) was performed on each sample to simulate a worst case scenario for extraction of trace elements from the particle without digesting the fundamental alumina-silicate matrix. In addition, simulated gastric fluid was used to assess the bioavailability from ingestion of particulate matter, and the EPA's Toxicity Characteristic Leaching Procedure (TCLP) was modified for use with the extremely small samples available. To simulate the TCLP and provide comparable data for toxicity due to groundwater leaching, samples were leached in an acetic acid buffer solution.

As expected, the concentrations of extractable elements appears related to the aggressiveness of the extraction procedure and strength of the acid. The amount of material extractable by a given technique is highly variable as a function of the specific element and also appears related to particle size. On the average, extractable percentages of trace elements were higher for the smaller size fractions. This may be attributed to an increase in surface area available for a given sample mass and, therefore, enhanced surface contact with the leaching agents.

These findings are important when assessing the potential health risks from flue gas particulate emissions. Extractable elemental concentrations should be considered when performing health risk assessments since the relative availability of particulate-borne HAPs is less than the total elemental concentration. To illustrate this, additional discussion on the toxicological effects of unit load, particle size, and extractable concentrations can be found in Section 6.

4.6 References

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5.0 TEST RESULTS

Similar trends in the test data were noted in both Phases I and II of this project, despite changes made in the sampling system and the plant FGD system (as described in Section 4). The test results, data trends, and plant performance are summarized and discussed in this section. Most of the results, data summaries, and discussion provided in this section relate to the Phase II testing.

5.1 General Observations and Summary

In general, the mass concentrations of volatile trace elements increase as particle size decreases. This would be expected if the amount of volatile element condensation is proportional to surface area as is generally hypothesized. Similarly, the extractable fraction of these condensed species would be enhanced by the high surface area-to-mass ratio of smaller particles. These trends are indicated by the results from both test phases.

As expected, trace element extractability was shown to be a function of the aggressiveness of the extraction procedure and the surface area-to-mass ratio or particle size. In addition, the valence state or form of the element associated with the particulate matter is also expected to affect its extractability; however, there were no data generated to support this assumption.

Unit load appears to have little effect on the bulk concentration of trace elements relative to particle size; however, it does seem to affect the particle removal efficiency of the scrubber. This was observed most dramatically during low load operation where greater penetration of larger particles was observed. A corresponding shift in the chemical characteristics was also observed, especially with respect to higher iron, chromium, and nickel concentrations. A corresponding decrease in aluminum and titanium was observed suggesting a higher level of contamination (possibly with stainless steel as a corrosion product or particle) or a decrease in the fly ash component of the Stage 1(>6.4 μm) particulate catch.

Extractable trace element concentrations also appear to be affected by changes in unit load, again due to a shift in the particle size distribution within the size fractions collected. At high load, the smallest size fraction made up a greater percentage of the total particulate catch. Consequently, The greater population of smaller particles enhances the surface area contacting the leaching agent and consequently increases the measured extractability of some substances.

The stack particulate data from both test phases indicate a significant level of enrichment relative to the concentrations in the coal (ash basis) and the FGD liquor. The following sections present an assessment of the data with respect to the overall performance of the plant and the FGD system. Mass flow rates, enrichment factors, and emission estimates are presented.

5.2 Plant and Process Performance

The plant and process performance, primarily for the Phase II testing, are discussed in this section of the report. For convenience, this discussion has been separated into several segments. The topics of these individual segments include:

- Loading estimates and assumptions;
- Estimates of some process conditions; and
- Mass flows.

5.2.1 Loading Estimates

During the Phase II testing, particulate loadings were not directly measured at the economizer outlet or scrubber outlet (stack). However, estimations, the accuracy of which are somewhat uncertain, are discussed below.

Economizer Outlet (FGD Inlet)

The particle size distribution (PSD) at the economizer outlet was measured one time using a high-capacity Anderson impactor. The particulate matter recovered from this impactor was used to estimate the particle loading in this stream. Accurate loadings are generally not achieved with impactors because of the difficulty in recovering all of the collected particulate material. In addition, the sampling point was far from ideal. Only a single sampling port was available at this location, so full traversing was not practical. Furthermore, the single available port was too small to insert the impactor into the duct, so the impactor was operated outside the duct with a probe inserted into the duct through the available port. For these reasons, the loading of 1,400 mg/Nm^3 measured with the Anderson impactor is undoubtedly biased low, although the magnitude of this bias could not be determined. This estimated loading was not used in any calculations because of its uncertain accuracy.

Scrubber Outlet (Stack)

Particulate loadings in the stack gas were estimated based on the cyclone/ESP and University of Washington (UW) impactor data. Under low plant load conditions, the particulate loadings from the

ESP system (15 mg/Nm^3) were quite similar to the loadings found with the UW impactor (16 mg/Nm^3). However, at the higher plant load conditions, the particulate loading from the UW impactor (29 mg/Nm^3) was almost twice as high as that determined from the cyclone/ESP system (16 mg/Nm^3). None of these methods are acceptable procedures for determining mass loading. Nevertheless, this information is useful for estimating minimum loading limits. Data from these methods could be biased low by up to 50% of the real values.

5.2.2 Process Conditions

Two process parameters, the coal firing rate and the stack gas rate, are needed to estimate mass flows and emission estimates. Neither of these parameters were directly measured as part of the testing protocol. Thus, these parameters had to be estimated.

Coal Firing Rate

The average coal firing rate for Unit 8 was estimated from the Widows Creek Plant Operating Period Statistics. These statistics were provided for several seven- to eight-day periods in September of 1993. An eight-day period during which the plant operated at the highest average gross load of 448 MW was selected as a representative period for estimating a basic coal firing rate. During this period, an average of 350,200 lb/hr of coal was fired in the boiler of Unit 8. This coal firing rate was used as the basis for several of the calculations performed in developing this report. To estimate coal firing rates at other gross load conditions, the basic coal firing rate was adjusted as necessary, assuming a linear relationship between the amount of coal fired and the gross load.

Stack Gas Rate

Since it was not measured directly during the testing, the stack gas volumetric flow rate was also estimated. The stack gas rates from three other plants in a DOE air toxics test program were used to estimate an average stack gas rate, expressed as dry standard cubic feet per million Btu of heat input (DSCF/10^6 Btu). These plants were:

- Cardinal Plant Unit 1, Ohio Power Company;
- Baldwin Power Station Unit 2, Illinois Power Company; and
- Niles Station Boiler No. 2, Ohio Edison Company.

All three boilers were fired with bituminous coal. The measured stack gas rates ranged from 13,200 to 14,900 DSCF/10^6 Btu, with an average rate of 13,700 DSCF/10^6 Btu. This average rate was used as to estimate the stack gas rate at the high- and low-load conditions during the Phase II testing period.

5.2.3 *Material Balances*

Individual elemental material balances across the scrubber could not be estimated because compositions and stream rates were not known for all the streams. For example, flow rates of the scrubber liquid were not available, so the particulate removed during the scrubbing process could not be calculated from the scrubber liquid information. Furthermore, only one scrubber inlet gas loading measurement was made during the testing, and, as mentioned previously, that measurement was made under very poor sampling conditions.

The measured inlet loading of 1,400 mg/Nm^3 is equivalent to a total inlet particulate rate of approximately 5,300 lb/hr. This particulate rate accounts for only about 13% of the ash entering the plant with the coal. Normally, the flue gas from a tangentail-fired boiler contains about 70-80% of the coal ash as fly ash. This assessment confirms the inaccuracy of the loading data derived from the economizer outlet testing. This loading data was not used in any subsequent calculations.

5.3 Mass Flows and Particle Composition

The detailed analytical results for the target trace elements and selected ash mineral elements for Phase II are presented in Appendix C. The particle composition and comparable estimated mass flows for the Phase II testing are provided in this section.

Table 5-1 is a summary of the individual element particulate mass flow rates and compositions at the stack under low-load (323 MW) operation. The flow rate of stack gas was estimated from the base case (448 MW) by assuming that the flow rate was directly proportional to the turbine output (in megawatts). This estimated flow rate may be biased slightly low, since the proportion of excess air is generally increased to maintain boiler efficiency at the lower firing rates. Using the loading as measured with the University of Washington impactor, the mass flow rate of particulate matter from the scrubber was estimated to be 41 lb/hr. The majority of this particulate, 27 lb/hr, was in the size range of <0.8 µm (Stage 3 cut). Approximately 11 lb/hr of particulate matter was in the coarse size range of >6.4 µm (Stage 1) and only 3.2 lb/hr (about 8% of the total particulate) of particulate in the intermediate size range of 6.4-0.8 µm (Stage 2 cut).

Since no economizer outlet measurements were made at the low load conditions, no comparison of the FGD inlet and outlet compositions could be made. However, the mass flow rates at the stack were compared to the mass flow rates of the substances entering the plant in the coal. These comparisons

Table 5-1
Stack Summary, Low Load (Phase II)

Elem	Boiling Point Deg C	Total in with Coal, Lb/hr (Low Load)	FGD Outlet Particulate Bulk Concentration, µg/g			Amount from Scrubber, lb/hr			Total	Outlet Mass/Mass in Coal
			Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3		
Hg	500	0.028	7.5	4.8	0.20	0.00082	0.000015	0.0000055	0.00010	0.0037
Se	500	0.50	920	120	180	0.010	0.00038	0.047	0.058	0.12
As	1,000	1.3	860	1,800	330	0.0095	0.0057	0.091	0.11	0.084
Na	1,300	110	960	2,100	100	0.011	0.0069	0.028	0.045	0.00043
Sb	1,400	NA	65	120	240	0.00071	0.00038	0.0066	0.0077	NA
Pb	1,500	2.0	190		150	0.0021		0.0041	0.0062	0.0031
K	1,500	510	2,600	13,000	5,000	0.029	0.043	0.14	0.21	0.00041
Cd	1,600	ND	140	230	350	0.0015	0.00074	0.0094	0.012	NA
V	1,800	21.0	790	1,800	2,200	0.0087	0.0057	0.061	0.075	0.0035
Cu	1,800	3.3	420	510	460	0.0046	0.0016	0.012	0.019	0.0057
Ni	1,900	5.8	23,000	19,000	1,700	0.25	0.061	0.046	0.36	0.062
Mo	1,900	1.0	350	370	770	0.0039	0.0012	0.021	0.026	0.026
Zn	2,000	NA	180	1,300	500	0.0020	0.0041	0.013	0.020	NA
Ba	2,200	18.0	3,900	8,700	19,000	0.042	0.028	0.51	0.58	0.032
Ti	2,200	180	3,300	6,500	5,100	0.036	0.021	0.14	0.20	0.0011
Fe	2,500	3,800	160,000	64,000	30,000	1.8	0.21	0.81	2.8	0.00072
Co	2,600	1.8	630	140	57	0.0069	0.00044	0.0015	0.0089	0.0051
Mg	2,800	120	1,100	1,900	1,500	0.012	0.0062	0.041	0.060	0.0005
Ca	2,900	680	6,900	43,000	31,000	0.076	0.14	0.84	1.1	0.0016
Al	3,000	3,300	23,000	62,000	33,000	0.25	0.20	0.9	1.4	0.00042
Sr	3,000	NA	180	1,700	1,100	0.0021	0.0053	0.031	0.038	NA
Cr	3,000	4.8	53,000	8,500	2,200	0.58	0.027	0.060	0.67	0.14
Mn	4,100	7.8	1,000	1,000	270	0.011	0.0033	0.0073	0.022	0.0028
Be	4,300	0.36	5.4	42	29	0.0001	0.00014	0.00079	0.00099	0.0027

are included in Table 5-1. The outlet mass flow of each of the elements being studied in this program is provided as a percentage of the mass flow of the element entering the plant in the coal ash. The total mass flow measured in the stack is equal to 0.15% of the total coal ash flow into the plant. If there was no enrichment or depletion in the particulate, the mass of each element in the stack would be equivalent to 0.15% of the mass of that element in the coal. Most elements are present in the exiting particulate matter at levels that are equivalent to substantially more than 0.15% of the coal. The percentages are particularly high (above 5%) for selenium, arsenic, nickel, and chromium.

The stack composition and the mass flow rates of the various elements of interest in the stack at the high-load conditions are summarized in Table 5-2. The particulate loading measured with the University of Washington impactor was used as the basis for the composition and flow rate estimates. The total particulate loading at the stack was estimated to be 112 lb/hr. It should be kept in mind, however, that this rate is probably biased low. The measured particulate loading in the stack gas at the higher load is approximately twice the loading measured at the lower load conditions. The total mass flow of 112 lb/hr is equivalent to 0.27% of the ash entering the plant in the coal.

The Stage 3 particles (<0.8 μm) predominate in the stack, accounting for over 80% of the particulate mass. This predominance of the smaller particles in the stack is consistent with the performance of venturi scrubbers, which are generally less effective in removing smaller particles, particularly those below 1 μm.

In Table 5-2, the mass flows of the individual elements in the stack at high loads are presented as a percentage of the elemental mass entering with the coal. If there were no enrichment in the particulate matter, each element would be present at a level equivalent to about 0.27% of the mass of the that element entering the plant with the coal. The majority of the elements in the emitted particulate are present at levels that are significantly above 0.27%, indicating enrichment. Selenium, arsenic, and molybdenum are present at levels equivalent to more than 5% of the mass entering with the coal.

The stack mass flows for both high- and low-load conditions are shown graphically in Figure 5-1. The percentage of most elements entering as coal ash and leaving the scrubber as particulate matter is higher at high load. This is not surprising, since the measured outlet loading at the high load is almost twice as high as that found when operating at low load, while the rate of coal fed to the unit is only about 50% greater at the high load. Prominent exceptions to this general pattern are mercury, nickel, cobalt, and chromium, which are all present at higher percentages during operations at the lower load, particularly in the larger-sized fractions. Since mercury is so volatile, very little is present in the solid particulate. The low levels of mercury found in the particulate are also difficult to measure accurately. Thus, the differences in the mercury levels between 0.1 and 0.15% are probably insignificant.

Table 5-2
Stack Summary, High Load (Phase II)

Elem	Boiling Point Deg C	Total in with Coal, lb/hr (High Load)	FGD Outlet Particulate Bulk Concentration, µg/g			Amount from Scrubber, lb/111.79lb			Total	Outlet Mass/Mass in Coal, %
			Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3		
Hg	500	0.042	2.1	0.39	0.18	0.00002	[illegible]	0.00002	[illegible]	0.099
Se	500	0.75	1,000	780	810	0.010	0.0090	0.074	0.093	12
As	1,000	1.9	1,900	2,200	3,000	0.018	0.025	0.27	0.32	17
Na	1,300	160	1,500	2,000	1,000	0.015	0.023	0.095	0.13	0.084
Sb	1,400	NA	140	160	230	0.0014	0.0018	0.021	0.024	NA
Pb	1,500	3	250	170	160	0.0024	0.0019	0.015	0.019	0.63
K	1,500	760	5,100	7,100	4,000	0.05	0.080	0.36	0.49	0.065
Cd	1,600	ND	270	1,700	310	0.0026	0.019	0.028	0.050	NA
V	1,800	32	2,100	2,500	2,900	0.020	0.029	0.26	0.31	0.99
Cu	1,800	4.9	440	250	290	0.0043	0.0029	0.027	0.034	0.69
Ni	1,900	8.7	4,500	710	1,300	0.044	0.0081	0.12	0.17	1.9
Mo	1,900	1.5	540	540	1,000	0.0052	0.0060	0.092	0.10	6.9
Zn	2,000	NA	1,100	1,000	1,100	0.011	0.011	0.098	0.12	NA
Ba	2,200	27	7,000	8,400	12,000	0.068	0.095	1.1	1.2	4.5
Ti	2,200	270	5,600	7,000	4,100	0.055	0.079	0.37	0.50	0.19
Fe	2,500	5,700	86,000	42,000	33,000	0.83	0.47	3.0	4.4	0.076
Co	2,600	2.6	91	58	39	0.00088	0.00065	0.0035	0.0051	0.19
Mg	2,800	180	200	3,100	1,800	0.019	0.035	0.17	0.22	0.12
Ca	2,900	1,000	37,000	28,000	38,000	0.36	0.31	3.4	4.1	0.40
Al	3,000	4,900	42,000	56,000	29,000	0.41	0.64	2.6	3.6	0.075
Sr	3,000	NA	550	760	720	0.0053	0.0086	0.065	0.079	NA
Cr	3,000	7.2	4,300	850	1,700	0.042	0.0096	0.15	0.20	2.8
Mn	4,100	12	700	220	240	0.0068	0.0025	0.022	0.031	0.27
Be	4,300	0.54	17	21	25	0.00016	0.00024	0.0023	0.0027	0.49

NA = Not applicable.
ND = Not detected.

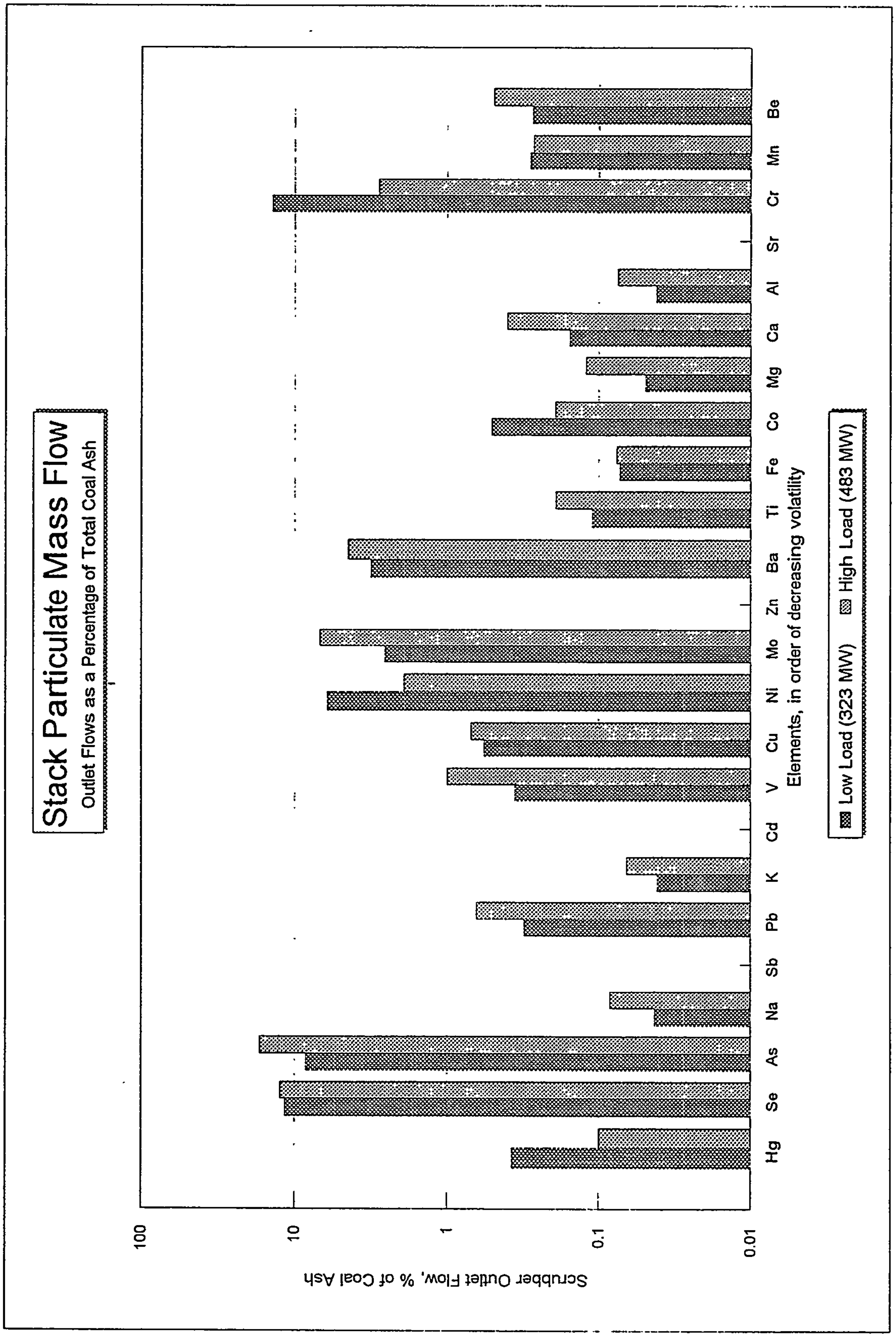

Figure 5-1
Stack Particualte Mass Flow

The levels of chromium and nickel at the low-load conditions are very inconsistent among the three size fractions. The chromium in the Stage 1 fraction is equivalent to more than 12% of the total chromium in the coal. The nickel in this stage is equal to 4.3% of the nickel in the coal entering the plant. The distributions, with the highest concentrations being found in the larger size fraction, are also directionally opposed to the generally observed behavior in which the metals are more highly concentrated in the smaller size particles. The relatively high concentrations of these metals, combined with a corresponding high concentration of iron, suggests contamination in the first stage of the sampling system. In contrast to the higher levels of chromium, nickel, manganese, and cobalt, the ash mineral levels (e.g., aluminum and titanium) are lower, relative to the high-load sample concentrations. Thus, a change in the composition of the larger particles is indicated, rather than greater penetration of the fly ash through the FGD system.

One rather obvious explanation for the high nickel and chromium in the particulate sample is contamination, possibly with stainless steel. In fact, the mass ratio of chromium:nickel:iron in the Stage 1 fraction is 22:10:68. This ratio is 18:11:69 (with 2.5% cobalt) in 316 Stainless steel. Cobalt is also present at relatively high levels in the Stage 1 fraction, compared to the other two fractions. However, it would only be equivalent to about 0.3% of the chromium/nickel/iron fraction. The similarity in composition between the particulate and 316 Stainless steel may be merely coincidental. However, other stainless steels have roughly similar compositions. In light of this observation, it would appear that contamination of the Stage 1 size fraction with stainless steel is a real possibility. Contamination could have been in the form of corrosion products or metal from ductwork. Higher levels of chromium, nickel, manganese, and cobalt were also found in the Stage 1 fraction during Phase I of the testing.

This shift in Stage 1 particle composition also explains the apparent decrease in other trace element concentrations exhibited in Stage 1 samples collected during low-load operating conditions. A comparison of the Stage 2 and Stage 3 results between the two load conditions show little difference in the concentrations. The effect of unit load on the composition of the smaller particles appears to be most significant with respect to scrubber operating efficiency and not from physical changes in the ash composition.

As expected, most of the targeted trace elements are concentrated in the smaller sized particles. This is the case for particles at the inlet and outlet of the scrubber system; however, element concentrations in the stack gas particulate matter are roughly ten times higher than those determined on material collected in comparable size ranges at the inlet. The arsenic results provide one example of this apparent enrichment. This enrichment appears consistently for most of the trace elements, and may be explained by the particle removal efficiency of the FGD system.

Major ash minerals (specifically Al and Ti) appear to be evenly distributed across the three particle size ranges collected at the economizer outlet (inlet to the venturi scrubber system). These elements are indicative of the ash component in the emitted particulate matter and exhibit slightly higher concentrations in the 6.4-0.8 µm size particles at the stack under both load conditions. Iron concentrations decrease with smaller particle size, and, as mentioned earlier in this section, the presence of iron in the larger size fraction at the stack indicates possible entrainment of gas duct or system corrosion products. These particulate sources of iron are typically collected in the first stage of the sampling system due to their larger size. The amount of contaminant collected in the first cyclone stage appears higher under low load. Calcium, a possible indicator of scrubber liquor carryover, trends towards lower concentrations in the small size particles at the scrubber inlet. Calcium levels in the high- and low-load particle samples from the stack are variable and may indicate corresponding variability in the FGD system's performance or operation under the two load conditions.

It appears from the PSD data at the stack that particulate removal through the venturi scrubber is less efficient for the fine particles in the 2-0.2 µm size range where the more volatile trace elements are concentrated. One hypothesis is that the selective removal of large particles effectively concentrates the smaller enriched particles and accounts for the higher trace element levels. This mechanism is discussed further in Section 5.4

In a few cases, elements are concentrated in a narrow size range of particulate. An example of this selective concentration on small size particle fractions is most noticeable in the high-load levels of cadmium in stack gas particulate. There is a predominance of cadmium and lead in the second collection stage from Phase II and the corresponding Stage 4 from Phase I, as shown in Figure 5-2. Based on the PSD data from the U of W impactor, the predominant size fraction represented by the material collected in the Stage 2 cyclone correlates well to the 1.7-0.8 µm size range collected in Stage 4 from Phase I.

5.4 Enrichment of Particulate Matter

In Table 5-3, the elemental enrichment in each size range of particulate matter in the stack gas (scrubber outlet) is shown for both the high- and low-load operating conditions of Phase II testing. Since one set of particulate samples was collected in the economizer outlet stream during the high-load operation, the enrichments of the emitted particulate relative to the economizer outlet particles were also determined. Average concentrations and enrichment factors are summarized in Table 5-4.

As expected, most of the targeted trace elements are concentrated in the smaller sized particles. The arsenic results provide one example of this apparent enrichment. The arsenic concentration in the raw coal is reported as 45 µg/g on an ash basis. At the economizer outlet, the average arsenic

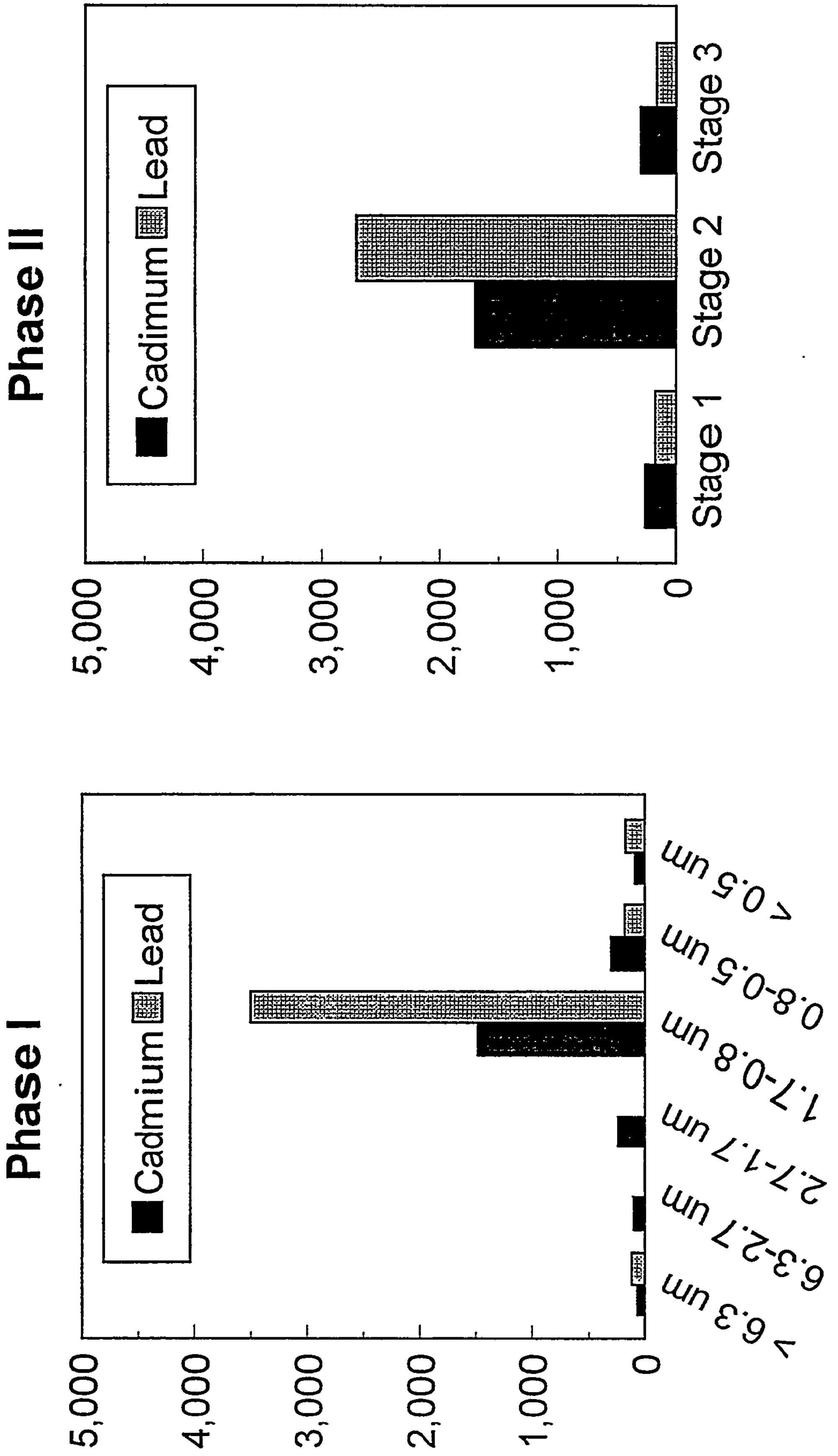

Figure 5-2
Selective Concentration of Cadmium and Lead, µg/g

Table 5-3
Enrichment in Collected Particles

Element	Oxide Boiling Point, Deg F	Element Level in Coal, µg/g	FGD Inlet Enrichment Factor			High-Load Enrichment Factor			Low-Load Enrichment Factor		
			Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Se	500	2.0	1.5	2.9	3.2	57.6	43.9	44.8	50.6	6.5	96.6
Hg	500	0.1	0.2	1.2	1.2	2.3	0.4	0.2	8.3	5.3	0.2
As	1,000	5.0	1.6	5.0	4.7	40.8	49.3	66.3	19.1	39.0	73.9
Na	1,275	400	0.7	0.9	1.1	0.4	0.6	0.3	0.3	0.6	0.3
Sb	1,425										
Pb	1,472	8.0	1.6	4.5	4.4	3.4	2.3	2.2	2.6	0	2.1
K	1,527	2,000	1.0	1.2	1.1	0.3	0.4	0.2	0.1	0.7	0.3
Cd	1,559										
V	1,750	84	0.5	0.8	0.8	2.8	3.3	3.8	1.0	2.3	2.9
Cu	1,800	13	1.8	3.3	2.7	3.7	2.1	2.5	3.6	4.3	3.9
Ni	1,900	23	1.5	1.5	1.7	21.8	3.4	6.1	109.1	90.8	8.2
Mo	1,927	4.0	1.3	3.5	4.6	14.8	14.8	27.9	9.7	10.3	21.4
Ba	2,200	72	2.7	3.7	3.5	10.7	12.8	17.8	5.9	13.3	28.8
Ti	2,227	700	1.5	1.6	1.7	0.9	1.1	0.6	0.5	1.0	0.8
Fe	2,527	15,200	0.4	0.4	0.5	0.4	0.3	0.2	1.2	0.5	0.2
Co	2,627	7.0	1.1	1.9	2.1	1.4	0.9	0.6	9.9	2.2	0.9
Mg	2,825	480	0.9	1.3	1.2	0.5	0.7	0.4	0.3	0.4	0.4
Ca	2,850	2,700	0.5	0.5	0.5	0.7	1.1	1.5	0.3	1.8	1.3
Al	2,980	12,900	1.2	1.2	1.3	0.4	0.5	0.2	0.2	0.5	0.3
Cr	3,000	19	1.1	2.4	5.5	25.3	5.0	9.6	307.3	49.2	12.8
Sr	3,000										
Mn	4,050	31	0.6	1.0	1.1	2.5	0.8	0.9	3.7	3.6	1.0
Be	4,260	1.4	1.5	2.2	2.3	1.3	1.6	2.0	0.4	3.3	2.3

Table 5-4
Trace Element Enrichment

Analyte (mg/kg)	Raw Coal Composite		Economizer Outlet		Stack—High Load		Stack—Low Load	
	Dry Coal Basis	Ash Basis	Weighted Average	Enrichment Factor	Weighted Average	Enrichment Factor	Weighted Average	Enrichment Factor
Ash (Wt. %)	11							
Aluminum	13,000	120,000	140,000	1.2	33,000	0.28	32,000	0.28
Antimony	NA	NA	13	NA	220	NA	200	NA
Arsenic	5	45	120	2.6	2,800	62	3,000	65
Barium	72	650	1,900	3	11,000	17	16,000	25
Beryllium	1.4	13	22	1.7	24	1.9	29	2.2
Cadmium	<0.1	<1	88	NA	450	NA	310	NA
Calcium	2,700	25,000	13,000	0.52	36,000	1.5	30,000	1.2
Chromium	19	170	320	1.9	1,800	11	7,400	43
Cobalt	7	63	86	1.3	45	0.71	120	1.8
Copper	13	120	260	2.2	300	2.6	460	3.9
Iron	15,000	140,000	60,000	0.44	39,000	0.28	45,000	0.33
Lead	8	72	180	2.5	170	2.3	140	1.9
Magnesium	480	4,300	4,500	1	2,000	0.45	1,700	0.44
Manganese	31	280	210	0.74	280	1	420	1.5
Mercury	0.1	0.9	<8	NA	0.37	0.41	1.3	1.5
Molybdenum	4	36	77	2.1	920	25	690	19
Nickel	23	210	200	0.94	1,500	7.3	5,400	26
Phosphorus	130	1,200	NA	NA	NA	NA	NA	NA

Table 5-4 (Continued)

Analyte (mg/kg)	Raw Coal Composite		Economizer Outlet		Stack—High Load		Stack—Low Load	
	Dry Coal Basis	Ash Basis	Weighted Average	Enrichment Factor	Weighted Average	Enrichment Factor	Weighted Average	Enrichment Factor
Potassium	2,000	18,000	20,000	1.1	4,400	0.24	5,700	0.31
Selenium	2	18	35	1.9	830	46	1,500	83
Sodium	420	3,800	NA	NA	NA	NA	NA	NA
Titanium	700	6,400	9,900	1.6	4,500	0.71	5,100	0.8
Vanadium	84	760	430	0.56	2,800	3.7	2,100	2.7
Zinc	NA	NA	4,000	NA	1,100	NA	550	NA

NA = Not applicable.

concentration calculated by weighing the results for all three size-fractionated sample fractions is 120 μg/g, an enrichment factor of approximately 2.6. At the stack, the average (weighted) arsenic concentration is 2,800 to 3,000 μg/g, 62 to 65 times the coal-ash arsenic level. This enrichment appears consistently for most of the trace elements, as shown in Table 5-4, and may be explained by the particle removal efficiency of the FGD system. Figure 5-3 presents the arsenic data for each size fraction at each sample location.

The particulate removal performance of the scrubber could not be directly determined from measurements made during the testing. The measured enrichment of the stack particulate relative to the economizer outlet particulate can, however, provide some modest insight into the relative effectiveness of the scrubber in removing the three size ranges of particles. In general, venturi scrubbers are not as effective in removing smaller particles as other removal devices such as electrostatic precipitators (ESPs) or fabric filters (FF). Removal is particularly poor for particles of 1 μm or less in diameter. This is illustrated in Figure 5-4.

The smaller particulate matter from coal combustion tends to be enriched, relative to the coal ash, in those metals present in the coal. The enrichment also tends to be higher for the more volatile substances. If the particulate matter in each of the three size fractions collected in these tests was homogeneous in composition, no enrichment would be expected across the venturi scrubber. On the other hand, if the larger particles within the size fractions were preferentially removed, the remaining material would appear to be relatively enriched, since the smaller particles within each size fraction are likely to be the more enriched. The larger size fractions might also be the ones that appear to show the greatest enrichment, since relatively more of the larger, less enriched particles within the size fraction would be removed.

This appears to be the case for the particles collected at the stack during high-load operation, as shown in Table 5-3 and Figure 5-5. Excluding mercury (because of its volatility), the enrichments (relative to the economizer outlet) measured for the Stage 3 size fraction are higher than the Stage 2 fraction enrichments for 17 of 23 elements. The Stage 3 fraction enrichments across the scrubber are higher than the enrichments in the Stage 1 fraction for 21 of the 23 elements. The enrichments across the scrubber are not as dramatic for the other two smaller size fractions. The enrichment for about half (13 of 23) of these fractions are similar across the scrubber, and about half (13 of 23) of the elements show no enrichment at all. This tends to indicate that removals of particulate matter in the venturi scrubber are generally similar across the size range of the two smaller size fractions, and the removal of the small particles is not as effective as removal of large particles.

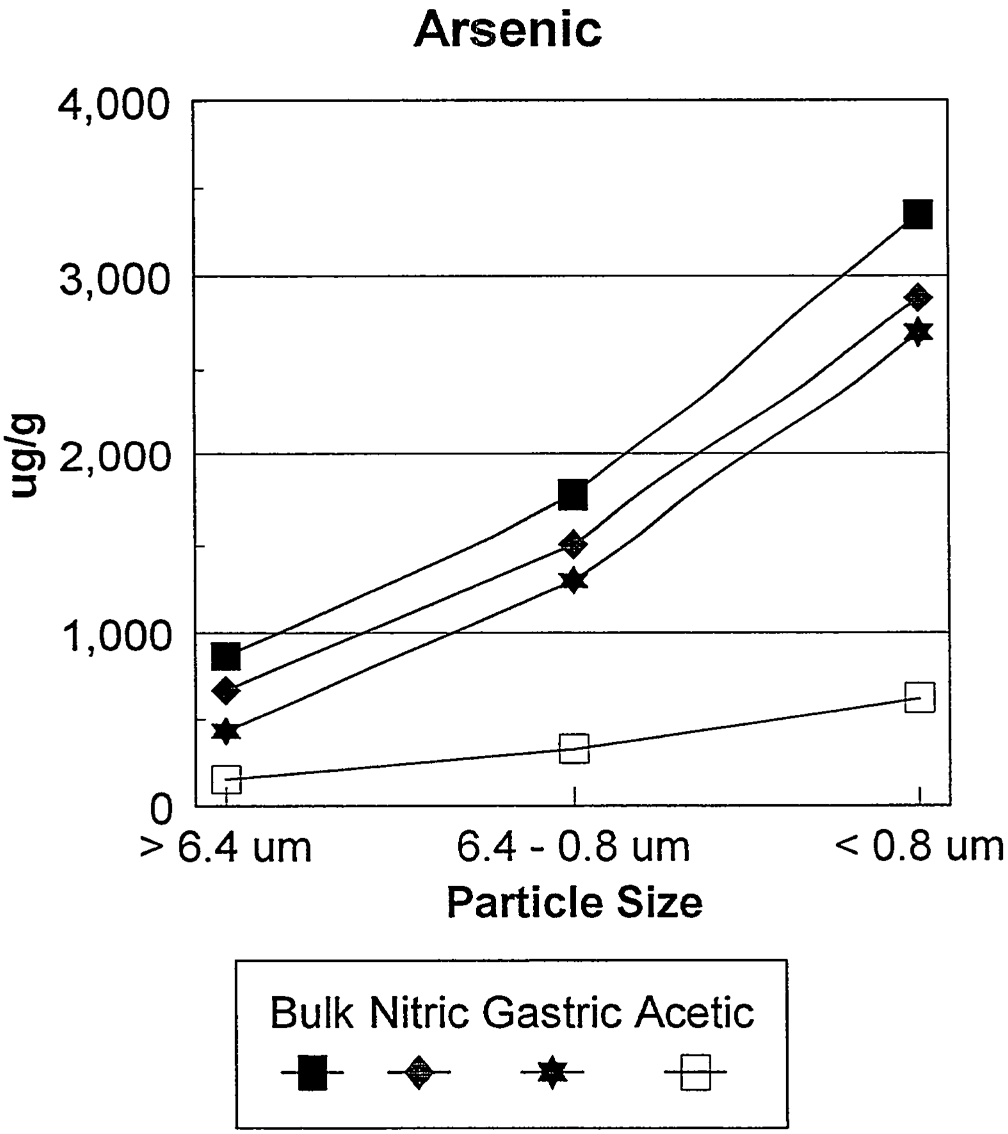

Figure 5-3
Example of Elemental Enrichment by Particle Size

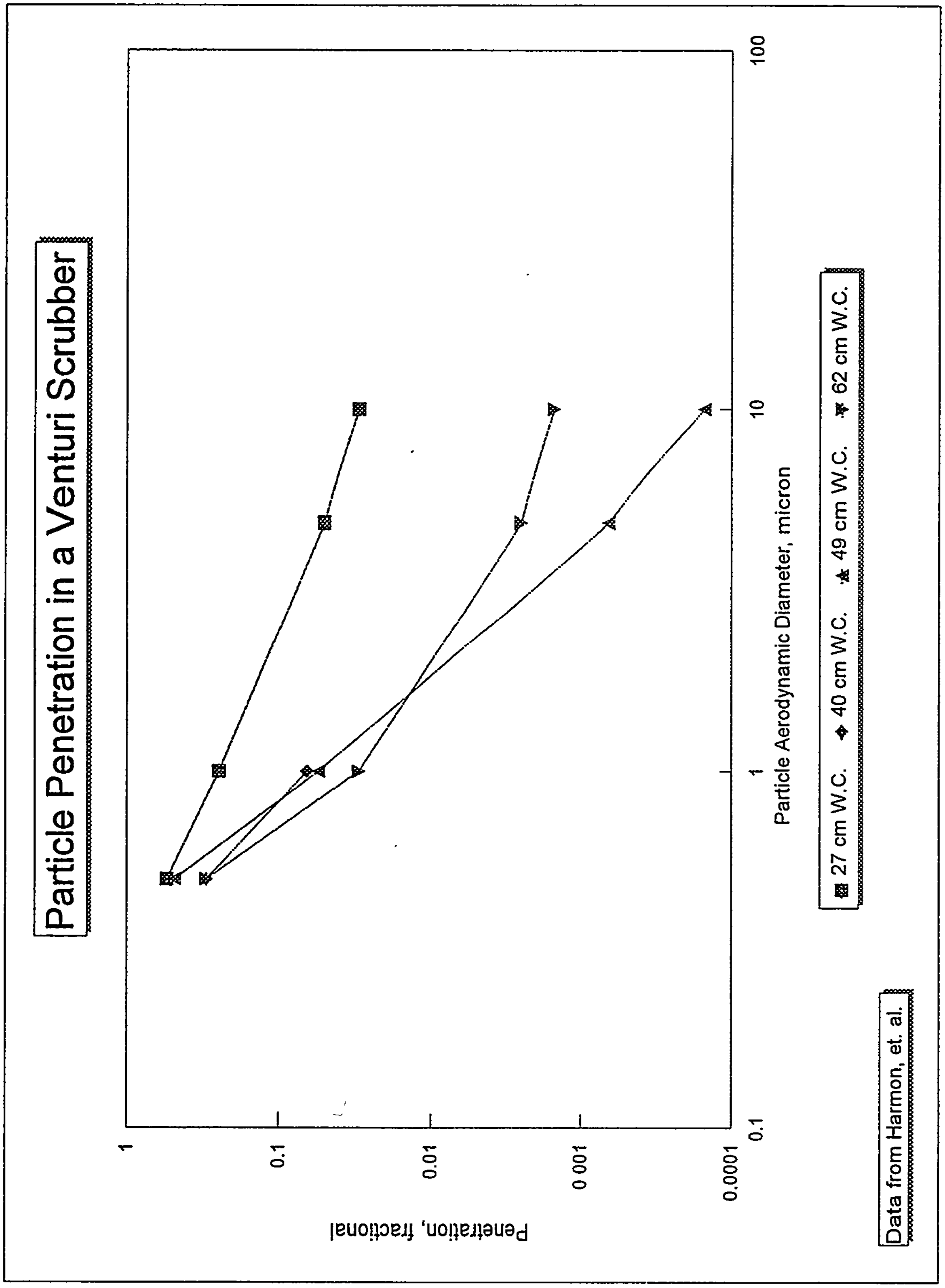

Figure 5-4
Particle Penetration in a Venturi Scrubber

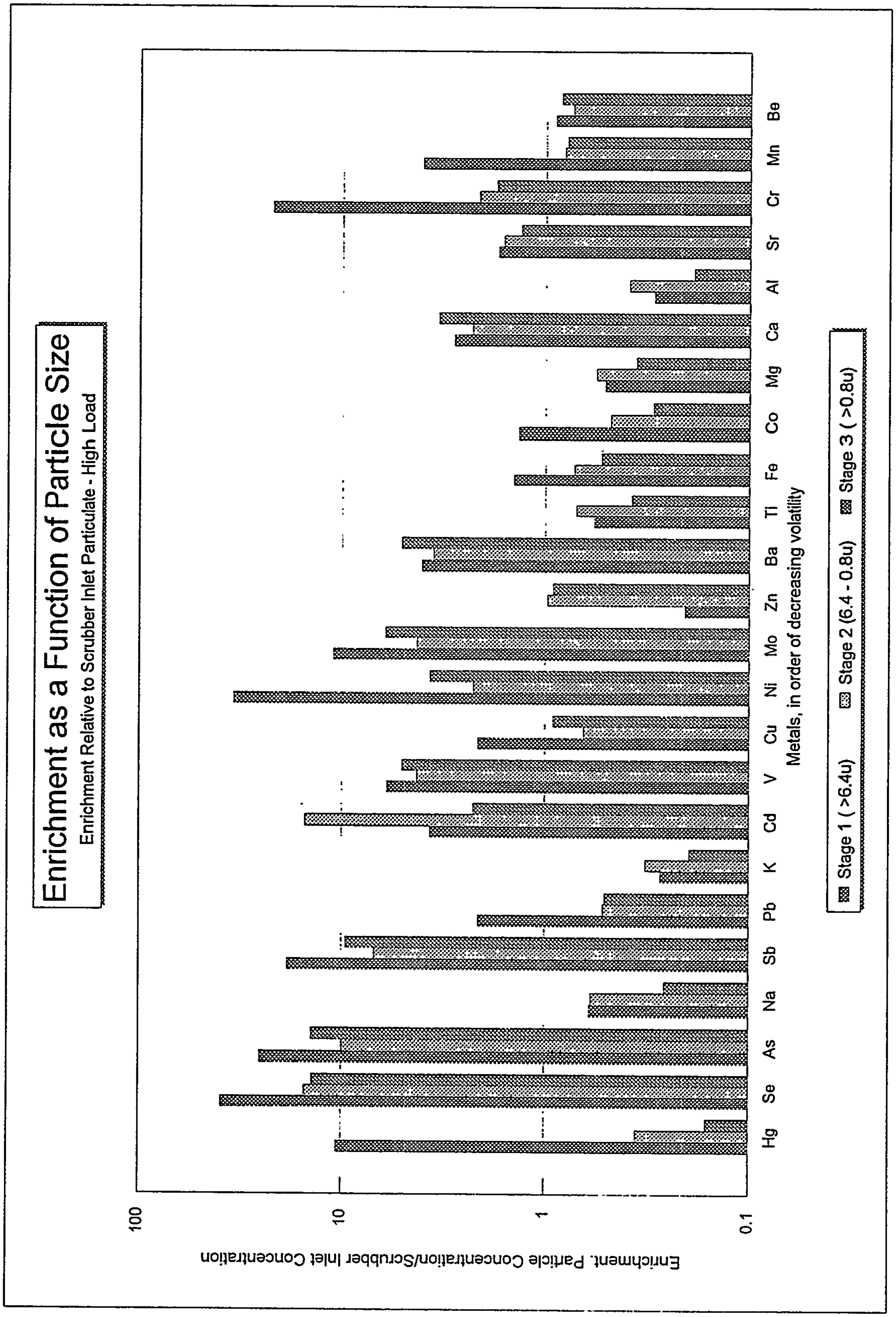

Figure 5-5
Enrichment as a Function of Particle Size

The effect of plant load on the total particle elemental enrichments is shown in Figure 5-6. With the exception of mercury, nickel, cobalt, and chromium, the effect of load on the enrichments appears to be small, if present at all. Mercury is both extremely volatile and somewhat difficult to measure accurately, particularly at low levels, so mercury enrichment levels in the particulate matter may be quite variable. The high enrichments of nickel and chromium at the low load conditions are due to the very high concentrations found in the Stage 1 size fraction. Possible contamination of this fraction was discussed previously.

Enrichment in each particle size fraction, relative to the coal ash, is shown for the low- and high-load plant operation in Figures 5-7 and 5-8, respectively. There does not appear to be any consistent pattern of enrichment within each load condition or for any of the three size fractions. In general and with a few exceptions, the load conditions of the plant do not appear to produce a distinctive difference in the enrichments found in the three particle size fractions At the low-load operation, the high enrichments of chromium in the Stage 1 fraction, of nickel in the Stage 1 and Stage 2 fractions, and of cobalt in the Stage 1 fraction, are very apparent. Somewhat high enrichments of nickel and chromium are also seen in the Stage 1 fraction under high-load operation, but these enrichments are much more modest both in magnitude and relative to the nickel and chromium enrichments seen in the other two size fractions.

The effects of plant load on enrichment are presented in somewhat more detail in Figures 5-9, 5-10, and 5-11. In each of these figures, the enrichment for a single size fraction is shown for the two load conditions. The high enrichments of nickel, cobalt and chromium in the Stage 1 size fraction at low load operation is very apparent in Figure 5-9. Enrichments of other elements, however, are comparable between the high- and low-load conditions. There is no consistent affect of load on the elemental enrichments in the Stage 1 particulate size fraction.

In Figure 5-10, the relatively high enrichments of nickel and chromium in the Stage 2 particulate size fraction are still very apparent. These enrichments stand out particularly because of the generally similar enrichments, as functions of plant load, of the other elements. There is no overriding uniformity in the pattern of enrichment found in this size fraction, and there is no distinct affect of load on enrichment for this size fraction of particles.

The enrichments of the fine particulate fraction (Stage 3), shown in Figure 5-11, are remarkably similar for the high- and low-load plant conditions. There does not seem to be any significant affect of the plant load on the enrichment of particles in this size range.

It has been shown that a very rough correlation exists between the elemental boiling point and the extent of enrichment on fly ash surfaces and smaller particles.[1] The enrichment data from Widows

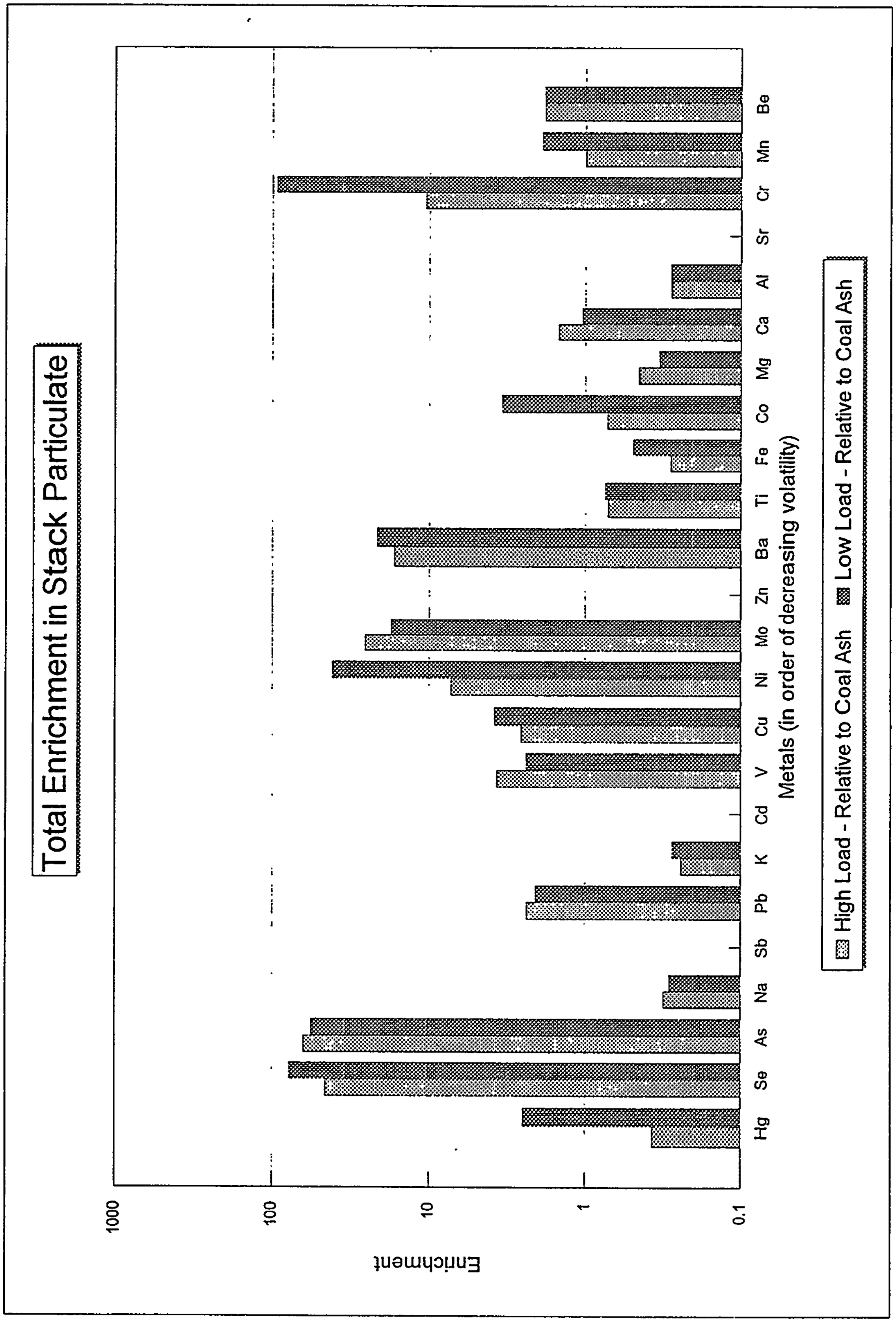

Figure 5-6
Total Enrichment in Stack Particulate

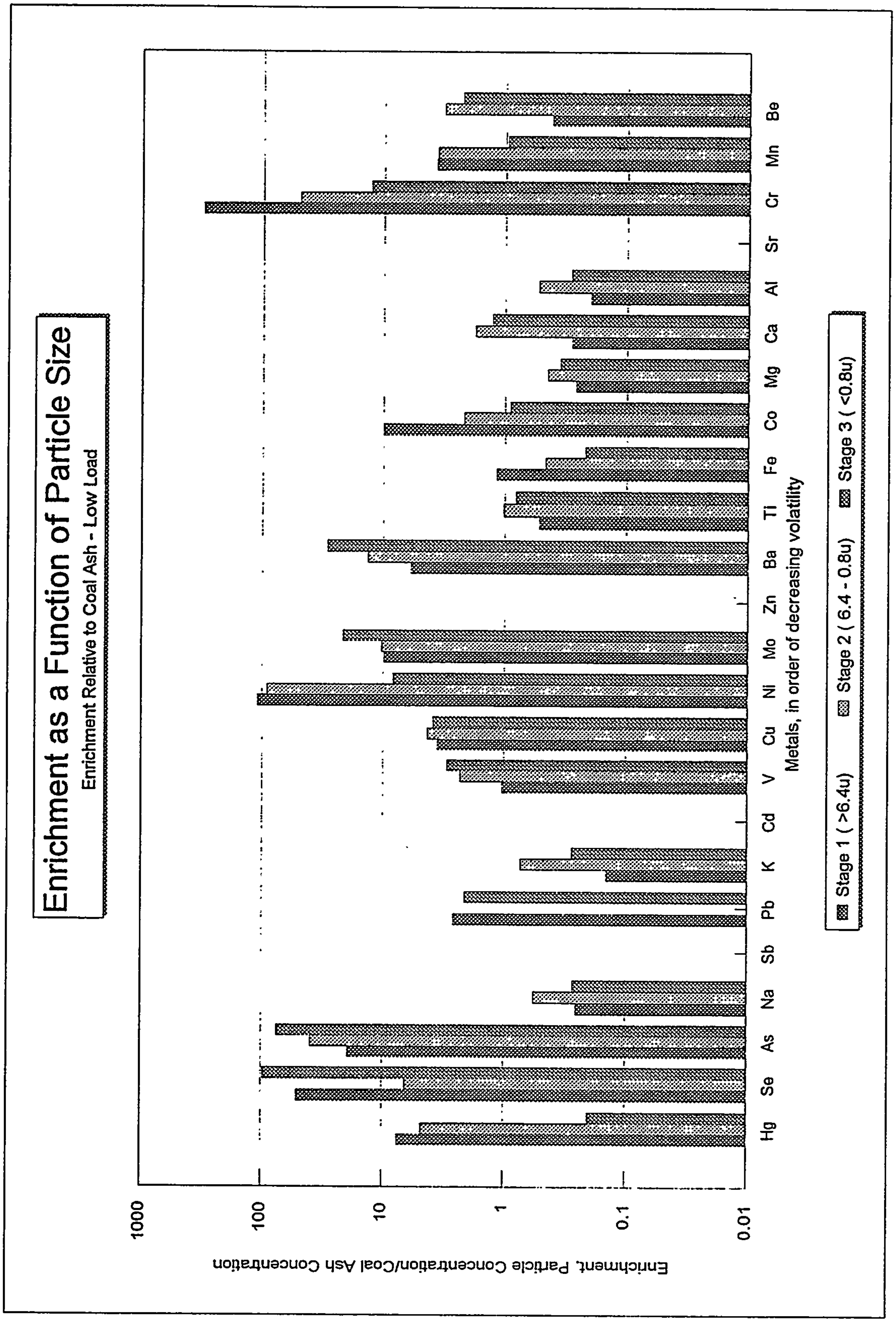

Figure 5-7
Enrichment as a Function of Particle Size - Low Load

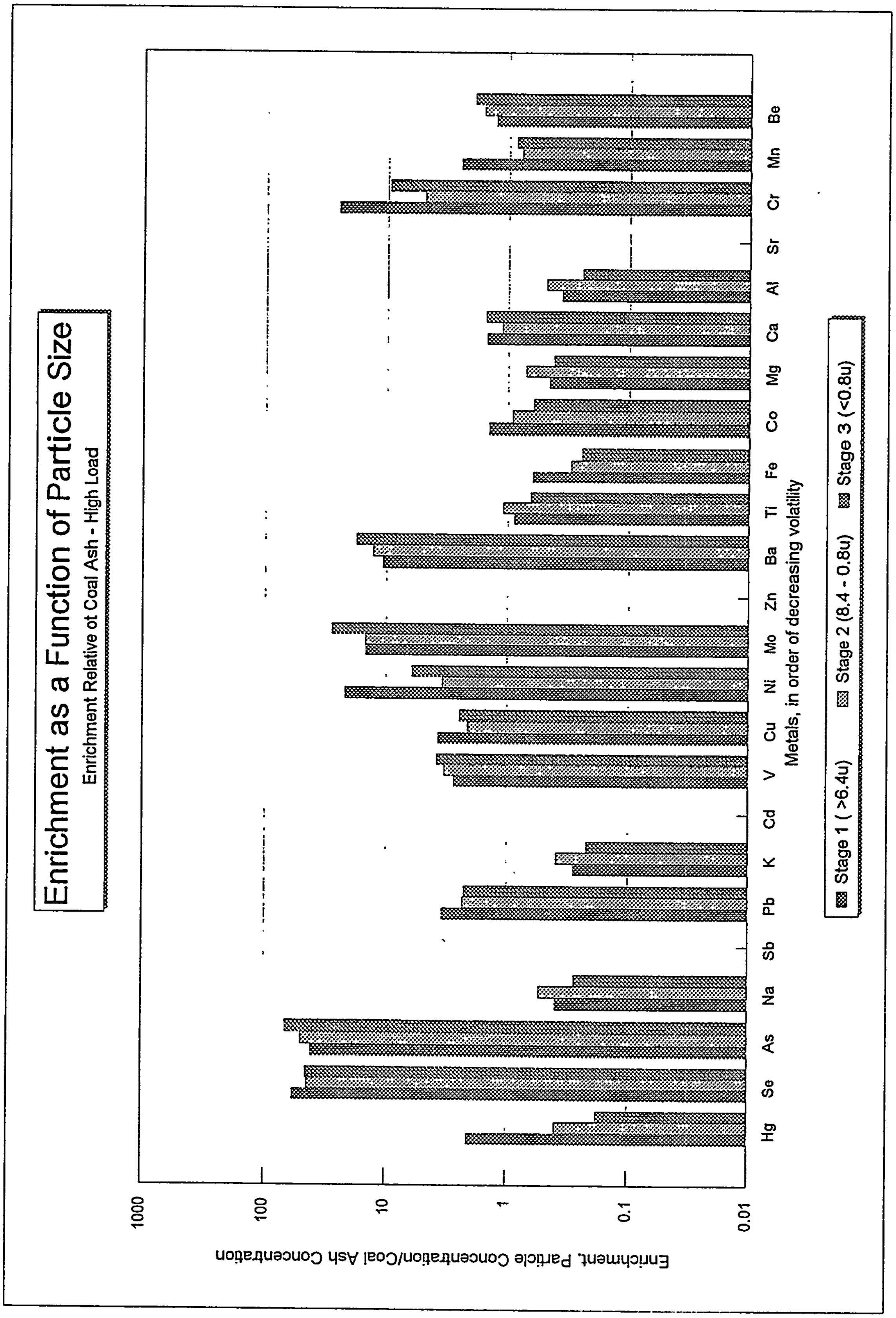

Figure 5-8
Enrichment as a Function of Particle Size - High Load

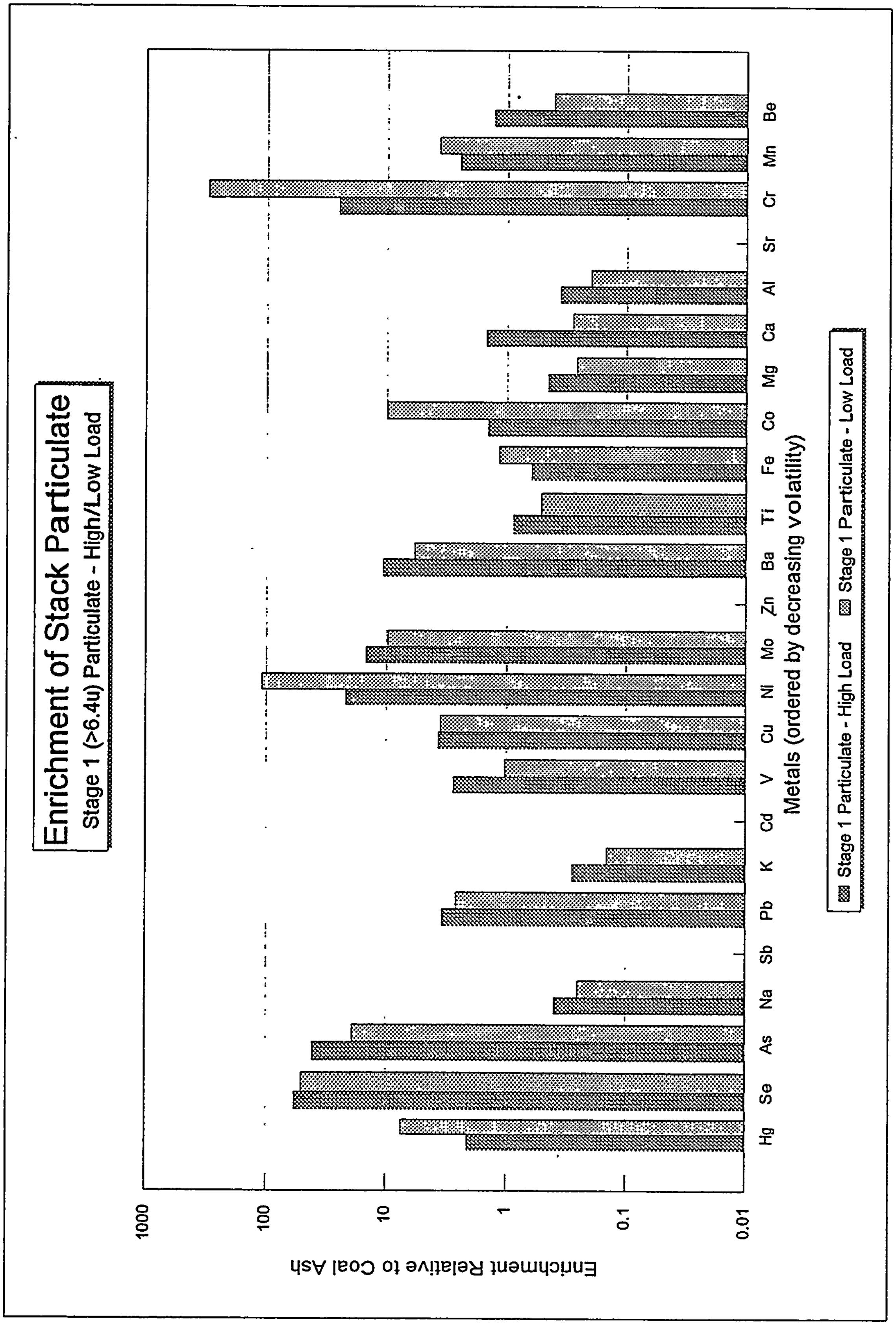

Figure 5-9
Enrichment of Stack Particulate - Stage 1, High/Low Load

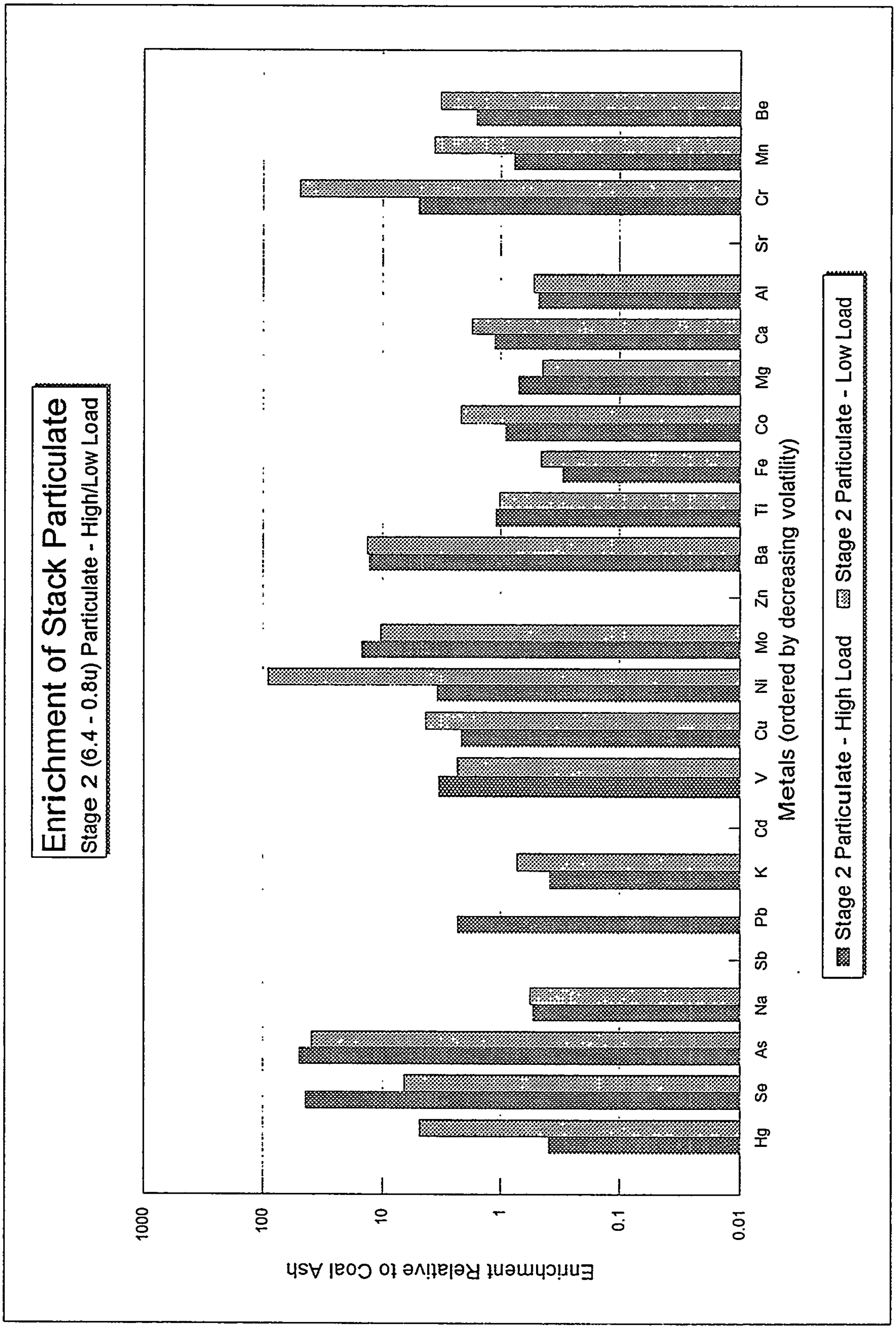

Figure 5-10
Enrichment of Stack Particulate - Stage 2, High/Low Load

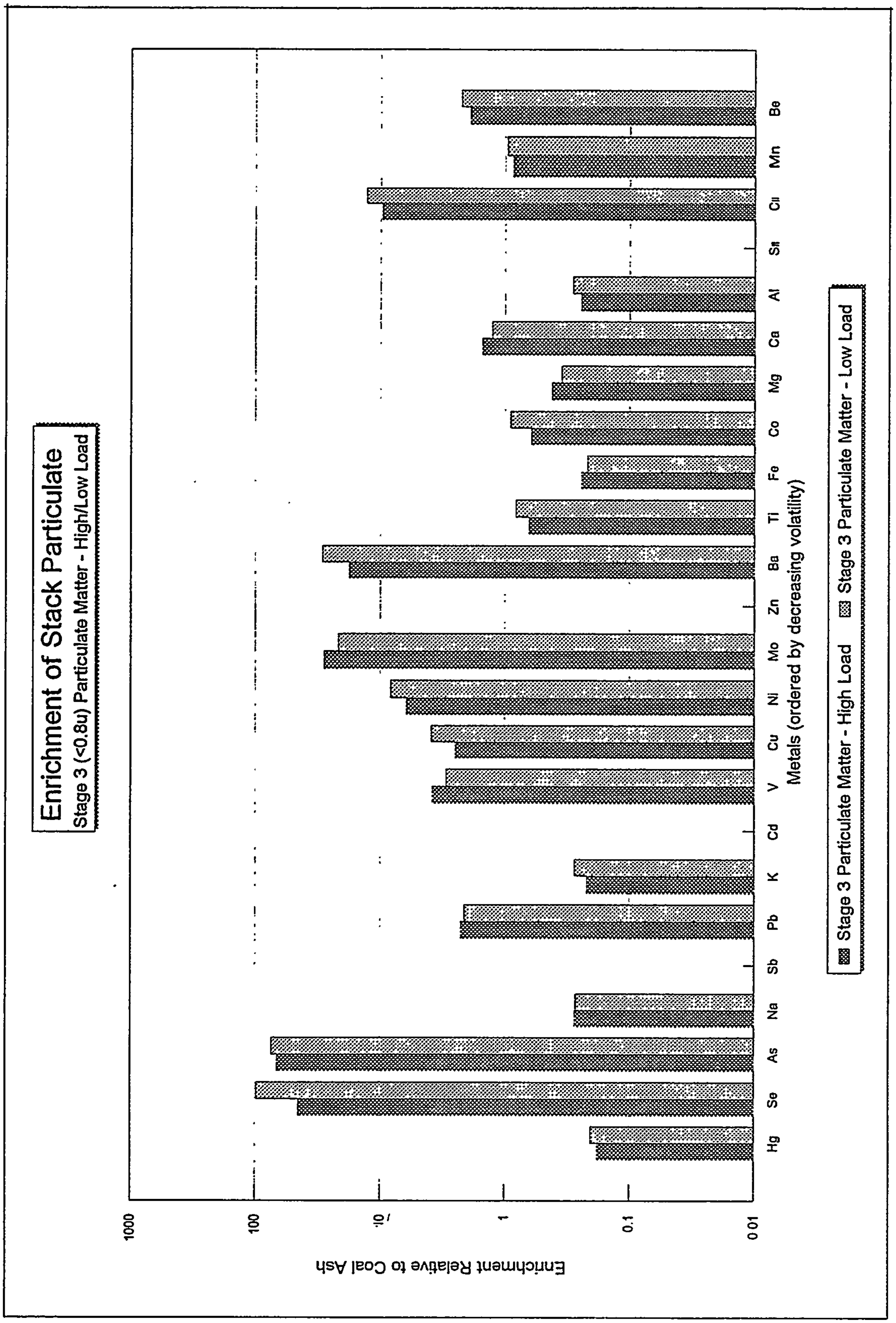

Figure 5-11
Enrichment of Stack Particulate - Stage 3, High/Low Load

Creek was tested to see if such a relationship existed. Linear regression was applied to test the correlation of enrichment with the inverse elemental oxide boiling temperature. The results are shown graphically in Figures 5-12, 5-13, and 5-14. The total enrichment for both high- and low-loads showed only a very weak correlation ($r^2 = 0.22\text{-}0.25$) with the inverse oxide boiling temperature. The linear correlation at the high- and low-plant loads is shown, along with the individual data points, in Figures 5-12 and 5-13, respectively.

The same relationship was tested for the Stage 3 particulate matter only. The results are shown in Figure 5-14. The correlation was slightly better ($r^2 = 0.3$), but still extremely weak. Thus, it appears that the oxide boiling point is not a good predictor of particle elemental enrichment, at least for this plant.

5.5 Emissions Estimates

Average emission rates were estimated for low- and high-load operation at the Widows Creek Unit 8. These factors, developed for comparative purposes only, are shown in Table 5-5. It has been noted that the particulate loadings were estimated using a method (in-stack impactor) that differs from the generally used and accepted EPA Method 5. The use of impactor results to estimate loadings generally gives a loading that is biased low, possibly by as much as 30-50%. The emission estimates were also developed using estimated coal firing rates and stack gas flows, as described earlier in this section.

For comparative purposes, the average emission factors developed during recent DOE-sponsored testing at three power plants are included in the table. The three selected plants all fired bituminous coal and were equipped with electrostatic precipitators (ESPs) for particulate control. None of the three plants had flue gas desulfurization systems. In general, the emission factors from the Baldwin Power Station Unit 2 are somewhat higher than those from the other two plants. This is a result of the overall lower particulate removal efficiency of the ESP at Baldwin.

For the majority of elements, the estimated emission factors from Widows Creek are generally comparable to those found at the other three plants. The estimated emission rates of a few elements at the Widows Creek Plant do stand out, even given the probable low bias of the estimated emission rates. These elements include barium, chromium (low load), mercury, nickel (low load), and sodium. Barium emissions (190-270 lb/10^{12} Btu) appear to be significantly higher than those found in the other plants (0.56-7.1 lb/10^{12} Btu). The reason for these higher emissions could not be discerned. Barium levels in the coals are all comparable, and there does not appear to be evidence of liquid carryover from the scrubber at the Widows Creek plant.

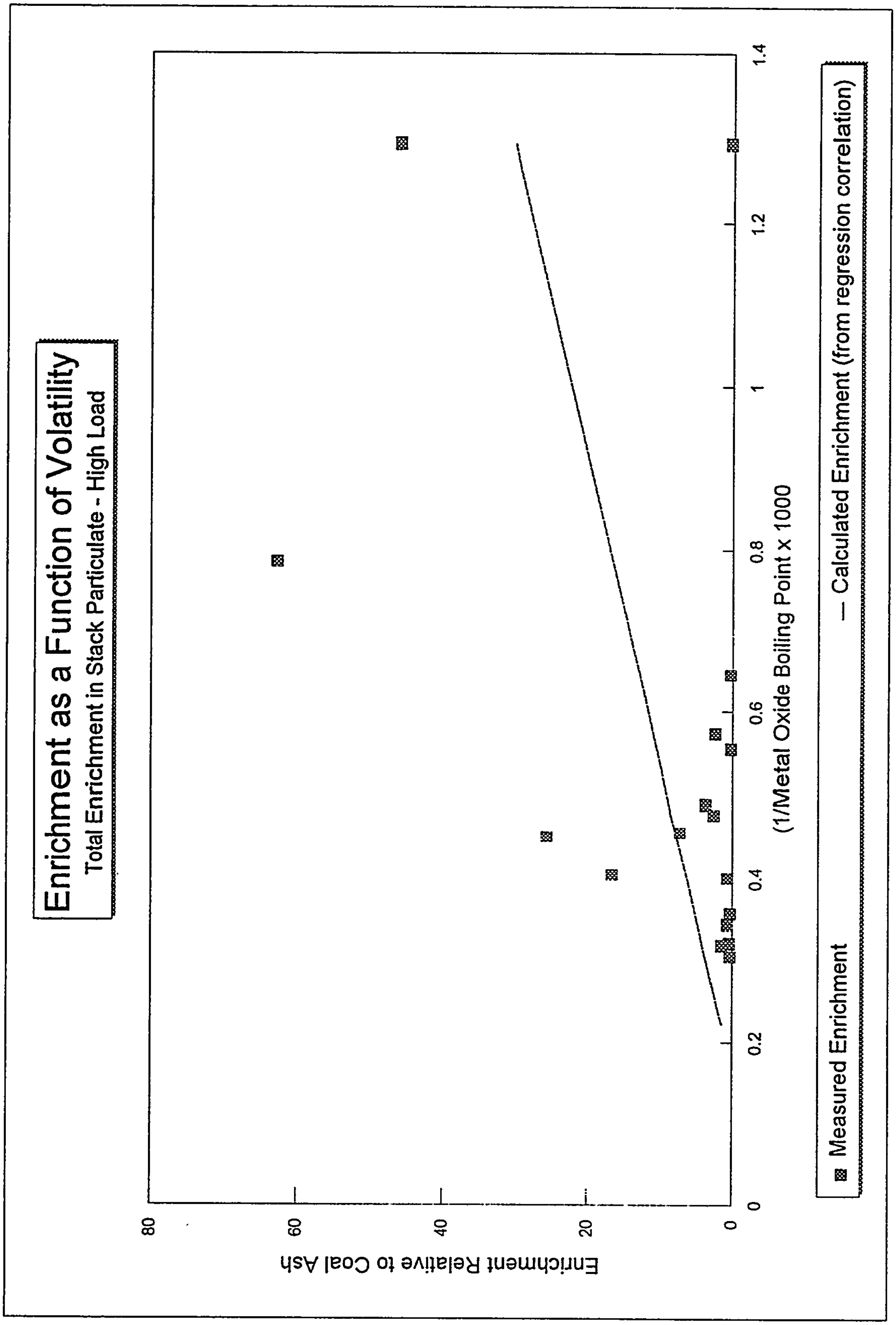

Figure 5-12
Enrichment as a Function of Volatility - High Load

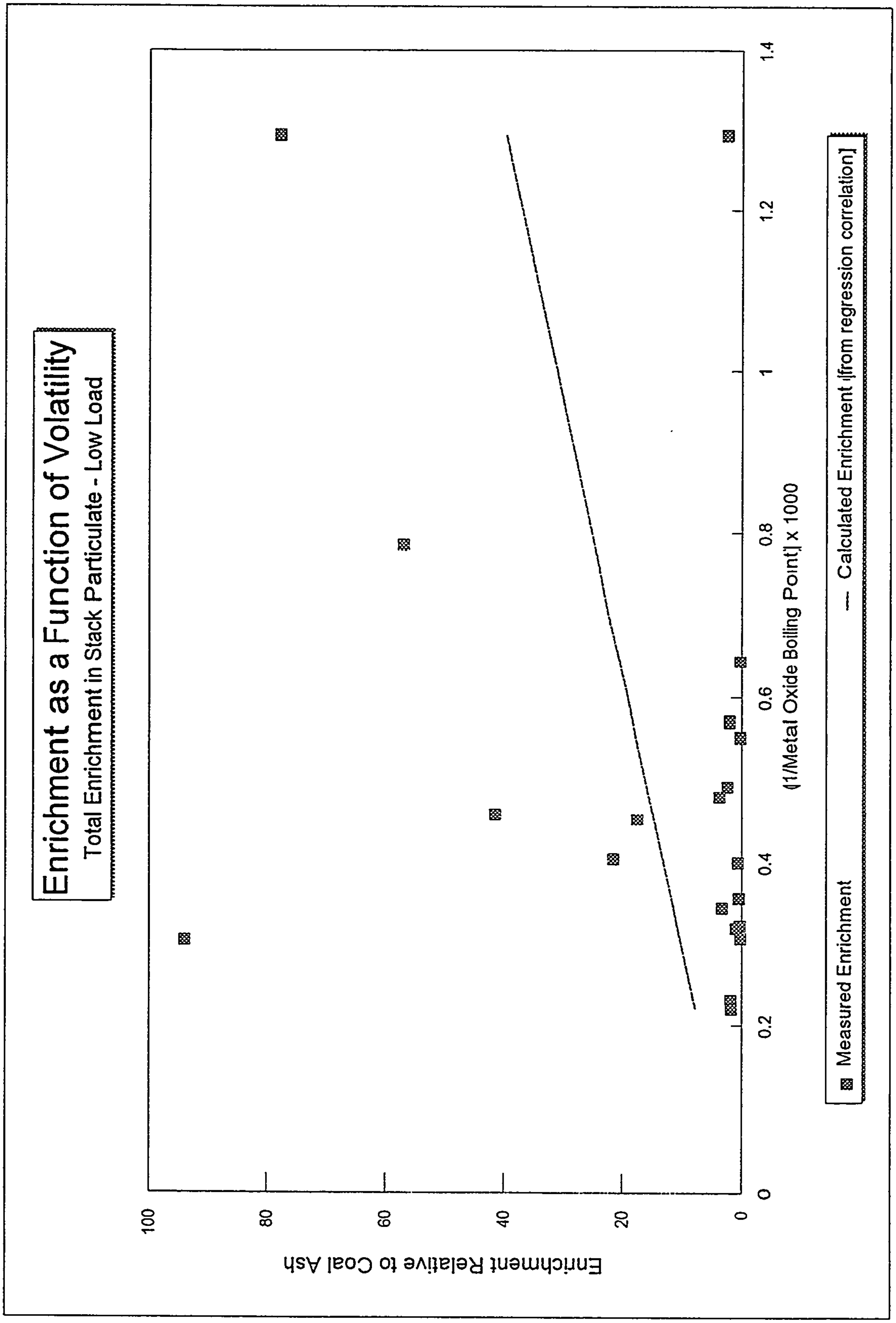

Figure 5-13
Enrichment as a Function of Volatility - Low Load

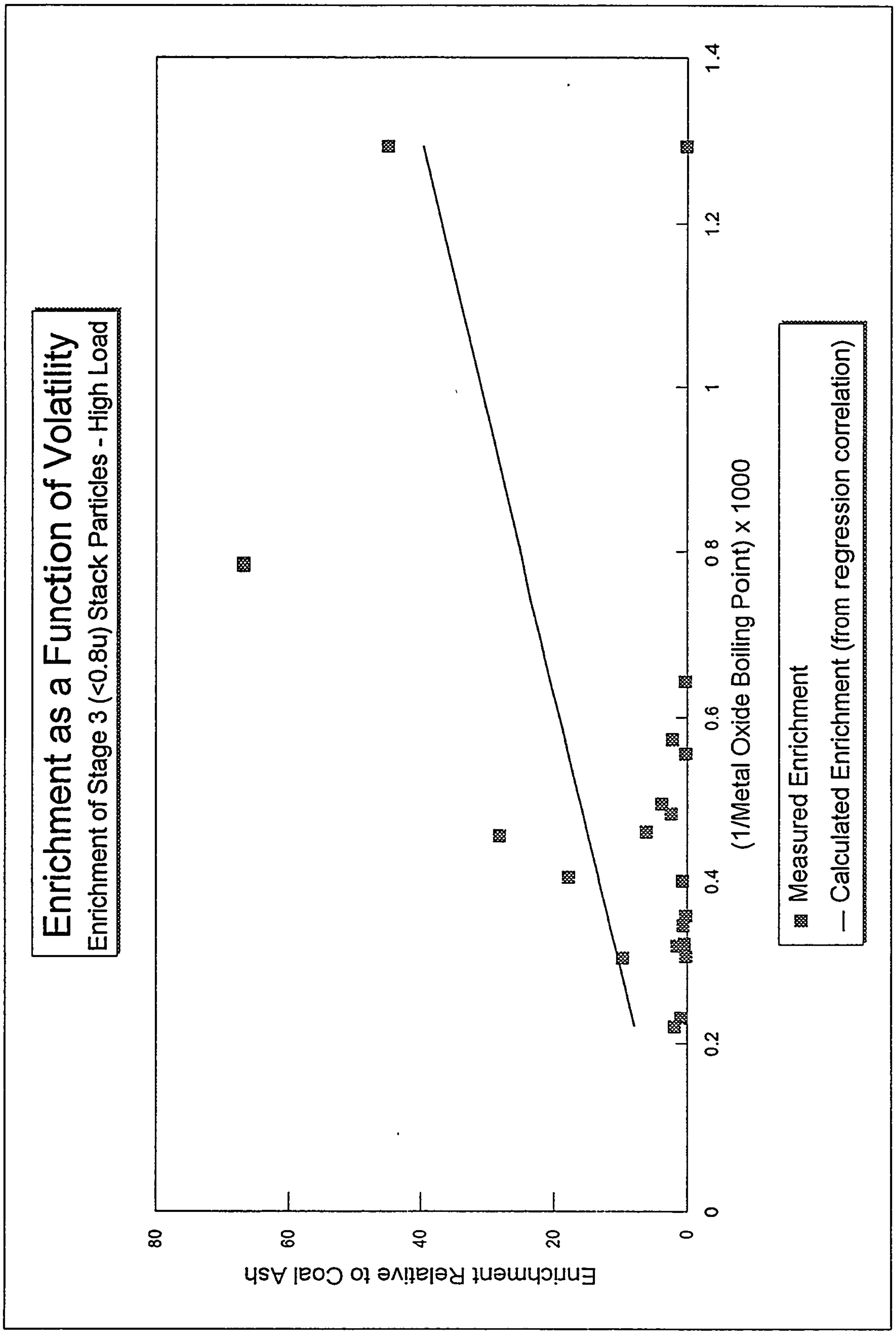

Figure 5-14
Enrichment as a Function of Volatility - Stage 3, High Load

Table 5-5
Estimated Emission Factors[a]

	Average Emission Factors, lb/10E12 Btu				Baldwin Power Station, Unit 2
	Widows Creek		Niles Station Boiler No. 2	Cardinal Plant Unit 1	
	High Load	Low Load			
Part. Removal, %	NA	NA	99	99-100	97
Al	800	450	1,100		5,600
Sb	5.3	2.5	<0.54	2.1	1.5
As	69	35	48	2.5	13
Ba	270	190	7.1	0.56	5.3
Be	0.58	0.32	0.25	0.0057	1.4
Cd	11	3.8	<0.14	0.77	3
Ca	890	350			330
Cr	44	220	3.9	5.8	51
Co	1.1	2.9	<0.21	0.53	6.8
Cu	7.4	6.1	5.2	1.2	19
Fe	950	910			8,400
Pb	4.2	2.0	3.1	3.3	29
Mg	48	20			280
Mn	6.9	7.2	3.9	14	22
Hg	0.0090	0.034		0.41	3.8
Mo	23	8.5	5.4	0.19	34
Ni	37	120	1.2	3.7	22
K	110	68	690		930
Se	20	19	62	79	130
Na	29	15	1,700		1,200
Sr	17	12			
Ti	110	64	34		380
V	69	25	4.2	1.2	100
Zn	26	6.4			

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[a] Emission factors for Widows Creek are estimates only for comparative purposes. Measured loading is probably biased significantly low, and plant operating parameters were estimated.

The relatively high emission factors for chromium and nickel at low load are due to the high enrichment of the particles, as mentioned previously in this discussion. The low emissions of sodium from the Widows Creek, relative to the emissions from the other plants, also cannot be readily explained. Sodium levels in the coal are comparable to those in the coals fired at the other plants. The mercury emission factor is low because only the particulate composition was used to calculate the emission factors. Most of the mercury in the flue gas is generally present in vapor forms, and vapor composition was not determined in this study.

5.6 References

1. Smith, R.D. "The Trace Element Chemistry of Coal During Combustion and the Emissions from Coal-Fired Plants." *Progress in Energy and Combustion Science,* Vol. 6. No. 1, pp. 53-119. Pergamon Press, New York, NY (1980).

6.0 TOXICOLOGICAL EVALUATION

Many of the inorganic elements found in stack gas from coal-fired power plants have the potential to produce adverse effects in exposed populations. This potential is a function of the toxicity of each chemical and the amount of exposure that occurs. Exposure is usually quantified by modeling the air dispersion of stack gas particulate to estimate the total concentration in inhaled air, and by using bulk analyses of the particulate to predict the air concentration of each specific element of concern. The concentration of the element in air can be used to estimate the mass of the element retained in the lung and available for absorption into the body.

The amount of any inhaled particulate that is retained in the lung is inversely related to particle size, such that greater fractions of small particles are retained compared to large particles. Particle size distribution data (when available) can be used to adjust the percentage of inhaled particulate that is retained; if these data are not available, it is conservatively assumed that 100% of the particulate is retained in the lung. Thus, the daily mass of a specific element to which an individual is exposed is estimated using the predicted concentration in air (determined by air dispersion modeling and bulk chemical analyses), the total volume of air inhaled in a 24-hour period, and the percent retained (predicted from particle size distribution).

The reliance on bulk analyses of particulate matter may both under- and overestimate the exposure. Studies have shown that the so-called volatile elements (those with a boiling point sufficiently low that they exist in the vapor phase in the boiler) may be "enriched" in the smaller size fractions of fly ash particulate. This is the result of the greater surface area-to-mass ratio of the small size particles, such that a greater mass of a volatile element per unit particle mass may condense on the small particles than on the large particles. Because the percentage of small particles retained in the lung is greater than that of large particles, the actual exposure to elements that are enriched on smaller particles may be significantly greater than that predicted on the basis of bulk analyses performed without regard to particle size.

In contrast, the actual exposure to elements in stack gas particulate may be overestimated using bulk analyses if the analytical methods use harsh conditions. The fly ash matrix consists primarily of an aluminum-silica complex that may "trap" other elements in the matrix structure. Exposure to any element in or on a particle will only occur to the extent the element can be extracted from the particle and dissolved in body fluids; this is called the bioavailability of the element. In the case of inhaled particles, contact with lung surfactant fluid would result in dissolution of some elements that would then be available for absorption into the body; however, this dissolution would likely be very limited due to the fairly neutral pH of surfactant fluid and the relatively benign conditions.

Inhaled particles are transported from the lungs on a blanket of mucus; little if any dissolution would occur during this period. The particles are transported to the pharyngeal region (the back of the throat) and then swallowed. Gastric fluid has a low pH (typically 1-4, depending on time since the last meal), and fairly thorough mixing occurs. Nonetheless, dissolution of elements into either lung surfactant fluid or gastric fluid would occur to a much lesser extent than that occurring during bulk analysis extractions, which may be so severe as to actually digest the aluminum-silica matrix. Thus, elemental compositions of fly ash that are determined using severe bulk analysis methods may overpredict the mass of elements that would be dissolved in the lung or stomach and available for absorption into the body.

Section 4 presented the analytical results for three different size ranges of particles for each of four analytical methods. Particles were collected from the economizer outlet, and from stack gas under both high- and low-load conditions. This section evaluates the toxicologic significance of the results presented in Section 4 in terms of the factors discussed above that are important for evaluating exposure. The bulk composition methods determined the total mass of each element in particles as a function of particle size range. The nitric acid digestion determined the mass of elements on the particle surface or loosely bound in the particle matrix; the extraction conditions were significantly more severe than those in either the lung or the stomach. The simulated gastric fluid extraction determined the mass of elements that would be bioavailable after particles were swallowed. This evaluation focuses on the toxicologic significance of the results using simulated gastric fluid for different particle size ranges and sampling conditions, and compares the conclusions to those predicted using bulk composition results to highlight the importance of the analytical method used.

Section 6.1 describes the effect of particle size on deposition in the lung. Section 6.2 summarizes the toxicity information available for the elements measured. Section 6.3 evaluates the concentrations of bioavailable elements for different particle size ranges for high- and low-load conditions. Section 6.4 compares the relative bioavailability results for samples from the economizer outlet to the stack gas particle samples. Section 6.5 presents the conclusions.

6.1 Deposition of Particles in the Lung

The site of deposition of a particle in the respiratory tract is extremely important to its potential toxicity, and is determined by the physical forces that affect particle behavior in an airstream and the anatomy of the respiratory tract itself. The total amount of a material deposited in the lung is less important than the location of that deposition, called the regional deposition. The regional deposition and the composition of the particle itself interact to determine the toxicity resulting from inhalation of the particles. The regional deposition affects the degree of absorption of toxic chemicals, the severity of toxic effects, and the clearance mechanisms available to remove the particle.

The human respiratory tract can be roughly divided into three different regions with differences in anatomy and physiology that have important effects on the deposition of inhaled particles. The nasopharyngeal region includes the nose and the throat to the level of the larynx. The tracheobronchial region includes the trachea, the bronchi, and the bronchioles, which conduct air to the region where oxygen/carbon dioxide exchange occurs. The alveolar region consists primarily of the very small air sacs where respiratory exchange takes place. The anatomic and physiologic characteristics of these three regions are summarized in the following paragraphs.

The nasopharyngeal region is lined with mucous epithelium with small hairs in the anterior portion. The lining of the posterior portion has cilia (microscopic hair-like structures), which act together to propel the overlying mucus layer in a particular direction. Large inhaled particles are filtered out of inhaled air by impaction on the hairs or on the mucus layer in this region. Mucus containing trapped particles can be removed from the nasopharyngeal region either by sneezing (as often occurs with particles that are irritating, such as pollen) or by ciliary transport to the throat, where the mucus is swallowed.

The tracheobronchial region includes several different reactive tissues, including smooth muscle (which widens or constricts the airways), epithelium (which lines the airways), nerves, and secretory cells. This region is coated by a thin layer of mucus produced by the secretory cells in this region. The mucus is continuously propelled upward to the oral cavity by the beating of cilia attached to the epithelium. This provides a clearance mechanism for particles that are trapped by the mucus in this region.

The alveolar region consists primarily of pneumocytes that provide the surface area necessary for respiratory exchange. The alveolar surface is covered by a very thin layer of surfactant that is secreted locally. The alveoli also contain macrophages, which are specially adapted immune cells that ingest inhaled particulate matter and clear it from the alveolar region.

These regional anatomic and physiologic differences affect the deposition of particles in inhaled air. The high air velocity and tortuous nature of the nasopharyngeal air passages force many sharp changes in air direction. These changes in air direction, combined with the presence of hairs and mucus, result in impaction of large particles in this region. Thus, more than 50% of particles greater than 2 μm in diameter, and more than 90% of particles greater than 10 μm in diameter are deposited in the nasopharyngeal region.

The tracheobronchial region has slower airflow and less abrupt changes in air direction. Although some impaction occurs (primarily in the upper portion of this region), sedimentation of particles is the predominant deposition mechanism in this region. Particles in the range of 0.001 to 0.1 μm in diameter are deposited in the tracheobronchial region, with more than 50% deposition occurring for particles in the range of approximately 0.002 to 0.015 μm. Particles in this region are deposited on the mucus layer, and are transported to the oral cavity and subsequently swallowed.

The velocity of airflow in the alveolar region is markedly decreased in comparison to that in the upper regions of the respiratory tract. Particles that penetrate to this region are largely deposited by diffusion. Relatively little deposition occurs in this region. The maximum deposition, approximately 30-35% occurs for particles ranging from 0.002 to 0.007 μm in diameter; a second deposition maximum of approximately 20% occurs for particles of 2 to 3 μm diameter. Particles that deposit in this region can dissolve (partially or completely) in the surfactant or can be ingested by macrophages and removed from the system. Particles that penetrate to the alveolar region, but are not deposited, are exhaled with expired air.

Most inhaled aerosols are heterogeneous in size, and the results in Section 4 indicate that this is true for the stack gas particulate collected in this project. Three different size fractions of particulate were collected: Stage 1, containing particles greater than 6.00 μm in diameter; Stage 2, containing particles ranging from 0.8 to 6.00 μm in diameter; and Stage 3, containing particles smaller than 0.8 μm in diameter. The regional deposition of these stages is summarized in Table 6-1. Using these size ranges and the information summarized by NCRP[1], the Stage 1 particles would be deposited primarily (>80%) in the nasopharyngeal region, with minor amounts deposited in the alveolar (<10%) and tracheobronchial (<8%) regions.

Table 6-1
Regional Deposition of Particles from Each Size Fraction

Stage	Approximate Particle Size Range (μm)	Estimated Regional Deposition (%)			Nasopharyngeal + Tracheobronchial (%)
		Nasopharyngeal	Tracheobronchial	Alveolar	
1	≥6.00	80	8	10	88
2	0.8-6.00	60	7	22	67
3	≤0.8	13	3	10	16

To estimate deposition of Stage 2 particles, the geometric mean particle size was first determined to be approximately 2.8 μm. At this particle size 60% would be deposited in the nasopharyngeal region, 22% in the alveolar region, and 7% in the tracheobronchial region; the remaining 11% is assumed to be exhaled. For Stage 3 particles, which were approximately 0.8 μm in diameter or smaller, an estimated 13% would be deposited in the nasopharyngeal region, 10% in the alveolar region, and 3% in the tracheobronchial region, and the remainder assumed to be exhaled.

As discussed above, particles deposited in the nasopharyngeal region are most likely to be carried by mucus to the throat and swallowed (assuming the particles are not irritating enough to cause sneezing). Particles deposited in the tracheobronchial region would also be carried to the throat by mucus and swallowed. Thus, exposure to particles deposited in these regions will occur by ingestion. Most elements produce the same type of noncarcinogenic effects regardless of route of exposure; the exposure route determines the amount of absorption and therefore the magnitude of the toxic effect. In contrast, some elements have been shown to be carcinogenic by inhalation but not after oral exposure (see Section 6.2). Although the reason for this difference is unknown, it is important when considering the biologic fate of stack gas particulate. Oral toxicity and carcinogenicity will be of primary interest for particles deposited in the nasopharyngeal and tracheobronchial regions.

Particles deposited in the alveolar region could dissolve in surfactant or be removed by macrophages. For simplicity it was assumed that all particles deposited in the alveolar region are subject to dissolution in surfactant fluid, and thus inhalation toxicity and carcinogenicity would be the primary concern. Table 6-1 presents the relative percentages deposited in the nasopharyngeal + tracheobronchial regions versus the alveolar region for each particle size fraction. The nasopharyngeal + tracheobronchial portion represents the fraction of particles for which oral toxicity is most important, while the alveolar portion represents the fraction for which inhalation toxicity is most important.

For Stage 1 particles, nasopharyngeal + tracheobronchial deposition occurs for more than 9 times the particles for which alveolar deposition occurs. Therefore, for Stage 1 particles oral toxicity is the most important endpoint. For Stage 2 particles, nasopharyngeal + tracheobronchial deposition is approximately three times that of alveolar; while oral toxicity will be more important than inhalation for these particles, inhalation toxicity cannot be ignored. For Stage 3 particles deposition in the nasopharyngeal + tracheobronchial regions is approximately equivalent to that in the alveolar region, so oral and inhalation toxicity are equally important. Thus, as particle size decreases while proceeding from Stage 1 to Stage 3, the importance of inhalation toxicity of an element increases.

6.2 Summary of Toxicity Information

Toxicity profiles for the elements measured are presented in Appendix E. Some of the elements are potentially carcinogenic when inhaled. Others have the potential to produce noncarcinogenic effects after long-term (chronic) exposure, and some elements have the potential to produce both carcinogenic and chronic toxic effects depending on the magnitude and duration of exposure. EPA has evaluated the potential for many compounds to produce carcinogenic and/or noncarcinogenic effects.

EPA develops specific toxicity values for chemicals to assess the likelihood of carcinogenic effects or of chronic toxicity, called noncarcinogenic effects. Carcinogenic effects are evaluated using the cancer slope factor, which is used to estimate the upper-bound probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen; this is called the lifetime excess cancer risk. Toxicity values used to evaluate noncarcinogenic effects include reference doses (RfDs) for oral toxicity and reference concentrations (RfCs) for inhalation toxicity. The RfDs and RfCs are estimates of the daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during the lifetime.

The Occupational Safety and Health Administration (OSHA) promulgates standards for exposure to specific chemicals in the workplace. The permissible exposure levels (PELs) may be 8-hour time-weighted average air concentrations, short-term exposure limits (15-minute averages), or ceiling values not to be exceeded. The American Conference of Governmental Industrial Hygienists (ACGIH) establishes Threshold Limit Values (TLVs) for workplace air. The TLV is a time-weighted average concentration for a normal 8-hour workday and a 40-hour work week to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

Occupational exposure levels are developed for protection of healthy workers, who are exposed over a well-defined workday. Exposures to the community, however, may occur on a continuous basis for those who spend most of their time at home, and include the young, the elderly, and others who may be more at risk of developing toxic effects than are workers. Thus, occupational exposure levels are not appropriate for estimating acceptable exposures for the community. However, since occupational exposure levels are developed on the same basis (the 40-hour work week), they can be used to compare the relative inhalation toxicity of the elements.

Table 6-2 summarizes the toxicity values and occupational exposure levels available for the elements analyzed in stack gas particulate; Table 6-3 summarizes the target organ(s) for toxicity for each element as identified by EPA in establishing toxicity values. Few elements have inhalation reference concentration values established. The three elements having RfC values, barium, manganese, and mercury, are of similar toxicity with RfC values ranging from 5.0E-05 mg/m^3 for manganese to 5.0E-04 mg/m^3 for barium. All of the elements except aluminum and iron have oral reference doses established. Elements can be ranked in order of oral toxicity by using the RfD values in inverse order. Thus, strontium, with the highest RfD, is the least toxic element with an RfD of 0.6 mg/kg/day, and cadmium is the most toxic with an RfD of 0.0005 mg/kg.

Oral slope factors have not been determined by EPA for any of these elements. Four of the elements are considered carcinogenic by inhalation: arsenic, cadmium, chromium VI, and nickel. The value presented in Table 6-2 for inhalation carcinogenic effects is the inhalation unit risk. This is defined as the lifetime excess cancer risk per µg/m^3 of the element in air. Thus, these values can be used in conjunction with the concentration of the element in air to determine the cancer risk. Nickel has the

Table 6-2
Summary of Toxicity Values and Allowable Workplace Exposure Levels

Compound	Toxicity Values				Workplace Exposure Levels	
	Noncarcinogenic Effects		Carcinogenic Effects (Slope Factors)			
	Inhalation RfC (mg/m^3)	Oral RfD (mg/kg)	Inhalation (µg/m^3)$^{-1}$	Oral (µg/kg)$^{-1}$	ACGIH TLV (mg/m^3)	OSHA PEL (mg/m^3)
Aluminum	--[a]	--	--	--	2	2
Antimony	--	4.0E-04	--	--	0.5	0.5
Arsenic	--	3.0E-04	4.3E-03	--	0.01	0.01
Barium	5.0E-04	7.0E-02	--	--	0.5	0.5
Cadmium	--	5.0E-04	1.8E-03	--	0.002	0.2
Chromium VI	--	5.0E-03	1.2E-02	--	0.05	--
Cobalt	--	--	--	--	0.05	0.05
Copper	--	4.0E-02[b]	--	--	1	1
Iron	--	--	--	--	1	1
Manganese	5.0E-05	5.0E-03	--	--	5	5[c]
Mercury	3.0E-04	3.0E-04	--	--	0.1	0.1[c]
Molybdenum	--	5.0E-03	--	--	5	5
Nickel	--	2.0E-02	2.4E-04	--	0.1	0.1
Selenium	--	5.0E-03	--	--	0.2	0.2
Strontium	--	6.0E-01	--	--	--	--
Titanium	--	--	--	--	10[d]	5[d]
Vanadium	--	7.0E-03	--	--	--	--
Zinc	--	3.0E-01	--	--	--	--

[a] Not available.
[b] Calculated from the safe drinking water level.
[c] Ceiling values not to be exceeded.
[d] Value for titanium dioxide.

Table 6-3
Summary of Target Organs by Chemical

Chemical	Target Organs by Exposure Route		
	Inhalation	**Ingestion**	**Dermal**
Aluminum	Respiratory	--	--
Antimony	Respiratory Circulatory Gastrointestinal Reproductive	--	Skin Eye
Arsenic	Respiratory Circulatory Gastrointestinal CNS/PNS[a] Developmental Reproductive Skin	Gastrointestinal Circulatory Skin	Skin
Barium	Reproductive	Circulatory	--
Beryllium	Respiratory Circulatory Hematological Liver Skin Eyes	Musculoskeletal	Respiratory Hematological Skin
Cadmium	Respiratory Kidney Liver Reproductive	Kidney	--
Chromium III	Respiratory	--	--
Chromium VI	Respiratory Gastrointestinal Liver	--	--
Cobalt	Respiratory Circulatory Kidney Liver Eyes	Circulatory Liver Eyes	--
Copper	Respiratory Liver Reproductive	Kidney Liver	--
Iron	Respiratory Skin	Gastrointestinal Circulatory CNS/PNS	--

Table 6-3 (Continued)

Chemical	Target Organs by Exposure Route		
	Inhalation	Ingestion	Dermal
Lead	Respiratory Hematological	Circulatory Hematological Musculoskeletal Liver Kidney Eyes CNS Developmental Reproductive	--
Manganese	Respiratory CNS/PNS Reproductive	--	--
Mercury	Respiratory CNS/PNS Kidney Developmental Eyes	--	--
Molybdenum	CNS/PNS Bone	Kidney	--
Nickel	Respiratory	--	Skin
Selenium	Respiratory Gastrointestinal	CNS/PNS Skin	--
Strontium	--	Bone	--
Titanium	Respiratory	--	--
Vanadium	Respiratory Eyes	--	--
Zinc	Respiratory	Circulatory	--

[a] CNS/PNS = Central nervous system/peripheral nervous system.

lowest inhalation risk of cancer of the four, with a unit risk value of 2.4E-04 ($\mu g/m^3$)$^{-1}$, and chromium VI has the highest risk, with a unit risk value of 1.2E-02 ($\mu g/m^3$)$^{-1}$.

All of the elements except strontium, vanadium, and zinc have at least one occupational exposure value. The occupational exposure values can be ranked in order of toxicity similar to reference doses; that is, elements with high TLVs or PELs are less toxic. TLVs are reviewed on an annual basis, and are updated as new toxicity information becomes available. PELs, however, are updated infrequently. Therefore, TLVs are the more appropriate occupational exposure level for toxicity comparison purposes (the TLVs in Table 6-2 were obtained from the 1993-1994 TLV listing). Where TLVs or PELs were available for more than one form of the element, the value for the metallic form, or dust, or soluble salts was selected in that order for presentation in the table. Titanium is the least toxic element, with a TLV of 10 mg/m^3, and cadmium is the most toxic, with a TLV of 0.002 mg/m^3.

6.3 Toxicologic Evaluation of Bioavailable Elements Under Two Load Conditions

The stack gas particulate was analyzed using four different methods: bulk analysis, nitric acid extraction, simulated gastric fluid extraction, and acetic acid extraction. The simulated gastric fluid mimicked the conditions in the stomach, and this extraction method was used to evaluate bioavailable concentrations of particular elements. Although simulated lung fluid extraction was attempted, the extraction method was not found to be practical due to growth of bacteria and difficulty in analysis. Therefore, the gastric fluid extraction results are used to evaluate bioavailability of the elements for both oral and inhalation toxicity.

Tables 6-4 and 6-5 present the bioavailability (simulated gastric fluid leach) of elements from two different perspectives. The data in Table 6-4 represents elemental concentrations for each size fraction collected under low- and high-load conditions. A concentration range (for providing a point of reference) is also presented for the economizer outlet. The elemental concentrations presented in Table 6-4 may not correlate with mass emission rates. Higher concentrations for a given size range or load condition do not necessarily reflect higher mass emission rates, which are the ultimate basis for health risk assessments. The original goals of this study did not include emissions estimates and appropriate test procedures to derive this data were not implemented. Table 6-5 presents the data as a function of the percentage (express as the percent extracted compared to the bulk analysis) extractable by the simulated gastric fluid leaching procedure. Changes in the bioavailability of the element gives an indication of changes in particle composition or morphology across the FGD system or differences due to load. The following subsections evaluate the toxicologic significance of these results for each element.

Table 6-4
Bioavailable Concentrations of Elements by Size Fraction[a]

Element	Economizer Outlet	Low-Load Conditions			High-Load Conditions		
		Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Antimony	0.7 - 1.8	10	24	50	27	40	48
Arsenic	55 - 170	440	1,300	2,700	1,400	1,800	2,200
Barium	410 - 590	1,800	4,900	2,900	2,400	3,200	2,100
Beryllium	1.5 - 4.2	2.2	13	17	12	16	16
Cadmium	1.2 - 5.5	22	320	120	180	1,200	120
Chromium	39 - 540	26,000	4,600	2,000	780	610	1,300
Cobalt	5 - 18	250	--[b]	32	33	28	23
Copper	41 - 73	260	250	290	190	200	190
Lead	19 - 61	42	290	34	750	3,000	84
Manganese	19 - 90	900	390	100	150	110	130
Mercury		1.7	<0.96	2.1	1.4	<0.92	1.5
Molybdenum	16 - 45	120	170	520	250	270	720
Nickel	11 - 100	12,000	3,200	1,000	880	500	1,000
Selenium	6 - 17	470	920	1,700	840	770	770
Vanadium	96 - 250	440	1,600	2,300	2,000	2,600	3,100

[a] Units are µg/g.

[b] Value exceeds bulk concentration.

Table 6-5
Effect of FGD and Increasing Load on Relative Bioavailability

Element	Stage 1			Stage 2			Stage 3		
	FGD Inlet	Low Load	High Load	FGD Inlet	Low Load	High Load	FGD Inlet	Low Load	High Load
Antimony	9.5[a]	15.4	19.1	4.3	20.0	24.7	7.5	20.8	20.9
Arsenic	75.4	50.6	75.7	83.2	73.7	78.7	80.3	80.4	73.8
Barium	23.7	46.7	34.1	24.8	56.0	37.6	23.7	15.5	17.8
Beryllium	7.8	40.0	72.2	12.3	31.6	77.7	14.2	58.0	65.5
Cadmium	1.7	16.3	64.9	4.2	--[b]	72.3	4.0	33.8	38.1
Chromium	19.7	48.7	17.9	38.7	54.1	71.9	56.2	92.7	75.5
Cobalt	7.4	39.5	36.0	9.8	--[b]	49.1	13.6	57.4	59.0
Copper	19.6	61.8	43.0	18.4	49.8	77.3	22.6	64.4	65.8
Lead	15.8	22.4	--[b]	17.8	--[b]	--[b]	19.0	22.4	52.1
Manganese	11.1	86.1	20.9	11.2	38.0	49.7	29.2	37.3	54.5
Mercury	42.4	22.5	65.0	10.6	20.1	--[b]	8.6	--[b]	--[b]
Molybdenum	32.1	33.8	47.3	30.6	46.7	50.1	27.0	66.6	71.1
Nickel	7.9	54.9	19.4	19.6	17.1	70.2	29.0	62.4	79.7
Selenium	21.8	51.2	80.6	25.2	--[b]	96.8	30.2	94.4	94.4
Vanadium	27.4	55.1	97.3	40.4	93.2	~100	43.7	~100	~100

[a] Percent of bulk concentration extracted by simulated gastric fluid.

[b] Extraction efficiency could not be calculated because extracted concentration exceeded bulk concentration.

6.3.1 Antimony

The concentration of bioavailable antimony was generally greater for each particle size fraction under high-load conditions compared to low-load conditions and both conditions were greatly enriched as compared to the economizer outlet. Bioavailable antimony increased with decreasing particle size under both low- and high-load conditions. Antimony is one of the more toxic elements on the basis of the RfD of 4.0E-04 mg/kg. The fact that bioavailable antimony was lower in the size fractions for which oral toxicity is most important suggests that differences in antimony inclusion in particles by size may have a mitigating effect on the toxicity of the particles. Since an RfC is not available for antimony, the TLV and PEL can be used to evaluate relative inhalation toxicity. Antimony is approximately in the middle of the range of workplace exposure values for the various elements. This suggests that relative enrichment of antimony on smaller particles, for which inhalation toxicity is more important than for large particles, will not result in a remarkable increase in toxicity of the particles in the smallest size range.

When comparing the relative bioavailibility, antimony in the stack gas particulate is 2-5 times more extractable than the economizer outlet particulate. Slight differences are noted between high- and low-load conditions, but these are not considered statistically significant.

6.3.2 Arsenic

Arsenic concentrations were about the same for high-load conditions compared to low-load conditions, with the exception of Stage 1 which was a factor of 3 lower for the low-load condition. Bioavailable arsenic concentrations increased with decreasing particle size. Arsenic is also relatively toxic orally; however, arsenic is considered carcinogenic by inhalation. Thus the relative enrichment of arsenic in the smallest size fraction, for which inhalation toxicity is as important as oral toxicity, suggests that the potential for carcinogenic effects is increased.

The relative bioavailability of arsenic did not change significantly across the FGD unit, nor as a function of unit load or particle size.

6.3.3 Barium

Bioavailable barium concentrations were highest for Stage 2 particulates for both load conditions, although none of the data vary significantly. Barium is not considered a carcinogen, although it is a pulmonary and oral toxin. The decreased bioavailability in the Stage 3 fraction, for which inhalation toxicity is as important as oral toxicity, suggests that the potential for pulmonary toxicity is diminished. At the same time, the potential for oral toxicity may be increased due to the amount of barium that may reach the GI tract. Barium concentrations are enriched across all size fractions when compared to the economizer outlet concentrations.

For Stages 1 and 2 particulates, the relative bioavailability of barium was highest in the stack gas under low-load conditions, followed by high-load conditions, then FGD inlet. For Stage 3 particulates, samples from the economizer outlet were highest, with the two load conditions being very similar. The amount of relative bioavailability was slightly lower for Stage 3 particles overall when compared with the other particle sizes.

6.3.4 Beryllium

With the exception of Stage 1, low-load, beryllium concentrations were very consistent across all size fractions and load conditions. The bioavailability of beryllium increased with decreasing particle size, although this trend was very slight. Beryllium is classified as a probable human carcinogen by both oral and inhalation exposure and is orally toxic. The significance of the potential pulmonary carcinogenicity of beryllium should be considered greater than the significance of the oral toxicity and carcinogenicity due to the increased bioavailabilty with decreasing particle size. There is probably no difference between potential pulmonary carcinogenicity or oral toxicity between load conditions.

For all particulate sizes, beryllium relative bioavailability was highest in the gas stack samples under high-load conditions, followed by low-load, then the samples taken at the economizer outlet. The bioavailability values were similar for all the sizes when looking across sampling location and conditions. Since beryllium is a carcinogen both by inhalation and oral exposure, and is an oral toxin, the increase in bioavailability seen behind the FGD system is significant. This is especially true for the high-load condition which resulted in the highest relative bioavailabilty.

6.3.5 Cadmium

Cadmium bioavailability concentrations were higher for high-load conditions than low-load conditions except for Stage 3 particles, for which there were no differences. Bioavailability was highest in Stage 2 particles. Cadmium is a pulmonary carcinogen and a relatively potent oral toxin. The decline in bioavailability at Stage 3 (where inhalation toxicity is as important as oral toxicity) compared to Stages 1 and 2 (where oral toxicity is more important than inhaled toxicity), suggests that oral toxicity should be of greater concern than pulmonary carcinogenicity, especially for high-load conditions.

The relative bioavailability of cadmium increased in stack gas particulate compared to the economizer outlet for all three particle size fractions. High-load conditions resulted in higher bioavailability compared to low-load conditions for all the particle sizes except Stage 2 (data unavailable). Cadmium is considered a carcinogen by inhalation and an oral toxin. The increase in bioavailable particles across the FGD system suggests a change in particle composition or morphology.

6.3.6 Chromium

Bioavailable chromium concentrations were higher for all particle sizes for low-load conditions compared to high-load conditions. It is not known if this difference is real or the result of contamination. Chromium is considered an inhalation carcinogen and an oral toxin. Pulmonary carcinogenicity should be greater of concern than oral toxicity during high-load conditions due to the increase in bioavailability with decreasing particle size. During low-load conditions, the potential for oral toxicity may be stronger than that for pulmonary carcinogenicity due the decrease in bioavailability with decreasing particle size. Assuming the low-load data are real, when comparing between load conditions, pulmonary carcinogenicity and oral toxicity should be of greatest concern for low-load conditions.

The relative bioavailability of chromium generally increased in stack gas particulate compared to the economizer outlet for all three particle size fractions. Stage 3 particulates overall had the highest bioavailability, followed by Stage 2, then Stage 1. Chromium is considered a carcinogen by inhalation and an oral toxin. The increase in bioavailable particles behind the FGD again suggests changes in particle composition or particle morphology across the FGD system appears, which may increase the potential for adverse effects of chromium, with pulmonary carcinogenicity being slightly more likely than oral toxicity.

6.3.7 Cobalt

The analysis of Stage 2 particulates under low-load conditions greatly exceeds the value for the bulk analysis and will not be used for this evaluation. The Stage 1 value for low load is high compared to the balance of the results, which are not significantly different from that of the economizer outlet values. This suggests that the bioavailability of cobalt is not greatly affected by load or significantly changed across the FGD system. Cancer slop factors, FfDs, or FfCs were not available for cobalt. The TLV and PEL values listed are relatively conservative. Due to the fact that toxicity and carcinogenicity values are unknown, the potential for carcinogenic and noncarcinogenic effects should not be ignored. If the Stage 1 analysis under low load is valid, oral toxicity and carcinogenicity would be of greatest concern, due to the increase in those particles relevant to oral adverse effects.

The relative bioavailability of cobalt increased in stack gas particulates compared to the economizer outlet for all three particle size fractions. Bioavailability tended to increase with decreasing particulate size. Cobalt is not a known carcinogen or toxin by either oral ingestion or inhalation. The importance of the increase in bioavailability behind the FGD would have significance if cobalt were found to have these adverse effects by these routes.

6.3.8 Copper

The bioavailability of copper was consistent across all size fractions and load conditions. Stack gas particulate concentrations of copper are approximately four times that of the economizer outlet. Copper is not known to be a carcinogen, but it is orally toxic. The relative bioavailability of copper increased by a factor of 2-3 in stack gas particulate compared to the economizer outlet. Copper is an oral toxin. The significance of the increased bioavailability of copper after the FGD is that the potential for oral toxicity increases.

6.3.9 Lead

Lead is significantly concentrated in Stage 1. When comparing across particle size, high-load conditions resulted in much higher lead concentrations than low-load conditions. Lead is highly orally toxic. It is classified as a probable human carcinogen when exposure is oral, but it is not known if it is carcinogenic when exposure is by inhalation. Oral toxicity and carcinogenicity should be of concern with Stages 1 and 2 particle sizes. This concern should be greater for high-load conditions than low-load conditions.

In general, the relative bioavailability of lead (Table 6-5) did not change across the FGD unit. The exception is for the Stage 3 high-load fraction which was twice as high. This may or may not be a significant increase.

6.3.10 Manganese

Disregarding the low-load Stages 1 and 2 (which are suspected of contamination), the bioavailability of manganese does not change significantly between load conditions or size fractions. Manganese is considered both an oral and inhalation toxin. Carcinogenicity data is not available. For low-load conditions, oral toxicity should be of greater concern than pulmonary toxicity due to the distribution of bioavailability with particle size.

Manganese relative bioavailability (Table 6-5) increased slightly for all three particulate sizes after the FGD system. Manganese is an oral and pulmonary toxin. The increased bioavailability after the FGD increases the potential for these toxicities.

6.3.11 Mercury

Since mercury is primarily a vapor-phase component, it is not surprising to see little difference in the bioavailable concentrations for mercury across the various particle sizes and load conditions. Mercury is toxic when exposure is inhalation or oral ingestion. It is not known to be a carcinogen.

The relative bioavailability of mercury (Table 6-5) before and after the FGD varied little with particulate size or load.

6.3.12 Molybdenum

The bioavailability of molybdenum increased with decreasing particle size for both low- and high-load conditions. When comparing across particle size, high-load conditions resulted in slightly higher concentrations than low-load conditions. Molybdenum is not a known carcinogen, but it has been found to be an oral toxin. The importance of this toxicity may be diminished due to the fact that the relative bioavailability of molybdenum from particles of a size relevant to oral toxicity is lower than the bioavailability of molybdenum from particles relevant to pulmonary toxicity.

Molybdenum relative bioavailability increased slightly in stack gas particulates compared to the economizer outlet for all three particle sizes. Changes in relative bioavailability due to load were insignificant.

6.3.13 Nickel

Assuming Stages 1 and 2 of the low-load conditions are contamination products, little change in nickel is seen by particle size or by load. However, stack particles do appear to be enriched by a factor of 10 over the economizer outlet. Nickel is known to be a carcinogen via inhalation and an toxin with oral ingestion.

Nickel relative bioavailability varied with particle size, sampling location, and load conditions. For Stage 1 particles, nickel bioavailability increased after the FGD, with low-load conditions resulting in more bioavailability than high-load conditions. For Stage 2 particulates, nickel bioavailability also increased after the FGD, with high-load conditions resulting in higher bioavailability than low-load conditions. For Stage 3 particulates, bioavailability was higher after the FGD, with high-load conditions having greater bioavailability than low-load conditions. Nickel is an oral toxin and inhalation carcinogen. For Stage 1 and 2 particulates, which oral toxicity is of greater concern than pulmonary adverse effects, the increase in bioavailability after the FGD increases the significance of potential oral toxicity. For Stage 3 particulates, which pulmonary adverse effects of greater concern than oral adverse effects, the increase in bioavailability after the FGD increases the significance of potential pulmonary carcinogenicity.

6.3.14 Selenium

Selenium bioavailability concentrations increased with decreasing particle size during low-load conditions. For high-load conditions, bioavailable concentrations remained about the same with decreasing particle size. The differences in bioavailable conditions between high and low load are probably not significant. As with most of the elements, the outlet concentrations are significantly more concentrated when compared to the economizer outlet.

The relative bioavailability of selenium (Table 6-5) increased in stack gas particulates compared to the economizer outlet for all three particulates. Since selenium is an oral toxin, the increased bioavailability after the FGD for Stages 1 and 2 particulates may increase the probability of oral toxicity. This increase may be more pronounced under high-load conditions than low-load conditions

6.3.15 Vanadium

Bioavailable vanadium (Table 6-4) concentrations increased with decreasing particle size for both low- and high-load conditions. When comparing across particle size, high-load conditions resulted in higher concentrations than low-load conditions. Vanadium is not a known carcinogen, but it has been found to be orally toxic. Because of the lower concentration of particles that are important in oral toxicity, the potential for oral toxicity may be diminished, especially under low-load conditions.

The relative bioavailability of vanadium (Table 6-5) increased in stack gas particulates compared to the economizer outlet for all three particulates. High-load conditions tended to result in higher bioavailability than low-load conditions. Relative bioavailability also increased with decreasing particulate size. Since vanadium is an oral toxin, the increased bioavailability after the FGD for Stages 1 and 2 particulates may increase the probability of oral toxicity. This increase may be more pronounced under high-load conditions compared to low-load conditions.

6.4 General Conclusions

The potential for adverse effects from inhalation of stack gas from coal-fired power plants depends on several factors. These factors include the general health and breathing patterns of those exposed, particulate concentrations in the stack gas, particle size, and the bioavailability of the potentially harmful elements found on the surface of the particles. Persons generally in good health may not have as many or as significant adverse effects when exposed to toxicants by inhalation compared to persons in generally poor health. The breathing patterns of those exposed and the particle size determine where the particles will be deposited in the lungs, and thus the extent and type of adverse effect observed. The particulate concentrations in stack gas and the bioavailability of the elements found on the particles work together to determine the amount of potentially harmful elements to which a person may be exposed.

The above discussion of the relative toxicities of the elements found in economizer outlet and stack gas particulate was based on the assumption that the route of exposure to these toxicants was nasal inhalation rather than oral inhalation. If the route of exposure to these toxicants were oral inhalation, the potential toxicities of these elements could change. With nasal inhalation, 88% of Stage 1 particulates, 67% of Stage 2 particulates, and 16% of Stage 3 particulates are deposited in the nasopharyngeal and tracheobronchial region. Ten percent of Stage 1 particulates, 22% of Stage 2 particulates, and 10% of Stage 3 particulates are deposited in the alveolar region (see Table 6-1). If the particulate were inhaled by mouth, no particles would be deposited in the nasopharyngeal region. The largest particulates (primarily Stage 1 particulates, but also Stage 2 particulates) that would normally be deposited in the nasopharyngeal region with nasal inhalation, would be deposited by impaction in the upper lungs where the lungs bifurcate with oral inhalation. Thus, particles that do not reach the lungs with nasal inhalation will reach the upper lungs with oral inhalation. The deposition of Stage 3 particulates should be the same for both nasal and oral inhalation. The potential for increased pulmonary toxicity caused by elements that are known pulmonary toxicants and in this case are found in the larger particulate fractions increases with oral inhalation compared to nasal inhalation.

The data from the various sampling methods used in this study indicated that the particulate concentrations, elemental content, and element bioavailability are somewhat different between high- and low-load conditions, and between those samples taken at the economizer outlet and those taken at the stack. These differences in particle concentration, elemental content, and element bioavailability will result in different potential effects with these differing conditions. Although it is impossible to predict accurately the types and extent of adverse effects seen with exposure to stack gas emissions, some general conclusions can be reached. These data indicated that high-load conditions have a greater potential for causing inhalation and pulmonary toxicity than low-load conditions, although the differences between the two conditions may not be significant. This is because 1) the greatest number of elements with high bioavailabilities, and 2) the relative bioavailability values for each element tended to be highest under high-load conditions (see Tables 6-4 and 6-5). The potential for oral toxicity may be greater than that for pulmonary toxicity with high-load conditions because the lungs retain a higher percentage of Stages 1 and 2 particulates compared to Stage 3 particulates. This conclusion is true of low-load conditions also (see Table 6-1). The overall effect, however, is difficult to quantify, as the bulk of the emissions generated are in the Stage 3 (smallest) fraction. Again, this study focused on the characterization of the particulate matter, not the quantification of emissions.

6.5 References

1. "Deposition, Retention, and Dosimetry of Inhaled Radioactive Substances." Draft Report. National Council on Radiation Protection, Washington, D.C. (1993).

APPENDIX A: PHASE I ANALYTICAL RESULTS

Table A-1. Phase I Bulk Concentration Results (ug/g)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.3 um	Aluminum	GDMS	ug/g	41989	26989	36040			35006	7554	21.6	18,753
> 6.3 um	Aluminum	INAA	ug/g	443976	424537	385423			417979	29822	7.1	74,037
> 6.3 um	Arsenic	GDMS	ug/g	840	540	737			706	152	21.6	379
> 6.3 um	Arsenic	INAA	ug/g	790	466	740			665	174	26.2	433
> 6.3 um	Barium	GDMS	ug/g	5459	2121	2990			3523	1732	49.2	4,299
> 6.3 um	Barium	INAA	ug/g	4410	3352	3611			3791	552	14.6	1,370
> 6.3 um	Beryllium	GDMS	ug/g	18.9	19.3	28.7			22.3	5.5	24.8	14
> 6.3 um	Cadmium	GDMS	ug/g	54.6	21.2	23.3			33.0	18.7	56.5	46
> 6.3 um	Cadmium	INAA	ug/g	119	< 22	93			74	56	76.1	140
> 6.3 um	Calcium	GDMS	ug/g	27293	15037	26211			22847	6785	29.7	16,846
> 6.3 um	Calcium	INAA	ug/g	< 47094	53491	46998			41345	15752	38.1	39,106
> 6.3 um	Chlorine	GDMS	ug/g	6298	3277	7781			5786	2295	39.7	5,699
> 6.3 um	Chlorine	INAA	ug/g	1154	933	1176			1088	134	12.3	333
> 6.3 um	Chromium	GDMS	ug/g	58785	18506	53241			43511	21831	50.2	54,198
> 6.3 um	Chromium	INAA	ug/g	34671	26015	38826			33171	6536	19.7	16,226
> 6.3 um	Cobalt	GDMS	ug/g	504	127	450			361	204	56.5	506
> 6.3 um	Cobalt	INAA	ug/g	432	198	474			368	149	40.4	369
> 6.3 um	Copper	GDMS	ug/g	462	212	655			443	222	50.2	552
> 6.3 um	Copper	INAA	ug/g	761	923	800			828	85	10.2	210
> 6.3 um	Fluorine	GDMS	ug/g	25.2	10.6	160			65.2	82.2	126.1	204
> 6.3 um	Iron	GDMS	ug/g	163758	67472	184295			138508	62371	45.0	154,841
> 6.3 um	Iron	INAA	ug/g	144689	100604	162687			135993	31942	23.5	79,299
> 6.3 um	Lead	GDMS	ug/g	151	98.3	102			117	29	25.1	73
> 6.3 um	Magnesium	GDMS	ug/g	42	1157	1966			1055	966	91.6	2,398
> 6.3 um	Magnesium	INAA	ug/g	9030	7172	8164			8122	930	11.4	2,308
> 6.3 um	Manganese	GDMS	ug/g	1932	733	1638			1434	625	43.6	1,552
> 6.3 um	Manganese	INAA	ug/g	2051	2021	2281			2117	142	6.7	353
> 6.3 um	Mercury	GDMS	ug/g	0.050	0.050	0.041			0.047	0.005	11.4	0.013
> 6.3 um	Mercury	INAA	ug/g	< 9.26	5.81	9.62			6.69	2.61	39.0	6
> 6.3 um	Molybdenum	GDMS	ug/g	840	328	614			594	257	43.2	637
> 6.3 um	Molybdenum	INAA	ug/g	219	11	205			145	116	80.2	289
> 6.3 um	Nickel	GDMS	ug/g	23514	6940	14744			15066	8292	55.0	20,585
> 6.3 um	Nickel	INAA	ug/g	17248	6411	18844			14167	6765	47.7	16,795
> 6.3 um	Phosphorus	GDMS	ug/g	1050	694	819			854	180	21.1	448
> 6.3 um	Potassium	GDMS	ug/g	756	185	225			389	319	82.0	791
> 6.3 um	Potassium	INAA	ug/g	9561	8953	11503			10006	1332	13.3	3,308

Table A-1. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.3 um	Selenium	GDMS	ug/g	193	110	139			147	42	28.6	105
> 6.3 um	Selenium	INAA	ug/g	369	201	344			305	91	29.8	226
> 6.3 um	Silicon	GDMS	ug/g	92376	55905	81909			76730	18779	24.5	46,621
> 6.3 um	Sodium	GDMS	ug/g	420	185	233			279	124	44.4	308
> 6.3 um	Sodium	INAA	ug/g	1824	1194	1756			1591	346	21.7	859
> 6.3 um	Strontium	GDMS	ug/g	248	100	147			165	75	45.6	187
> 6.3 um	Strontium	INAA	ug/g	< 989	< 467	< 1025			< 1025	NA	NA	NA
> 6.3 um	Sulfur	GDMS	ug/g	138564	269886	147436			185295	73392	39.6	182,203
> 6.3 um	Titanium	GDMS	ug/g	3023	1735	2990			2583	734	28.4	1,823
> 6.3 um	Titanium	INAA	ug/g	10924	9891	8540			9785	1196	12.2	2,968
> 6.3 um	Vanadium	GDMS	ug/g	882	520	778			727	186	25.6	462
> 6.3 um	Vanadium	INAA	ug/g	5143	4788	4457			4796	343	7.2	852
6.3 - 2.7 um	Aluminum	INAA	ug/g	378850	NA	NA			378850	NA	NA	NA
6.3 - 2.7 um	Arsenic	INAA	ug/g	1164	NA	NA			1164	NA	NA	NA
6.3 - 2.7 um	Barium	INAA	ug/g	5634	NA	NA			5634	NA	NA	NA
6.3 - 2.7 um	Cadmium	INAA	ug/g	102	NA	NA			102	NA	NA	NA
6.3 - 2.7 um	Calcium	INAA	ug/g	40158	NA	NA			40158	NA	NA	NA
6.3 - 2.7 um	Chlorine	INAA	ug/g	979	NA	NA			979	NA	NA	NA
6.3 - 2.7 um	Chromium	INAA	ug/g	36355	NA	NA			36355	NA	NA	NA
6.3 - 2.7 um	Cobalt	INAA	ug/g	502	NA	NA			502	NA	NA	NA
6.3 - 2.7 um	Copper	INAA	ug/g	800	NA	NA			800	NA	NA	NA
6.3 - 2.7 um	Iron	INAA	ug/g	133520	NA	NA			133520	NA	NA	NA
6.3 - 2.7 um	Magnesium	INAA	ug/g	6654	NA	NA			6654	NA	NA	NA
6.3 - 2.7 um	Manganese	INAA	ug/g	2161	NA	NA			2161	NA	NA	NA
6.3 - 2.7 um	Mercury	INAA	ug/g	< 7.80	NA	NA			< 7.80	NA	NA	NA
6.3 - 2.7 um	Molybdenum	INAA	ug/g	185	NA	NA			185	NA	NA	NA
6.3 - 2.7 um	Nickel	INAA	ug/g	18552	NA	NA			18552	NA	NA	NA
6.3 - 2.7 um	Potassium	INAA	ug/g	10101	NA	NA			10101	NA	NA	NA
6.3 - 2.7 um	Selenium	INAA	ug/g	488	NA	NA			488	NA	NA	NA
6.3 - 2.7 um	Sodium	INAA	ug/g	1942	NA	NA			1942	NA	NA	NA
6.3 - 2.7 um	Strontium	INAA	ug/g	< 1042	NA	NA			< 1042	NA	NA	NA
6.3 - 2.7 um	Titanium	INAA	ug/g	10013	NA	NA			10013	NA	NA	NA
6.3 - 2.7 um	Vanadium	INAA	ug/g	5660	NA	NA			5660	NA	NA	NA
2.7 - 1.7 um	Aluminum	INAA	ug/g	580288	580961	567104			576118	7813	1.4	19,397
2.7 - 1.7 um	Arsenic	INAA	ug/g	1702	1633	1769			1702	68	4.0	168
2.7 - 1.7 um	Barium	INAA	ug/g	10203	7573	8203			8660	1373	15.9	3,408

Table A-1. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
2.7 - 1.7 um	Cadmium	INAA	ug/g	225	251	254			243	16	6.7	40
2.7 - 1.7 um	Calcium	INAA	ug/g	< 21473	60512	47584			39611	25828	65.2	64,120
2.7 - 1.7 um	Chlorine	INAA	ug/g	1474	1428	1588			1497	82	5.5	204
2.7 - 1.7 um	Chromium	INAA	ug/g	5406	5295	5658			5453	186	3.4	462
2.7 - 1.7 um	Cobalt	INAA	ug/g	47.2	41.4	46.7			45.1	3.2	7.1	8
2.7 - 1.7 um	Copper	INAA	ug/g	868	849	754			824	61	7.4	151
2.7 - 1.7 um	Iron	INAA	ug/g	64529	57511	62048			61363	3559	5.8	8,836
2.7 - 1.7 um	Magnesium	INAA	ug/g	12194	10193	13001			11796	1446	12.3	3,589
2.7 - 1.7 um	Manganese	INAA	ug/g	893	953	876			907	41	4.5	101
2.7 - 1.7 um	Mercury	INAA	ug/g	< 7.24	< 6.97	< 5.60			< 7.24	NA	NA	NA
2.7 - 1.7 um	Molybdenum	INAA	ug/g	303	534	312			383	131	34.2	325
2.7 - 1.7 um	Nickel	INAA	ug/g	2189	2085	2388			2221	154	6.9	383
2.7 - 1.7 um	Potassium	INAA	ug/g	10206	7123	11511			9613	2253	23.4	5,594
2.7 - 1.7 um	Selenium	INAA	ug/g	656	555	617			609	51	8.3	126
2.7 - 1.7 um	Sodium	INAA	ug/g	2105	2043	2310			2153	140	6.5	348
2.7 - 1.7 um	Strontium	INAA	ug/g	< 724	< 399	< 434			< 724	NA	NA	NA
2.7 - 1.7 um	Titanium	INAA	ug/g	15954	13967	13684			14535	1237	8.5	3,071
2.7 - 1.7 um	Vanadium	INAA	ug/g	8349	8416	8185			8317	119	1.4	296
1.7 - 0.8 um	Aluminum	GDMS	ug/g	40841	45113	50358			45438	4767	10.5	11,834
1.7 - 0.8 um	Aluminum	INAA	ug/g	461802	482246	464417			469488	11126	2.4	27,620
1.7 - 0.8 um	Arsenic	GDMS	ug/g	2199	2045	2384			2209	169	7.7	421
1.7 - 0.8 um	Arsenic	INAA	ug/g	1826	1940	1921			1896	61	3.2	152
1.7 - 0.8 um	Barium	GDMS	ug/g	4084	5414	5707			5068	865	17.1	2,147
1.7 - 0.8 um	Barium	INAA	ug/g	9034	9302	9193			9176	135	1.5	335
1.7 - 0.8 um	Beryllium	GDMS	ug/g	69.1	75.2	83.9			76.1	7.4	9.8	18
1.7 - 0.8 um	Cadmium	GDMS	ug/g	1508	962	537			1003	487	48.5	1,208
1.7 - 0.8 um	Cadmium	INAA	ug/g	1431	1587	1425			1481	92	6.2	227
1.7 - 0.8 um	Calcium	GDMS	ug/g	53408	48121	57073			52867	4500	8.5	11,173
1.7 - 0.8 um	Calcium	INAA	ug/g	229299	204471	143928			192566	43913	22.8	109,019
1.7 - 0.8 um	Chlorine	GDMS	ug/g	4084	60151	1108			21781	33263	152.7	82,578
1.7 - 0.8 um	Chlorine	INAA	ug/g	1047	1144	960			1050	92	8.8	228
1.7 - 0.8 um	Chromium	GDMS	ug/g	6912	6917	6714			6848	116	1.7	287
1.7 - 0.8 um	Chromium	INAA	ug/g	6897	7432	7808			7379	458	6.2	1,137
1.7 - 0.8 um	Cobalt	GDMS	ug/g	91.1	90.2	90.6			90.7	0.4	0.5	1
1.7 - 0.8 um	Cobalt	INAA	ug/g	66.8	85.3	85.3			79.1	10.7	13.5	27
1.7 - 0.8 um	Copper	GDMS	ug/g	660	331	302			431	199	46.1	493

Table A-1. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
1.7 - 0.8 um	Copper	INAA	ug/g	978	989	890			953	54	5.7	135
1.7 - 0.8 um	Fluorine	GDMS	ug/g	34.6	9.6	27.5			23.9	12.9	53.8	32
1.7 - 0.8 um	Iron	GDMS	ug/g	84824	84211	83930			84322	457	0.5	1,134
1.7 - 0.8 um	Iron	INAA	ug/g	59982	61992	63111			61695	1585	2.6	3,936
1.7 - 0.8 um	Lead	GDMS	ug/g	6597	3308	705			3537	2953	83.5	7,331
1.7 - 0.8 um	Magnesium	GDMS	ug/g	3770	2617	3693			3360	645	19.2	1,601
1.7 - 0.8 um	Magnesium	INAA	ug/g	6776	8316	9647			8246	1437	17.4	3,567
1.7 - 0.8 um	Manganese	GDMS	ug/g	1539	1414	1309			1421	115	8.1	286
1.7 - 0.8 um	Manganese	INAA	ug/g	1253	1306	1314			1291	33	2.6	83
1.7 - 0.8 um	Mercury	GDMS	ug/g	0.009	0.009	0.012			0.010	0.002	16.4	0.004
1.7 - 0.8 um	Mercury	INAA	ug/g	< 5.62	< 7.95	< 7.59			< 7.95	NA	NA	NA
1.7 - 0.8 um	Molybdenum	GDMS	ug/g	754	752	772			759	11	1.5	28
1.7 - 0.8 um	Molybdenum	INAA	ug/g	321	335	341			332	11	3.2	26
1.7 - 0.8 um	Nickel	GDMS	ug/g	5341	4812	4700			4951	342	6.9	849
1.7 - 0.8 um	Nickel	INAA	ug/g	2842	3773	3539			3385	484	14.3	1,203
1.7 - 0.8 um	Phosphorus	GDMS	ug/g	2953	2767	3357			3026	302	10.0	749
1.7 - 0.8 um	Potassium	GDMS	ug/g	188	96.2	181			155	51	33.0	127
1.7 - 0.8 um	Potassium	INAA	ug/g	8082	< 19968	12510			10192	2221	21.8	5,515
1.7 - 0.8 um	Selenium	GDMS	ug/g	239	391	63.8			231	164	70.8	406
1.7 - 0.8 um	Selenium	INAA	ug/g	596	807	768			724	112	15.5	278
1.7 - 0.8 um	Silicon	GDMS	ug/g	109957	96241	114145			106781	9365	8.8	23,249
1.7 - 0.8 um	Sodium	GDMS	ug/g	91.1	42.1	94.0			75.7	29.2	38.5	72
1.7 - 0.8 um	Sodium	INAA	ug/g	1460	1617	1570			1549	81	5.2	200
1.7 - 0.8 um	Strontium	GDMS	ug/g	223	241	275			246	27	10.8	66
1.7 - 0.8 um	Strontium	INAA	ug/g	651	1092	< 706			699	372	53.2	923
1.7 - 0.8 um	Sulfur	GDMS	ug/g	175931	189475	164504			176637	12501	7.1	31,034
1.7 - 0.8 um	Titanium	GDMS	ug/g	3456	4211	5036			4234	790	18.7	1,962
1.7 - 0.8 um	Titanium	INAA	ug/g	11014	15158	12628			12933	2089	16.2	5,186
1.7 - 0.8 um	Vanadium	GDMS	ug/g	1508	1865	2149			1840	321	17.4	797
1.7 - 0.8 um	Vanadium	INAA	ug/g	9757	9572	9237			9522	264	2.8	654
0.8 - 0.5 um	Aluminum	GDMS	ug/g	52651	141134	51247			81677	51496	63.0	127,844
0.8 - 0.5 um	Aluminum	INAA	ug/g	405730	447124	413105			421986	22080	5.2	54,816
0.8 - 0.5 um	Arsenic	GDMS	ug/g	2422	1730	2392			2181	391	17.9	971
0.8 - 0.5 um	Arsenic	INAA	ug/g	2225	2471	2293			2330	127	5.5	316
0.8 - 0.5 um	Barium	GDMS	ug/g	6318	13658	8541			9506	3764	39.6	9,344
0.8 - 0.5 um	Barium	INAA	ug/g	10560	10468	11926			10985	816	7.4	2,026

Table A-1. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
0.8 - 0.5 um	Beryllium	GDMS	ug/g	84.2	86.5	74.0			81.6	6.6	8.1	17
0.8 - 0.5 um	Cadmium	GDMS	ug/g	65.8	309.6	79.7			151.7	136.9	90.2	340
0.8 - 0.5 um	Cadmium	INAA	ug/g	289	310	289			296	12	4.1	30
0.8 - 0.5 um	Calcium	GDMS	ug/g	47386	100160	54094			67213	28729	42.7	71,323
0.8 - 0.5 um	Calcium	INAA	ug/g	78537	97374	74667			83526	12148	14.5	30,159
0.8 - 0.5 um	Chlorine	GDMS	ug/g	203	20.9	769			331	390	117.9	968
0.8 - 0.5 um	Chlorine	INAA	ug/g	199	153	196			183	26	14.0	64
0.8 - 0.5 um	Chromium	GDMS	ug/g	3159	10927	3416			5834	4412	75.6	10,954
0.8 - 0.5 um	Chromium	INAA	ug/g	2745	3191	2994			2977	224	7.5	555
0.8 - 0.5 um	Cobalt	GDMS	ug/g	31.6	54.6	37.0			41.1	12.0	29.3	30
0.8 - 0.5 um	Cobalt	INAA	ug/g	32.4	35.9	34.3			34.2	1.7	5.1	4
0.8 - 0.5 um	Copper	GDMS	ug/g	421	1685	598			901	684	75.9	1,698
0.8 - 0.5 um	Copper	INAA	ug/g	1287	941	1029			1086	179	16.5	446
0.8 - 0.5 um	Fluorine	GDMS	ug/g	23.7	24.1	27.9			25.2	2.3	9.2	6
0.8 - 0.5 um	Iron	GDMS	ug/g	44753	77396	54094			58748	16812	28.6	41,737
0.8 - 0.5 um	Iron	INAA	ug/g	41229	44752	43566			43182	1793	4.2	4,451
0.8 - 0.5 um	Lead	GDMS	ug/g	97.4	196	228			174	68	39.1	169
0.8 - 0.5 um	Magnesium	GDMS	ug/g	2290	10016	2221			4842	4481	92.5	11,124
0.8 - 0.5 um	Magnesium	INAA	ug/g	9262	10189	9599			9683	469	4.8	1,165
0.8 - 0.5 um	Manganese	GDMS	ug/g	395	1593	512			834	661	79.3	1,640
0.8 - 0.5 um	Manganese	INAA	ug/g	503	564	519			529	32	6.0	79
0.8 - 0.5 um	Mercury	GDMS	ug/g	0.008	0.028	0.007			0.014	0.012	83.4	0.030
0.8 - 0.5 um	Mercury	INAA	ug/g	< 5.46	< 7.50	< 5.72			< 7.50	NA	NA	NA
0.8 - 0.5 um	Molybdenum	GDMS	ug/g	605	546	683			612	69	11.2	171
0.8 - 0.5 um	Molybdenum	INAA	ug/g	304	311	315			310	6	1.8	14
0.8 - 0.5 um	Nickel	GDMS	ug/g	1422	2823	1594			1946	764	39.3	1,897
0.8 - 0.5 um	Nickel	INAA	ug/g	1230	1327	1335			1297	58	4.5	145
0.8 - 0.5 um	Phosphorus	GDMS	ug/g	2896	1502	3132			2510	881	35.1	2,186
0.8 - 0.5 um	Phosphorus	GDMS	ug/g	2896	1502	3132			2510	881	35.1	2,186
0.8 - 0.5 um	Potassium	GDMS	ug/g	226	141	23.6			130	102	78.1	253
0.8 - 0.5 um	Potassium	INAA	ug/g	5940	7535	7745			7073	987	14.0	2,450
0.8 - 0.5 um	Selenium	GDMS	ug/g	605	137	740			494	317	64.1	787
0.8 - 0.5 um	Selenium	INAA	ug/g	701	732	739			724	20	2.7	49
0.8 - 0.5 um	Silicon	GDMS	ug/g	100037	95607	105341			100328	4874	4.9	12,099
0.8 - 0.5 um	Sodium	GDMS	ug/g	182	114	18.5			105	82	78.3	203
0.8 - 0.5 um	Sodium	INAA	ug/g	1284	1404	1217			1302	95	7.3	235

Table A-1. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
0.8 - 0.5 um	Strontium	GDMS	ug/g	258	455	313			342	102	29.7	253
0.8 - 0.5 um	Strontium	INAA	ug/g	< 371	1187	783			719	504	70.1	1,251
0.8 - 0.5 um	Sulfur	GDMS	ug/g	207972	86502	193600			162691	66372	40.8	164,776
0.8 - 0.5 um	Titanium	GDMS	ug/g	4212	2094	4555			3621	1333	36.8	3,309
0.8 - 0.5 um	Titanium	INAA	ug/g	9839	13132	9577			10849	1981	18.3	4,919
0.8 - 0.5 um	Vanadium	GDMS	ug/g	1948	1229	2164			1780	489	27.5	1,215
0.8 - 0.5 um	Vanadium	INAA	ug/g	10199	11451	11137			10929	651	6.0	1,617
< 0.5 um	Aluminum	GDMS	ug/g	64933	55541	79282			66585	11956	18.0	29,683
< 0.5 um	Aluminum	INAA	ug/g	22280	27309	30077			26555	3952	14.9	9,812
< 0.5 um	Arsenic	GDMS	ug/g	2892	3818	3792			3501	527	15.1	1,309
< 0.5 um	Arsenic	INAA	ug/g	1967	1801	2034			1934	120	6.2	298
< 0.5 um	Barium	GDMS	ug/g	9445	10067	11720			10411	1176	11.3	2,919
< 0.5 um	Barium	INAA	ug/g	15356	13791	14008			14385	848	5.9	2,105
< 0.5 um	Beryllium	GDMS	ug/g	94.4	76.4	68.9			79.9	13.1	16.4	33
< 0.5 um	Cadmium	GDMS	ug/g	85.6	86.8	141			105	32	30.5	79
< 0.5 um	Cadmium	INAA	ug/g	64	92	110			89	23	26.1	57
< 0.5 um	Calcium	GDMS	ug/g	59030	83312	72388			71577	12162	17.0	30,192
< 0.5 um	Calcium	INAA	ug/g	65780	58099	55354			59745	5404	9.0	13,416
< 0.5 um	Chlorine	GDMS	ug/g	189	6.60	72.4			89.3	92.3	103.4	229
< 0.5 um	Chlorine	INAA	ug/g	122	171	155			149	25	16.9	63
< 0.5 um	Chromium	GDMS	ug/g	2125	1875	2137			2046	148	7.2	368
< 0.5 um	Chromium	INAA	ug/g	1542	1530	1407			1493	75	5.0	186
< 0.5 um	Cobalt	GDMS	ug/g	24.8	26.4	23.1			24.8	1.6	6.6	4
< 0.5 um	Cobalt	INAA	ug/g	22	22	21			21.8	0.8	3.7	2
< 0.5 um	Copper	GDMS	ug/g	708	521	552			594	101	17.0	250
< 0.5 um	Copper	INAA	ug/g	813	849	870			844	29	3.4	72
< 0.5 um	Fluorine	GDMS	ug/g	10.6	2.71	2.17			5.17	4.73	91.6	12
< 0.5 um	Iron	GDMS	ug/g	47224	62484	48259			52655	8527	16.2	21,170
< 0.5 um	Iron	INAA	ug/g	32898	35116	34708			34241	1180	3.4	2,930
< 0.5 um	Lead	GDMS	ug/g	127	226	183			178	50	27.7	123
< 0.5 um	Magnesium	GDMS	ug/g	2243	1909	2378			2177	242	11.1	600
< 0.5 um	Magnesium	INAA	ug/g	822	761	870			818	55	6.7	136
< 0.5 um	Manganese	GDMS	ug/g	325	417	379			373	46	12.4	115
< 0.5 um	Manganese	INAA	ug/g	162	183	176			174	11	6.3	27
< 0.5 um	Mercury	GDMS	ug/g	0.014	0.002	0.038			0.018	0.018	100.1	0.045
< 0.5 um	Mercury	INAA	ug/g	< 7.21	< 6.98	< 6.00			< 7.21	NA	NA	NA

Table A-1. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.5 um	Molybdenum	GDMS	ug/g	974	903	1241			1039	178	17.2	443
< 0.5 um	Molybdenum	INAA	ug/g	203	500	485			396	167	42.2	415
< 0.5 um	Nickel	GDMS	ug/g	1564	1701	1344			1537	180	11.7	447
< 0.5 um	Nickel	INAA	ug/g	727	638	641			668	50	7.5	125
< 0.5 um	Phosphorus	GDMS	ug/g	3247	4513	3033			3598	800	22.2	1,985
< 0.5 um	Potassium	GDMS	ug/g	27.7	1458	379			622	745	119.9	1,850
< 0.5 um	Potassium	INAA	ug/g	8242	9141	10779			9388	1286	13.7	3,194
< 0.5 um	Selenium	GDMS	ug/g	413	11.8	41.4			155	224	143.9	555
< 0.5 um	Selenium	INAA	ug/g	772	779	780			777	4	0.5	10
< 0.5 um	Silicon	GDMS	ug/g	103302	124968	124094			117455	12264	10.4	30,448
< 0.5 um	Sodium	GDMS	ug/g	50.2	1041	221			437	530	121.2	1,316
< 0.5 um	Sodium	INAA	ug/g	925	1017	1051			998	65	6.5	162
< 0.5 um	Strontium	GDMS	ug/g	295	451	414			387	81	21.1	202
< 0.5 um	Strontium	INAA	ug/g	< 318	< 350	< 303			< 350	NA	NA	NA
< 0.5 um	Sulfur	GDMS	ug/g	185943	149267	148223			161145	21483	13.3	53,333
< 0.5 um	Titanium	GDMS	ug/g	4722	5207	4136			4689	536	11.4	1,331
< 0.5 um	Titanium	INAA	ug/g	9952	11669	10982			10868	864	8.0	2,146
< 0.5 um	Vanadium	GDMS	ug/g	2243	1979	1965			2062	157	7.6	389
< 0.5 um	Vanadium	INAA	ug/g	1633	1874	2013			1840	192	10.5	478

Table A-2. Phase I Nitric Acid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.3 um	Arsenic	ICP/MS	ug/g	605	519	517	526	1.7	548	49	8.94	122
> 6.3 um	Arsenic	GFAA	ug/g	NA	NA	1128	NA	NA	1128	NA	NA	NA
> 6.3 um	Barium	ICP/MS	ug/g	3617	3238	3213	3208	0.1	3355	227	6.77	564
> 6.3 um	Barium	ICP	ug/g	NA	NA	3426	NA	NA	3426	NA	NA	NA
> 6.3 um	Beryllium	ICP/MS	ug/g	8.72	7.94	7.15	9.56	28.8	8.34	0.39	4.65	1
> 6.3 um	Cadmium	ICP/MS	ug/g	47.4	66.2	47.1	45.1	4.4	53.2	11.2	21.13	28
> 6.3 um	Chromium	ICP/MS	ug/g	13081	13098	13418	13986	4.1	13294	354	2.66	878
> 6.3 um	Chromium	ICP	ug/g	NA	NA	30880	NA	NA	30880	NA	NA	NA
> 6.3 um	Cobalt	ICP/MS	ug/g	305	301	310	311	0.2	305	5	1.54	12
> 6.3 um	Copper	ICP/MS	ug/g	415	344	382	383	0.5	381	35	9.31	88
> 6.3 um	Lead	ICP/MS	ug/g	77.5	85.0	74.5	73.9	0.8	78.9	5.5	6.98	14
> 6.3 um	Manganese	ICP/MS	ug/g	1226	1236	1486	1554	4.4	1327	167	12.58	414
> 6.3 um	Mercury	ICP/MS	ug/g	0.20	< 0.44	< 0.44	2.01	128.0	0.51	0.52	102.07	1
> 6.3 um	Molybdenum	ICP/MS	ug/g	360	330	325	332	2.3	340	18	5.24	44
> 6.3 um	Nickel	ICP/MS	ug/g	12184	11878	11832	12113	2.3	12012	156	1.30	388
> 6.3 um	Nickel	ICP	ug/g	NA	NA	14244	NA	NA	14244	NA	NA	NA
> 6.3 um	Selenium	ICP/MS	ug/g	380	352	398	341	15.6	367	14	3.79	35
> 6.3 um	Selenium	GFAA	ug/g	NA	NA	548	NA	NA	548	NA	NA	NA
> 6.3 um	Vanadium	ICP/MS	ug/g	733	623	628	645	2.7	664	60	9.02	149
6.3 - 2.7 um	Arsenic	ICP/MS	ug/g	1160	925	953	940	1.4	1010	130	12.86	323
6.3 - 2.7 um	Barium	ICP/MS	ug/g	6159	4840	4758	4827	1.4	5264	776	14.74	1,926
6.3 - 2.7 um	Barium	ICP	ug/g	NA	NA	4991	NA	NA	4991	NA	NA	NA
6.3 - 2.7 um	Beryllium	ICP/MS	ug/g	14.0	12.5	10.6	8.4	22.8	12.0	2.3	19.20	6
6.3 - 2.7 um	Cadmium	ICP/MS	ug/g	85.8	69.3	74.0	72.1	2.7	76.0	8.7	11.43	22
6.3 - 2.7 um	Chromium	ICP/MS	ug/g	1133	897	926	913	1.4	983	130	13.22	323
6.3 - 2.7 um	Chromium	ICP	ug/g	NA	NA	17081	NA	NA	17081	NA	NA	NA
6.3 - 2.7 um	Cobalt	ICP/MS	ug/g	71.1	142	224	220	1.5	145	75	52.00	187
6.3 - 2.7 um	Copper	ICP/MS	ug/g	288	259	352	368	4.3	302	52	17.29	130
6.3 - 2.7 um	Lead	ICP/MS	ug/g	89.2	68.2	86.6	87.8	1.4	81.5	11.6	14.19	29
6.3 - 2.7 um	Manganese	ICP/MS	ug/g	753	848	1060	1036	2.3	883	151	17.06	374
6.3 - 2.7 um	Mercury	ICP/MS	ug/g	< 0.44	< 0.44	< 0.43	< 0.43	0.0	< 0.44	NA	NA	NA
6.3 - 2.7 um	Molybdenum	ICP/MS	ug/g	321	274	313	317	1.4	304	25	8.37	63
6.3 - 2.7 um	Nickel	ICP/MS	ug/g	2596	4871	8312	8331	0.2	5263	2883	54.78	7,157
6.3 - 2.7 um	Nickel	ICP	ug/g	NA	NA	9449	NA	NA	9449	NA	NA	NA
6.3 - 2.7 um	Selenium	ICP/MS	ug/g	694	582	563	627	10.7	624	61	9.84	152
6.3 - 2.7 um	Selenium	GFAA	ug/g	NA	NA	850	NA	NA	850	NA	NA	NA

Table A-2. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.3 - 2.7 um	Vanadium	ICP/MS	ug/g	1122	911	729	746	2.4	923	192	20.84	478
2.7 - 1.7 um	Arsenic	ICP/MS	ug/g	1185	1191	1305	1288	1.3	1224	63	5.12	156
2.7 - 1.7 um	Arsenic	GFAA	ug/g	NA	NA	2750	NA	NA	2750	NA	NA	NA
2.7 - 1.7 um	Barium	ICP/MS	ug/g	5577	3973	6711	6515	3.0	5388	1330	24.69	3,303
2.7 - 1.7 um	Barium	ICP	ug/g	NA	NA	6649	NA	NA	6649	NA	NA	NA
2.7 - 1.7 um	Beryllium	ICP/MS	ug/g	19.2	18.6	15.6	21.2	30.5	18.7	0.4	2.03	1
2.7 - 1.7 um	Cadmium	ICP/MS	ug/g	109	181	177	170	4.2	155	40	25.57	98
2.7 - 1.7 um	Chromium	ICP/MS	ug/g	3396	4080	4120	4087	0.8	3860	402	10.41	998
2.7 - 1.7 um	Chromium	ICP	ug/g	NA	NA	4670	NA	NA	4670	NA	NA	NA
2.7 - 1.7 um	Cobalt	ICP/MS	ug/g	35.7	42.3	45.7	46.7	2.2	41.4	5.3	12.75	13
2.7 - 1.7 um	Copper	ICP/MS	ug/g	314	356	372	393	5.4	351	35	9.94	87
2.7 - 1.7 um	Lead	ICP/MS	ug/g	94.4	97.4	111	111	0.4	101	9	8.78	22
2.7 - 1.7 um	Manganese	ICP/MS	ug/g	533	691	693	701	1.2	640	93	14.55	231
2.7 - 1.7 um	Mercury	ICP/MS	ug/g	< 0.44	< 0.44	< 0.44	< 0.44	0.0	< 0.44	NA	NA	NA
2.7 - 1.7 um	Molybdenum	ICP/MS	ug/g	356	384	400	412	2.8	382	25	6.63	63
2.7 - 1.7 um	Nickel	ICP/MS	ug/g	1680	1990	2063	2125	3.0	1921	216	11.22	535
2.7 - 1.7 um	Nickel	ICP	ug/g	NA	NA	2011	NA	NA	2011	NA	NA	NA
2.7 - 1.7 um	Selenium	ICP/MS	ug/g	741	674	759	691	9.5	713	35	4.93	87
2.7 - 1.7 um	Selenium	GFAA	ug/g	NA	NA	1099	NA	NA	1099	NA	NA	NA
2.7 - 1.7 um	Vanadium	ICP/MS	ug/g	1167	1198	1304	1314	0.7	1225	75	6.10	186
1.7 - 0.8 um	Arsenic	ICP/MS	ug/g	1531	1388	1383	1361	1.6	1430	88	6.12	217
1.7 - 0.8 um	Barium	ICP/MS	ug/g	2244	1937	2248	2198	2.3	2135	171	8.02	425
1.7 - 0.8 um	Barium	ICP	ug/g	NA	NA	4032	NA	NA	4032	NA	NA	NA
1.7 - 0.8 um	Beryllium	ICP/MS	ug/g	17.3	10.7	13.8	13.8	0.0	13.9	3.3	23.68	8
1.7 - 0.8 um	Cadmium	ICP/MS	ug/g	869	702	917	910	0.8	828	112	13.48	277
1.7 - 0.8 um	Chromium	ICP/MS	ug/g	4449	4484	4485	4361	2.8	4452	30	0.68	76
1.7 - 0.8 um	Chromium	ICP	ug/g	NA	NA	5645	NA	NA	5645	NA	NA	NA
1.7 - 0.8 um	Cobalt	ICP/MS	ug/g	73.0	66.3	68.5	68.7	0.3	69.3	3.4	4.87	8
1.7 - 0.8 um	Copper	ICP/MS	ug/g	374	311	310	298	3.8	330	39	11.82	97
1.7 - 0.8 um	Lead	ICP/MS	ug/g	347	465	1526	1160	27.2	718	544	75.79	1,351
1.7 - 0.8 um	Manganese	ICP/MS	ug/g	930	853	900	871	3.2	889	39	4.33	96
1.7 - 0.8 um	Mercury	ICP/MS	ug/g	5.58	< 0.44	< 0.44	< 0.44	0.0	2.00	3.09	154.35	8
1.7 - 0.8 um	Molybdenum	ICP/MS	ug/g	431	407	413	398	3.7	414	15	3.50	36
1.7 - 0.8 um	Nickel	ICP/MS	ug/g	2884	2561	2897	2776	4.2	2761	174	6.32	433
1.7 - 0.8 um	Nickel	ICP	ug/g	NA	NA	3107	NA	NA	3107	NA	NA	NA
1.7 - 0.8 um	Selenium	ICP/MS	ug/g	905	841	916	821	10.8	872	32	3.69	80

Table A-2. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
1.7 - 0.8 um	Selenium	GFAA	ug/g	NA	NA	1140	NA	NA	1140	NA	NA	NA
1.7 - 0.8 um	Vanadium	ICP/MS	ug/g	1788	1758	1749	1646	6.1	1748	46	2.65	115
0.8 - 0.5 um	Arsenic	ICP/MS	ug/g	1575	1563	1647	1632	0.9	1593	41	2.58	102
0.8 - 0.5 um	Arsenic	GFAA	ug/g	NA	NA	3152	NA	NA	3152	NA	NA	NA
0.8 - 0.5 um	Barium	ICP/MS	ug/g	1859	2332	2464	2439	1.0	2214	313	14.15	778
0.8 - 0.5 um	Barium	ICP	ug/g	NA	NA	4309	NA	NA	4309	NA	NA	NA
0.8 - 0.5 um	Beryllium	ICP/MS	ug/g	17.8	12.8	15.6	13.2	16.5	15.0	2.6	17.19	6
0.8 - 0.5 um	Cadmium	ICP/MS	ug/g	130	114	162	179	9.9	138	29	20.86	72
0.8 - 0.5 um	Chromium	ICP/MS	ug/g	2268	2177	2136	2106	1.4	2189	74	3.37	183
0.8 - 0.5 um	Chromium	ICP	ug/g	NA	NA	2272	NA	NA	2272	NA	NA	NA
0.8 - 0.5 um	Cobalt	ICP/MS	ug/g	32.3	29.8	30.1	30.1	0.0	30.7	1.3	4.32	3
0.8 - 0.5 um	Copper	ICP/MS	ug/g	393	275	309	295	4.6	323	61	18.97	152
0.8 - 0.5 um	Lead	ICP/MS	ug/g	340	213	687	683	0.6	412	244	59.16	606
0.8 - 0.5 um	Manganese	ICP/MS	ug/g	366	331	337	331	1.6	344	20	5.74	49
0.8 - 0.5 um	Mercury	ICP/MS	ug/g	< 0.44	< 0.44	< 0.44	< 0.44	0.0	< 0.44	NA	NA	NA
0.8 - 0.5 um	Molybdenum	ICP/MS	ug/g	388	376	376	379	0.7	381	7	1.73	16
0.8 - 0.5 um	Nickel	ICP/MS	ug/g	1048	984	953	918	3.7	989	57	5.73	141
0.8 - 0.5 um	Nickel	ICP	ug/g	NA	NA	1089	NA	NA	1089	NA	NA	NA
0.8 - 0.5 um	Selenium	ICP/MS	ug/g	976	930	945	965	2.1	954	23	2.44	58
0.8 - 0.5 um	Selenium	GFAA	ug/g	NA	NA	1312	NA	NA	1312	NA	NA	NA
0.8 - 0.5 um	Vanadium	ICP/MS	ug/g	1877	1563	1647	1827	10.4	1725	157	9.11	390
< 0.5 um	Arsenic	ICP/MS	ug/g	1929	NA	1962	1987	1.2	1951	32	1.66	292
< 0.5 um	Barium	ICP/MS	ug/g	1907	NA	3052	3038	0.5	2476	805	32.49	7,225
< 0.5 um	Barium	ICP	ug/g	NA	NA	3067	NA	NA	3067	NA	NA	NA
< 0.5 um	Beryllium	ICP/MS	ug/g	25.8	NA	26.9	25.1	6.9	25.9	0.1	0.41	1
< 0.5 um	Cadmium	ICP/MS	ug/g	100	NA	115	113	1.4	107	10	9.22	89
< 0.5 um	Chromium	ICP/MS	ug/g	1371	NA	1340	1380	3.0	1366	8	0.58	71
< 0.5 um	Chromium	ICP	ug/g	NA	NA	1233	NA	NA	1233	NA	NA	NA
< 0.5 um	Cobalt	ICP/MS	ug/g	25.5	NA	24.6	23.4	5.0	24.8	1.1	4.41	10
< 0.5 um	Copper	ICP/MS	ug/g	1446	NA	1556	1769	12.8	1554	153	9.86	1,377
< 0.5 um	Lead	ICP/MS	ug/g	63.6	NA	136	133	2.5	99	50	50.58	450
< 0.5 um	Manganese	ICP/MS	ug/g	256	NA	257	265	3.1	258	4	1.37	32
< 0.5 um	Mercury	ICP/MS	ug/g	0.60	NA	< 0.44	< 0.44	0.0	0.41	0.27	65.43	2
< 0.5 um	Molybdenum	ICP/MS	ug/g	502	NA	540	560	3.7	526	34	6.45	305
< 0.5 um	Nickel	ICP/MS	ug/g	1240	NA	1290	1334	3.4	1276	51	3.96	454
< 0.5 um	Nickel	ICP	ug/g	NA	NA	1068	NA	NA	1068	NA	NA	NA

Table A-2. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.5 um	Selenium	ICP/MS	ug/g	1054	NA	948	1003	5.6	1015	56	5.50	501
< 0.5 um	Selenium	GFAA	ug/g	NA	NA	1273	NA	NA	1273	NA	NA	NA
< 0.5 um	Vanadium	ICP/MS	ug/g	1711	NA	1722	1806	4.7	1737	37	2.15	335

Table A-3. Phase I Gastric Fliud-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.3 um	Arsenic	ICP/MS	1992	1786	1661	1815	8.8	1815	166	9.1	411
> 6.3 um	Arsenic	GFAA	NA	NA	348	NA	NA	348	NA	NA	NA
> 6.3 um	Barium	ICP/MS	192	157	130	160	20.1	160	31	19.6	78
> 6.3 um	Beryllium	ICP/MS	7.16	8.85	8.34	8.02	3.9	8.02	0.85	10.6	2
> 6.3 um	Cadmium	ICP/MS	39.4	44.4	45.3	43.3	4.4	43.3	3.6	8.2	9
> 6.3 um	Chromium	ICP/MS	6568	5294	5338	5763	7.7	5763	700	12.1	1,738
> 6.3 um	Cobalt	ICP/MS	235	183	181	201	10.2	201	29	14.6	73
> 6.3 um	Copper	ICP/MS	428	442	406	426	5.0	426	17	3.9	41
> 6.3 um	Lead	ICP/MS	14.5	19.7	14.7	16.2	9.9	16.2	3.0	18.7	8
> 6.3 um	Manganese	ICP/MS	1138	1058	1031	1077	4.3	1077	54	5.0	134
> 6.3 um	Mercury	ICP/MS	8.66	9.10	7.37	8.34	12.3	8.34	0.96	11.6	2
> 6.3 um	Molybdenum	ICP/MS	132	159	144	146	1.2	146	14	9.4	34
> 6.3 um	Nickel	ICP/MS	9618	7622	7965	8434	5.7	8434	1048	12.4	2,602
> 6.3 um	Selenium	ICP/MS	119	131	122	126	2.7	126	6	5.1	16
> 6.3 um	Vanadium	ICP/MS	2042	1896	1660	1888	12.8	1888	158	8.4	393
6.3 - 2.7 um	Arsenic	ICP/MS	1615	NA	NA	1433	12.0	1524	NA	NA	NA
6.3 - 2.7 um	Arsenic	GFAA	347	NA	NA	349	0.6	348	NA	NA	NA
6.3 - 2.7 um	Barium	ICP/MS	282	NA	NA	280	0.9	281	NA	NA	NA
6.3 - 2.7 um	Beryllium	ICP/MS	7.45	NA	NA	7.53	1.1	7.49	NA	NA	NA
6.3 - 2.7 um	Cadmium	ICP/MS	502	NA	NA	509	1.5	505	NA	NA	NA
6.3 - 2.7 um	Chromium	ICP/MS	6215	NA	NA	5989	3.7	6102	NA	NA	NA
6.3 - 2.7 um	Cobalt	ICP/MS	206	NA	NA	206	0.2	206	NA	NA	NA
6.3 - 2.7 um	Copper	ICP/MS	1450	NA	NA	1403	3.3	1427	NA	NA	NA
6.3 - 2.7 um	Lead	ICP/MS	666	NA	NA	667	0.1	667	NA	NA	NA
6.3 - 2.7 um	Manganese	ICP/MS	1097	NA	NA	1076	1.9	1086	NA	NA	NA
6.3 - 2.7 um	Mercury	ICP/MS	6.95	NA	NA	6.94	0.1	6.95	NA	NA	NA
6.3 - 2.7 um	Molybdenum	ICP/MS	119	NA	NA	114	3.7	116	NA	NA	NA
6.3 - 2.7 um	Nickel	ICP/MS	9008	NA	NA	8754	2.9	8881	NA	NA	NA
6.3 - 2.7 um	Selenium	ICP/MS	106	NA	NA	135	24.2	121	NA	NA	NA
6.3 - 2.7 um	Selenium	GFAA	86.6	NA	NA	NA	NA	86.6	NA	NA	NA
6.3 - 2.7 um	Vanadium	ICP/MS	1672	NA	NA	1554	7.3	1613	NA	NA	NA
2.7 - 1.7 um	Arsenic	ICP/MS	1694	2124	1763	1869	5.8	1869	226	12.1	562
2.7 - 1.7 um	Arsenic	GFAA	1285	NA	NA	NA	NA	1285	NA	NA	NA
2.7 - 1.7 um	Barium	ICP/MS	280	394	142	272	62.7	272	127	46.6	314
2.7 - 1.7 um	Beryllium	ICP/MS	14.6	15.1	16.9	15.2	11.0	15.2	0.5	3.4	1
2.7 - 1.7 um	Cadmium	ICP/MS	147	174	167	163	2.4	163	14	8.8	36

Table A-3. (Continued)

Size Range	Element	Analysis	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
2.7 - 1.7 um	Chromium	ICP/MS	1715	1755	1748	1733	0.8	1733	20	1.2	51
2.7 - 1.7 um	Cobalt	ICP/MS	28.5	28.3	28.4	28.4	0.0	28.4	0.1	0.4	0.3
2.7 - 1.7 um	Copper	ICP/MS	357	359	373	361	3.4	361	5	1.3	12
2.7 - 1.7 um	Lead	ICP/MS	12.4	13.5	10.1	12.0	17.3	12.0	1.7	14.0	4
2.7 - 1.7 um	Manganese	ICP/MS	543	545	592	559	5.8	559	25	4.5	62
2.7 - 1.7 um	Mercury	ICP/MS	7.53	6.71	6.80	7.08	4.1	7.08	0.41	5.8	1
2.7 - 1.7 um	Molybdenum	ICP/MS	393	417	410	407	0.8	407	13	3.2	32
2.7 - 1.7 um	Nickel	ICP/MS	1309	1339	1345	1321	1.8	1321	15	1.2	38
2.7 - 1.7 um	Selenium	ICP/MS	300	398	318	342	7.2	342	50	14.7	125
2.7 - 1.7 um	Vanadium	ICP/MS	2459	2539	2584	2517	2.6	2517	51	2.0	126
1.7 - 0.8 um	Arsenic	ICP/MS	951	1210	1088	1097	0.8	1097	133	12.1	330
1.7 - 0.8 um	Arsenic	GFAA	1220	NA	NA	NA	NA	1220	NA	NA	NA
1.7 - 0.8 um	Barium	ICP/MS	276	133	571	328	54.0	328	226	68.8	561
1.7 - 0.8 um	Beryllium	ICP/MS	16.1	16.0	14.4	15.6	7.6	15.6	0.9	5.7	2
1.7 - 0.8 um	Cadmium	ICP/MS	1274	1015	907	1067	16.2	1067	186	17.4	461
1.7 - 0.8 um	Chromium	ICP/MS	1937	2220	2032	2066	1.6	2066	143	6.9	355
1.7 - 0.8 um	Cobalt	ICP/MS	46.0	48.0	86.6	60.6	35.3	60.6	23.6	38.9	59
1.7 - 0.8 um	Copper	ICP/MS	304	280	291	294	1.2	294	13	4.3	31
1.7 - 0.8 um	Lead	ICP/MS	800	618	340	585	53.0	585	233	39.8	578
1.7 - 0.8 um	Manganese	ICP/MS	626	643	633	636	0.5	636	9	1.4	22
1.7 - 0.8 um	Mercury	ICP/MS	2.81	2.79	2.78	2.74	1.3	2.74	0.10	3.6	0.2
1.7 - 0.8 um	Molybdenum	ICP/MS	450	452	459	455	0.8	455	8	1.8	20
1.7 - 0.8 um	Nickel	ICP/MS	1860	1905	1836	1872	2.0	1872	28	1.5	70
1.7 - 0.8 um	Selenium	ICP/MS	238	310	366	307	17.7	307	67	22.0	168
1.7 - 0.8 um	Selenium	GFAA	420	NA	NA	NA	NA	420	NA	NA	NA
1.7 - 0.8 um	Vanadium	ICP/MS	1912	1924	1882	1904	1.2	1904	26	1.3	63
0.8 - 0.5 um	Arsenic	ICP/MS	1229	1306	1358	1304	4.1	1304	74	5.7	183
0.8 - 0.5 um	Arsenic	GFAA	1883	NA	NA	NA	NA	1883	NA	NA	NA
0.8 - 0.5 um	Barium	ICP/MS	223	275	487	322	40.7	322	130	40.4	323
0.8 - 0.5 um	Beryllium	ICP/MS	17.8	16.4	16.2	16.9	4.5	16.9	0.7	4.3	2
0.8 - 0.5 um	Cadmium	ICP/MS	118	91.0	94.2	102	7.6	102	15	14.3	36
0.8 - 0.5 um	Chromium	ICP/MS	1478	1509	1778	1587	11.4	1587	162	10.2	402
0.8 - 0.5 um	Cobalt	ICP/MS	23.6	40.0	28.0	30.5	8.7	30.5	8.5	27.8	21
0.8 - 0.5 um	Copper	ICP/MS	287	274	267	275	3.0	275	11	3.9	27
0.8 - 0.5 um	Lead	ICP/MS	20.4	6.79	4.73	10.7	77.0	10.7	8.5	80.1	21
0.8 - 0.5 um	Manganese	ICP/MS	302	316	365	329	10.4	329	34	10.5	86

Table A-3. (Continued)

Size Range	Element	Analysis	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
0.8 - 0.5 um	Mercury	ICP/MS	2.77	3.56	3.41	3.30	3.2	3.30	0.46	14.1	1
0.8 - 0.5 um	Molybdenum	ICP/MS	564	485	560	535	4.5	535	43	8.1	108
0.8 - 0.5 um	Nickel	ICP/MS	812	821	1037	891	15.1	891	129	14.5	321
0.8 - 0.5 um	Selenium	ICP/MS	452	468	563	484	15.1	484	51	10.5	126
0.8 - 0.5 um	Vanadium	ICP/MS	2088	1943	2073	2033	2.0	2033	78	3.8	194
< 0.5 um	Arsenic	ICP/MS	2423	204	982	1227	22.2	1227	1119	91.2	2,779
< 0.5 um	Arsenic	GFAA	2020	NA	NA	NA	NA	2020	NA	NA	NA
< 0.5 um	Barium	ICP/MS	205	113	114	144	22.9	144	53	36.7	131
< 0.5 um	Beryllium	ICP/MS	15.5	4.79	16.1	12.1	28.9	12.1	6.3	52.2	16
< 0.5 um	Cadmium	ICP/MS	83.0	54.8	88.0	74.9	16.0	74.9	17.6	23.5	44
< 0.5 um	Chromium	ICP/MS	866	267	778	642	19.1	642	327	50.9	812
< 0.5 um	Cobalt	ICP/MS	14.4	5.36	14.7	11.5	24.3	11.5	5.3	46.2	13
< 0.5 um	Copper	ICP/MS	325	110	321	253	23.8	253	124	49.1	308
< 0.5 um	Lead	ICP/MS	4.73	0.80	3.65	3.07	17.3	3.07	2.03	66.1	5
< 0.5 um	Manganese	ICP/MS	177	53.0	180	135	28.5	135	71	52.7	177
< 0.5 um	Mercury	ICP/MS	4.55	2.08	3.39	3.34	1.5	3.34	1.24	37.1	3
< 0.5 um	Molybdenum	ICP/MS	792	298	600	567	5.7	567	250	44.0	620
< 0.5 um	Nickel	ICP/MS	746	249	714	571	22.2	571	279	48.8	692
< 0.5 um	Selenium	ICP/MS	869	233	501	532	6.0	532	320	60.2	794
< 0.5 um	Selenium	GFAA	748	NA	NA	NA	NA	748	NA	NA	NA
< 0.5 um	Vanadium	ICP/MS	1968	629	1916	1507	23.9	1507	761	50.5	1,890

Table A-4. Phase I Acetic Acid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.3 um	Arsenic	ICP/MS	ug/g	10.6	6.86	13.5	13.3	1.5	10.3	3.3	31.9	8
> 6.3 um	Barium	ICP/MS	ug/g	222	297	156	152	2.7	224	72	32.0	178
> 6.3 um	Beryllium	ICP/MS	ug/g	6.60	4.44	3.54	4.95	33.2	5.09	1.31	25.6	3
> 6.3 um	Cadmium	ICP/MS	ug/g	45.0	41.4	38.0	36.5	4.2	41.2	3.9	9.4	10
> 6.3 um	Chromium	ICP/MS	ug/g	1995	2117	2042	2026	0.8	2049	62	3.0	155
> 6.3 um	Cobalt	ICP/MS	ug/g	252	311	283	278	2.1	281	30	10.6	74
> 6.3 um	Copper	ICP/MS	ug/g	198	172	191	208	8.3	190	16	8.3	39
> 6.3 um	Lead	ICP/MS	ug/g	0.74	2.24	2.88	2.74	5.0	1.78	1.46	82.1	13
> 6.3 um	Manganese	ICP/MS	ug/g	1188	1234	1252	1244	0.7	1223	31	2.5	77
> 6.3 um	Mercury	ICP/MS	ug/g	3.86	3.61	4.51	4.68	3.7	4.02	0.51	12.7	1
> 6.3 um	Molybdenum	ICP/MS	ug/g	0.79	1.09	1.46	1.08	29.3	1.05	0.24	23.1	1
> 6.3 um	Nickel	ICP/MS	ug/g	593	7131	6683	6584	1.5	4786	3640	76.1	9,037
> 6.3 um	Selenium	ICP/MS	ug/g	28.2	31.5	14.5	17.3	17.8	25.2	8.2	32.7	20
> 6.3 um	Vanadium	ICP/MS	ug/g	13.4	4.27	16.1	16.8	4.5	11.4	6.3	55.7	16
6.3 - 2.7 um	Arsenic	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Barium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Beryllium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Cadmium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Chromium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Cobalt	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Copper	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Lead	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Manganese	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Mercury	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Molybdenum	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Nickel	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Selenium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
6.3 - 2.7 um	Vanadium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Arsenic	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Barium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Beryllium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Cadmium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Chromium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Cobalt	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Copper	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Lead	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table A-4. (Continued)

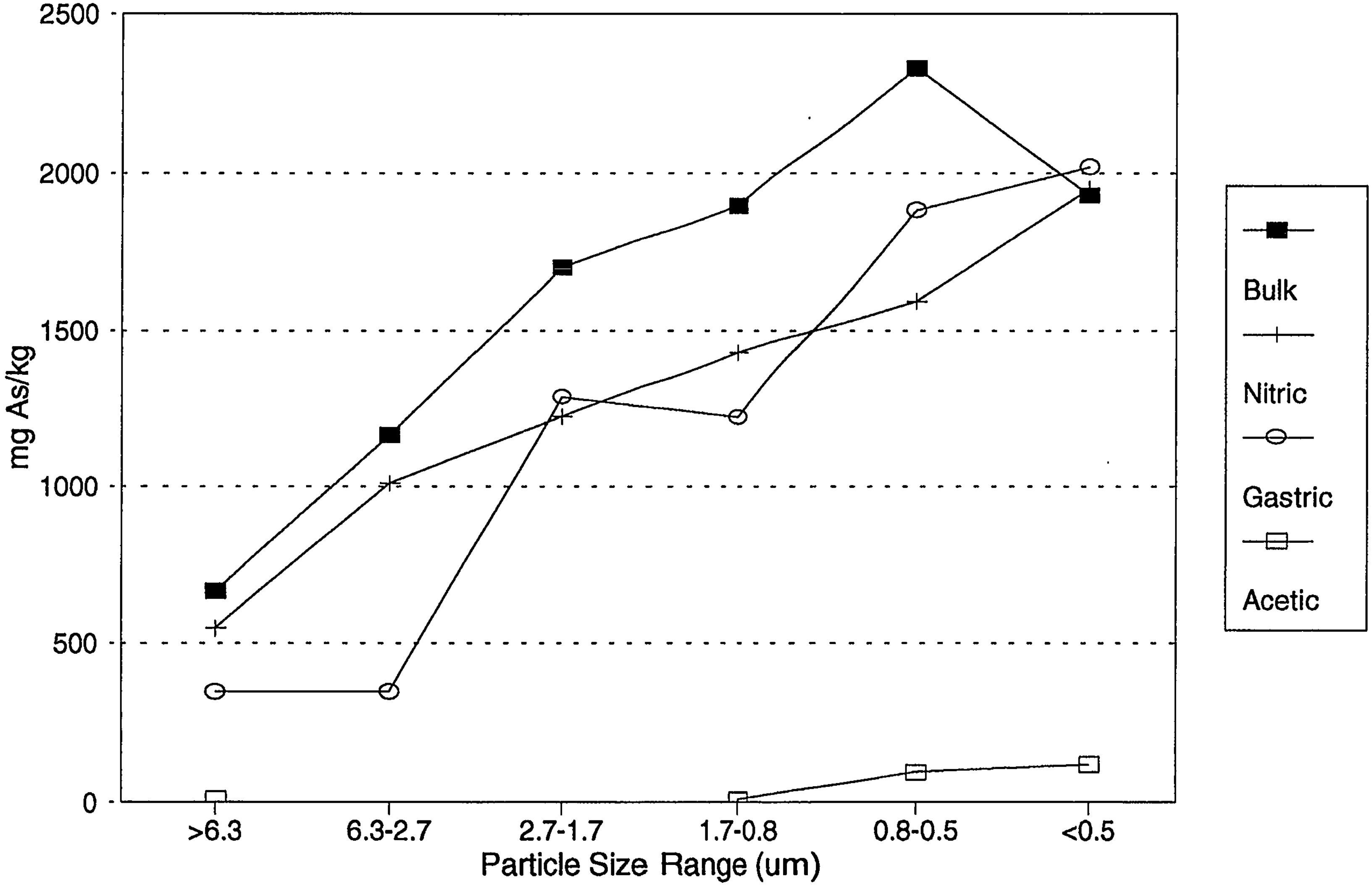
Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
2.7 - 1.7 um	Manganese	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Mercury	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Molybdenum	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Nickel	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Selenium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
2.7 - 1.7 um	Vanadium	ICP/MS	ug/g	NA	NA	NA	NA	NA	NA	NA	NA	NA
1.7 - 0.8 um	Arsenic	ICP/MS	ug/g	10.9	3.37	10.0	8.30	19.0	7.8	4.0	50.6	10
1.7 - 0.8 um	Barium	ICP/MS	ug/g	95.1	161	181	178	1.6	145	45	30.7	111
1.7 - 0.8 um	Beryllium	ICP/MS	ug/g	16.3	16.7	18.0	15.4	15.9	16.6	0.2	1.4	1
1.7 - 0.8 um	Cadmium	ICP/MS	ug/g	696	1405	1065	1050	1.4	1053	355	33.7	881
1.7 - 0.8 um	Chromium	ICP/MS	ug/g	1752	1661	1588	1552	2.3	1661	91	5.5	225
1.7 - 0.8 um	Cobalt	ICP/MS	ug/g	115.2	69.0	62.6	60.1	4.0	81.8	29.1	35.6	72
1.7 - 0.8 um	Copper	ICP/MS	ug/g	330	283	305	269	12.6	300	26	8.6	64
1.7 - 0.8 um	Lead	ICP/MS	ug/g	23.6	913	686	645	6.1	534	459	86.0	1,140
1.7 - 0.8 um	Manganese	ICP/MS	ug/g	882	879	819	777	5.3	853	47	5.6	118
1.7 - 0.8 um	Mercury	ICP/MS	ug/g	5.71	4.91	7.16	4.85	38.4	5.54	0.57	10.2	1
1.7 - 0.8 um	Molybdenum	ICP/MS	ug/g	2.54	1.40	4.85	2.40	67.8	2.52	1.11	44.1	3
1.7 - 0.8 um	Nickel	ICP/MS	ug/g	2555	2605	2431	2376	2.3	2521	105	4.2	261
1.7 - 0.8 um	Selenium	ICP/MS	ug/g	30.5	20.2	30.5	21.1	36.4	25.5	5.2	20.4	13
1.7 - 0.8 um	Vanadium	ICP/MS	ug/g	16.4	4.63	16.8	12.4	30.5	11.9	6.3	53.4	16
0.8 - 0.5 um	Arsenic	ICP/MS	ug/g	97.6	73.7	113	109	3.5	94.1	18.9	20.1	47
0.8 - 0.5 um	Barium	ICP/MS	ug/g	98.8	146	141	142	0.8	129	26	20.2	65
0.8 - 0.5 um	Beryllium	ICP/MS	ug/g	18.8	19.2	19.8	20.5	3.2	19.4	0.7	3.7	2
0.8 - 0.5 um	Cadmium	ICP/MS	ug/g	110	107	105	103	1.7	107	3	2.4	6
0.8 - 0.5 um	Chromium	ICP/MS	ug/g	1039	1275	1214	1222	0.7	1177	123	10.4	305
0.8 - 0.5 um	Cobalt	ICP/MS	ug/g	30.2	38.3	34.4	34.1	0.9	34.3	4.0	11.8	10
0.8 - 0.5 um	Copper	ICP/MS	ug/g	311	262	367	315	15.1	305	40	13.1	99
0.8 - 0.5 um	Lead	ICP/MS	ug/g	9.74	3.75	6.43	6.91	7.1	6.72	3.00	44.6	7
0.8 - 0.5 um	Manganese	ICP/MS	ug/g	342	394	383	380	0.8	373	28	7.4	68
0.8 - 0.5 um	Mercury	ICP/MS	ug/g	3.98	4.03	4.21	4.79	12.8	4.17	0.29	6.9	1
0.8 - 0.5 um	Molybdenum	ICP/MS	ug/g	20.3	9.50	16.3	15.3	6.2	15.2	5.4	35.6	13
0.8 - 0.5 um	Nickel	ICP/MS	ug/g	1186	1345	1231	1230	0.1	1254	82	6.5	204
0.8 - 0.5 um	Selenium	ICP/MS	ug/g	49.0	32.2	43.4	46.9	7.7	42.1	8.8	20.9	22
0.8 - 0.5 um	Vanadium	ICP/MS	ug/g	190	72.2	160	162	1.3	141	61	43.5	152
< 0.5 um	Arsenic	ICP/MS	ug/g	144	16.8	196	192	2.5	118	91	77.2	227
< 0.5 um	Barium	ICP/MS	ug/g	89.2	99.6	135	133	1.4	108	24	21.9	58

Table A-4. (Continued)

Size Range	Element	Analysis	Units	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.5 um	Beryllium	ICP/MS	ug/g	18.8	19.5	17.0	15.9	7.0	18.2	1.6	8.8	4
< 0.5 um	Cadmium	ICP/MS	ug/g	85.6	86.3	98.8	96.8	2.1	89.9	6.9	7.6	17
< 0.5 um	Chromium	ICP/MS	ug/g	748	750	761	776	1.9	755	11	1.5	28
< 0.5 um	Cobalt	ICP/MS	ug/g	23.3	22.5	20.0	20.9	4.2	22.1	1.5	6.7	4
< 0.5 um	Copper	ICP/MS	ug/g	391	427	294	290	1.7	370	70	18.9	173
< 0.5 um	Lead	ICP/MS	ug/g	3.18	2.17	2.76	2.91	5.3	2.73	0.51	18.9	1
< 0.5 um	Manganese	ICP/MS	ug/g	253	235	239	241	0.9	242	9	3.8	23
< 0.5 um	Mercury	ICP/MS	ug/g	4.49	4.39	4.11	3.91	5.0	4.30	0.25	5.9	1
< 0.5 um	Molybdenum	ICP/MS	ug/g	18.1	17.0	30.6	28.1	8.8	21.5	6.8	31.8	17
< 0.5 um	Nickel	ICP/MS	ug/g	1308	1370	1201	1196	0.5	1292	87	6.7	215
< 0.5 um	Selenium	ICP/MS	ug/g	73.4	57.1	72.8	62.6	15.1	66.1	8.2	12.5	20
< 0.5 um	Vanadium	ICP/MS	ug/g	218	149	358	350	2.2	240	105	43.5	260

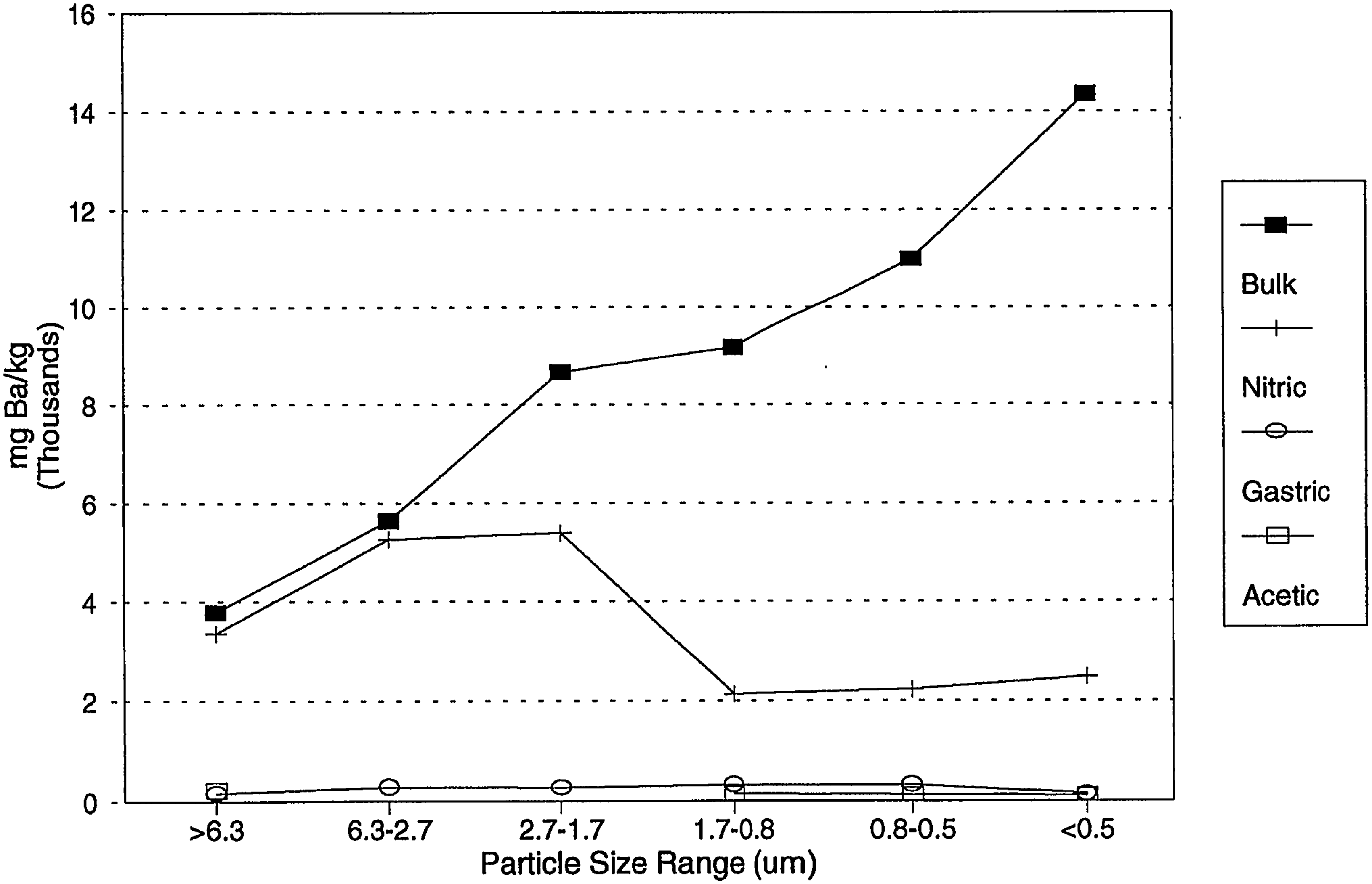
Phase I

Arsenic Concentration

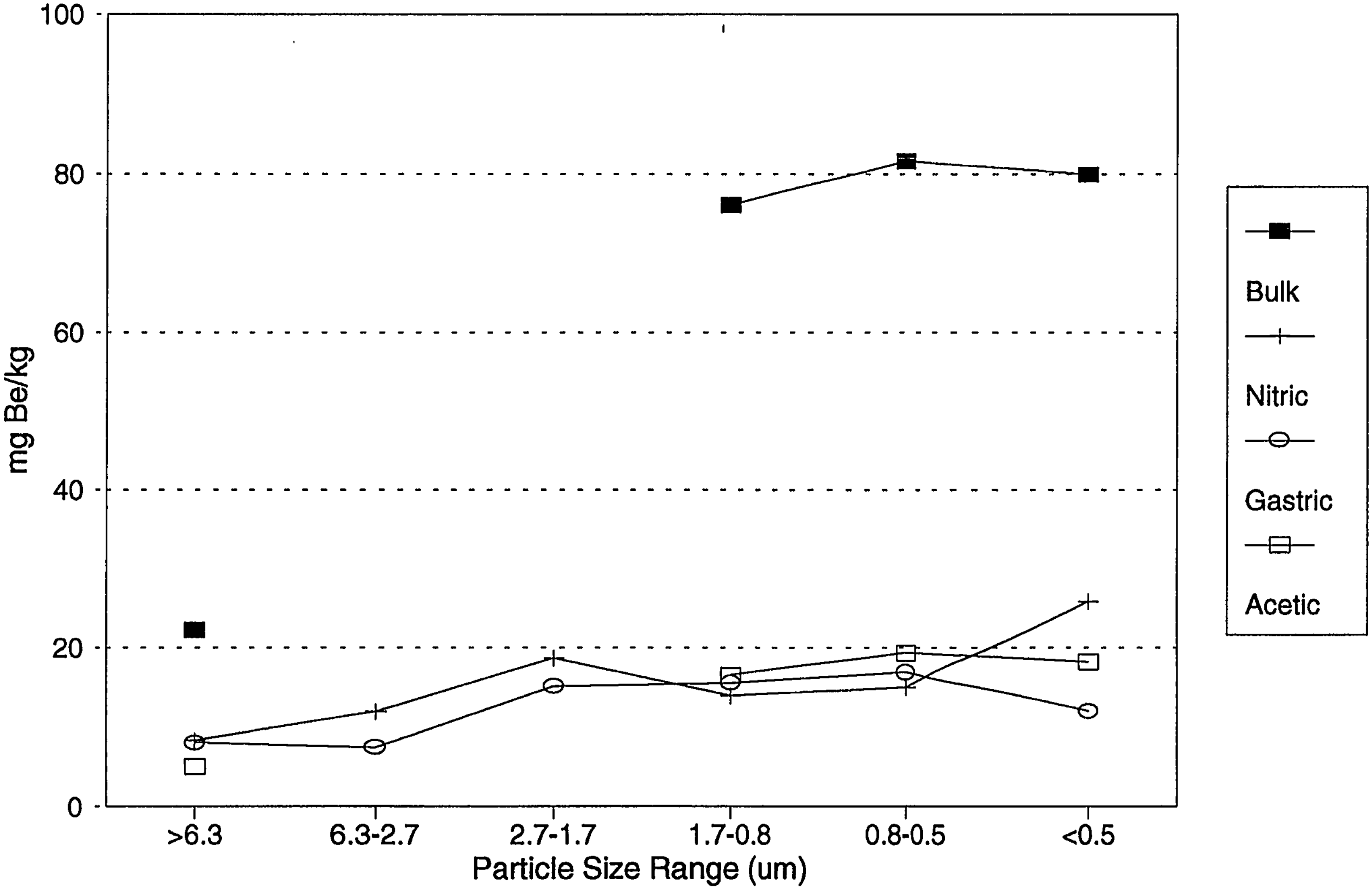


Phase I

Barium Concentration

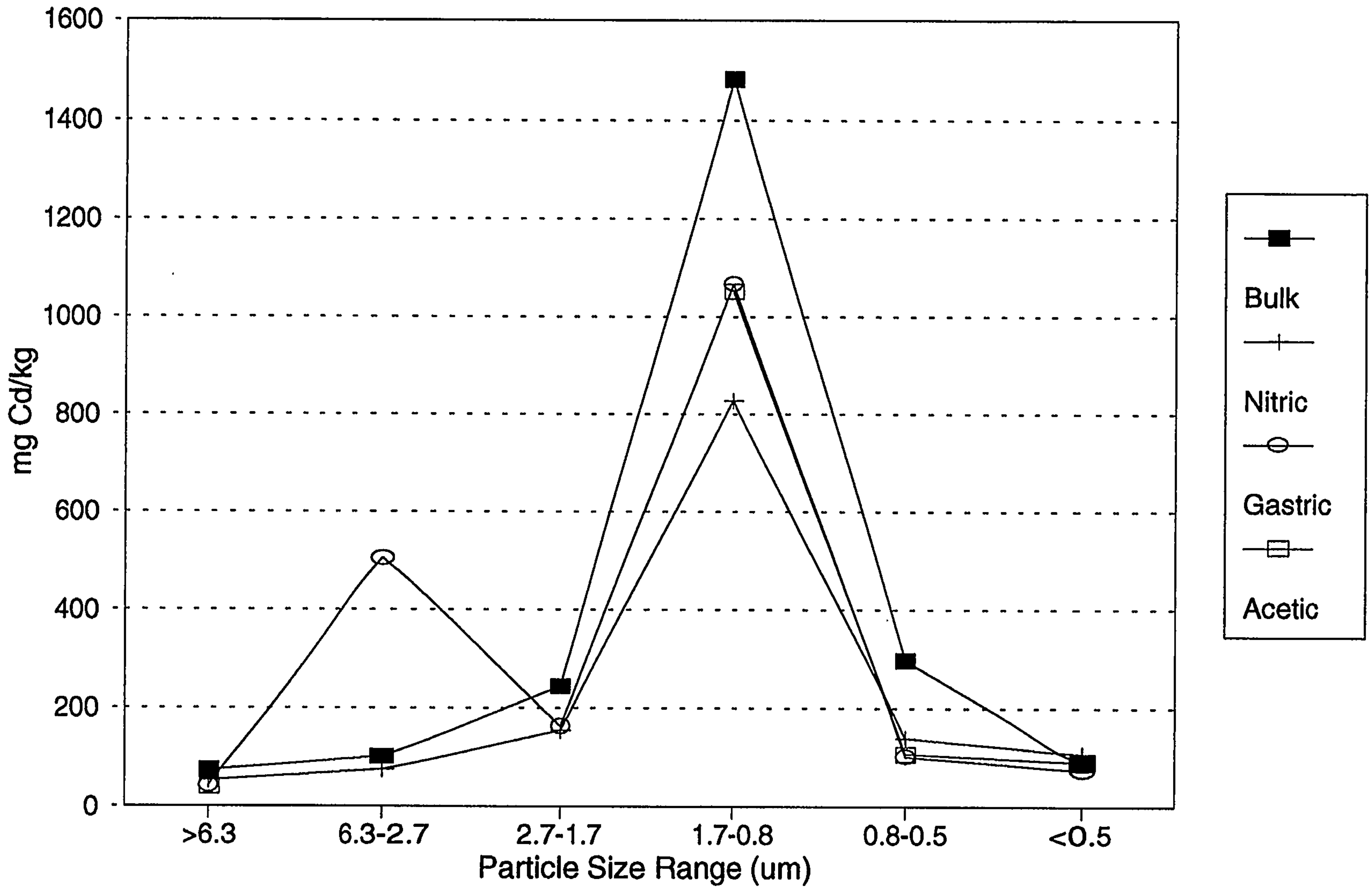


Phase I
Beryllium Concentration



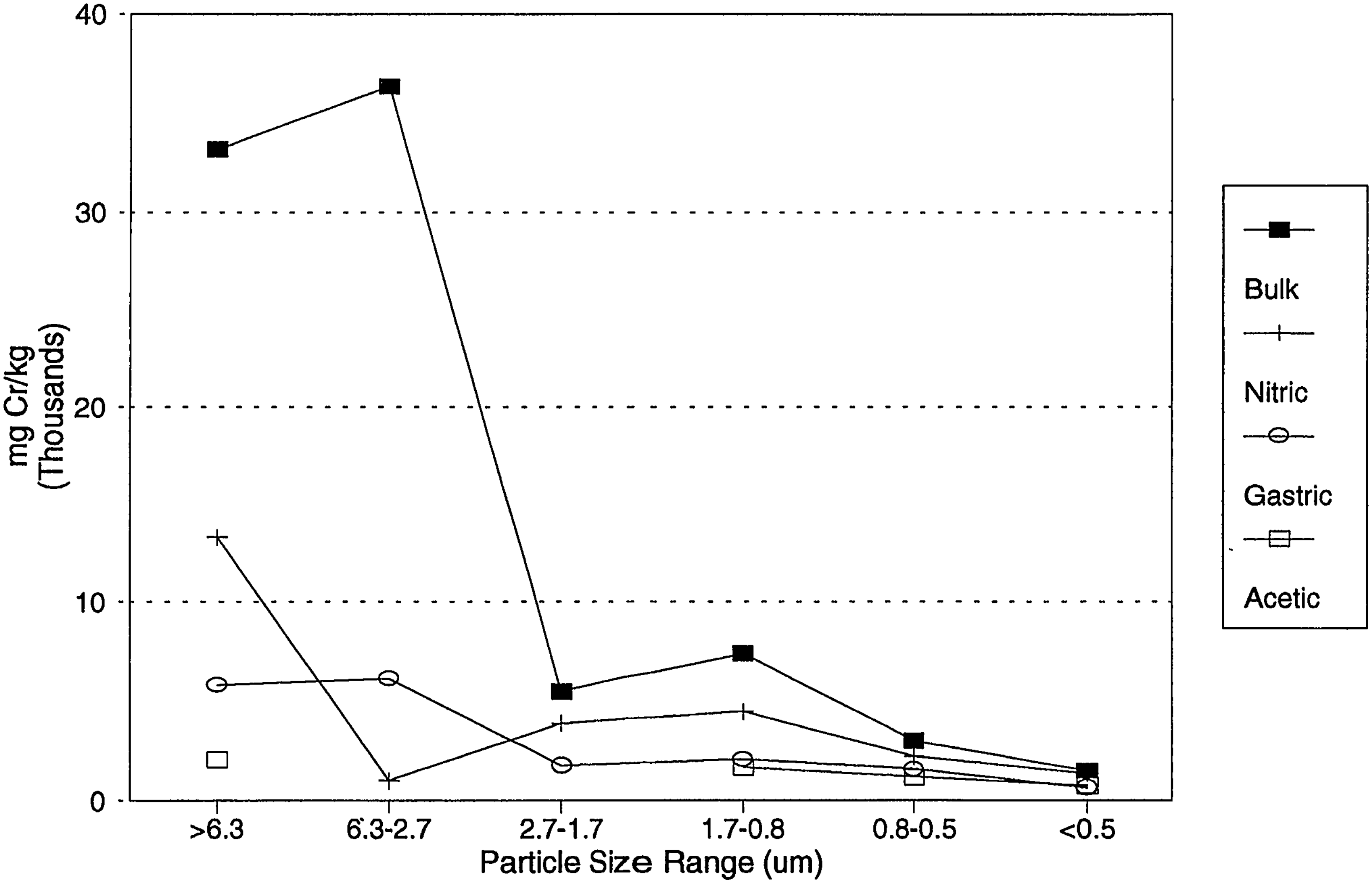
Phase I

Cadmium Concentration



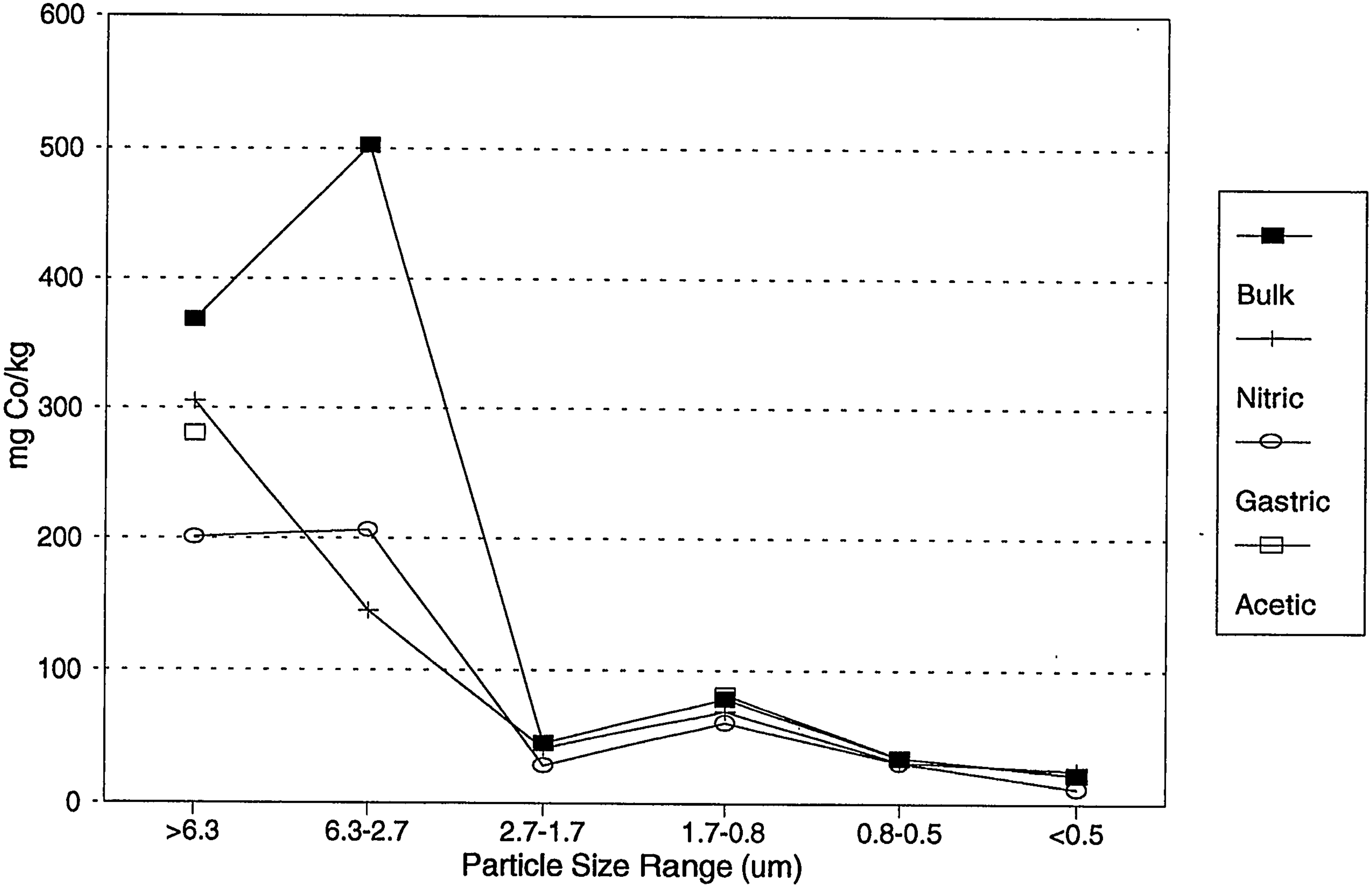
Phase I

Chromium Concentration



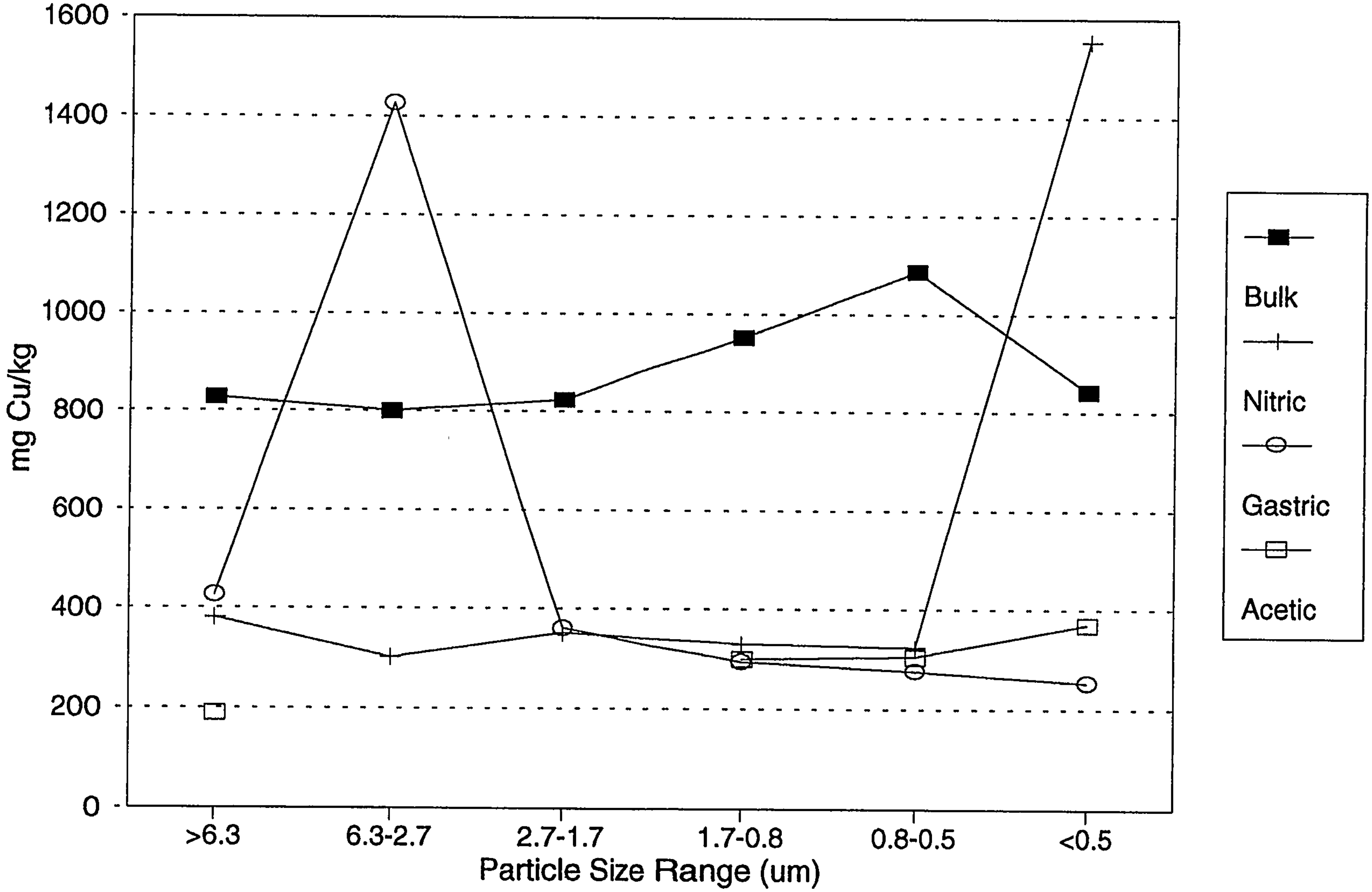
Phase I

Cobalt Concentration



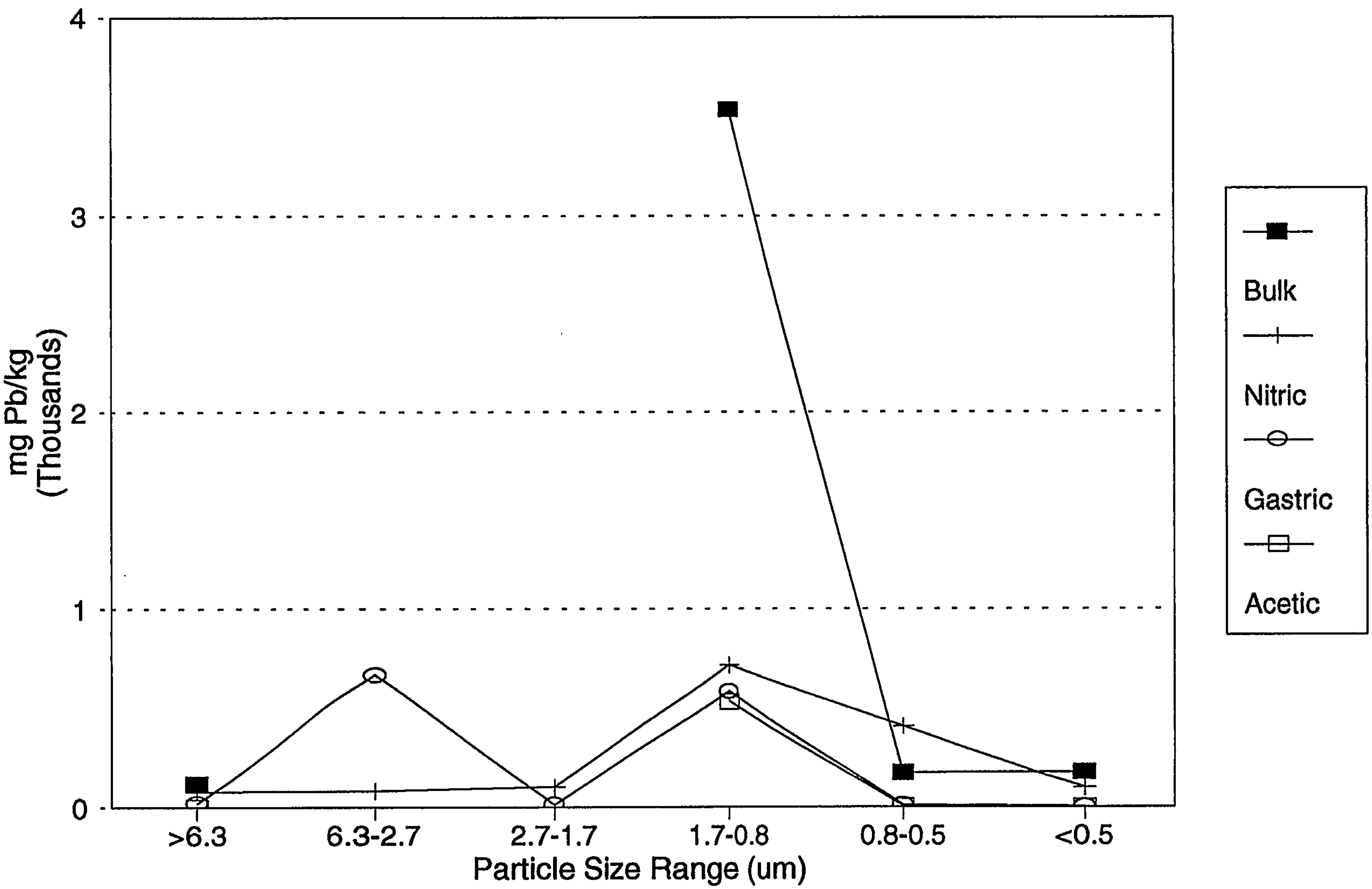
Phase I

Copper Concentration



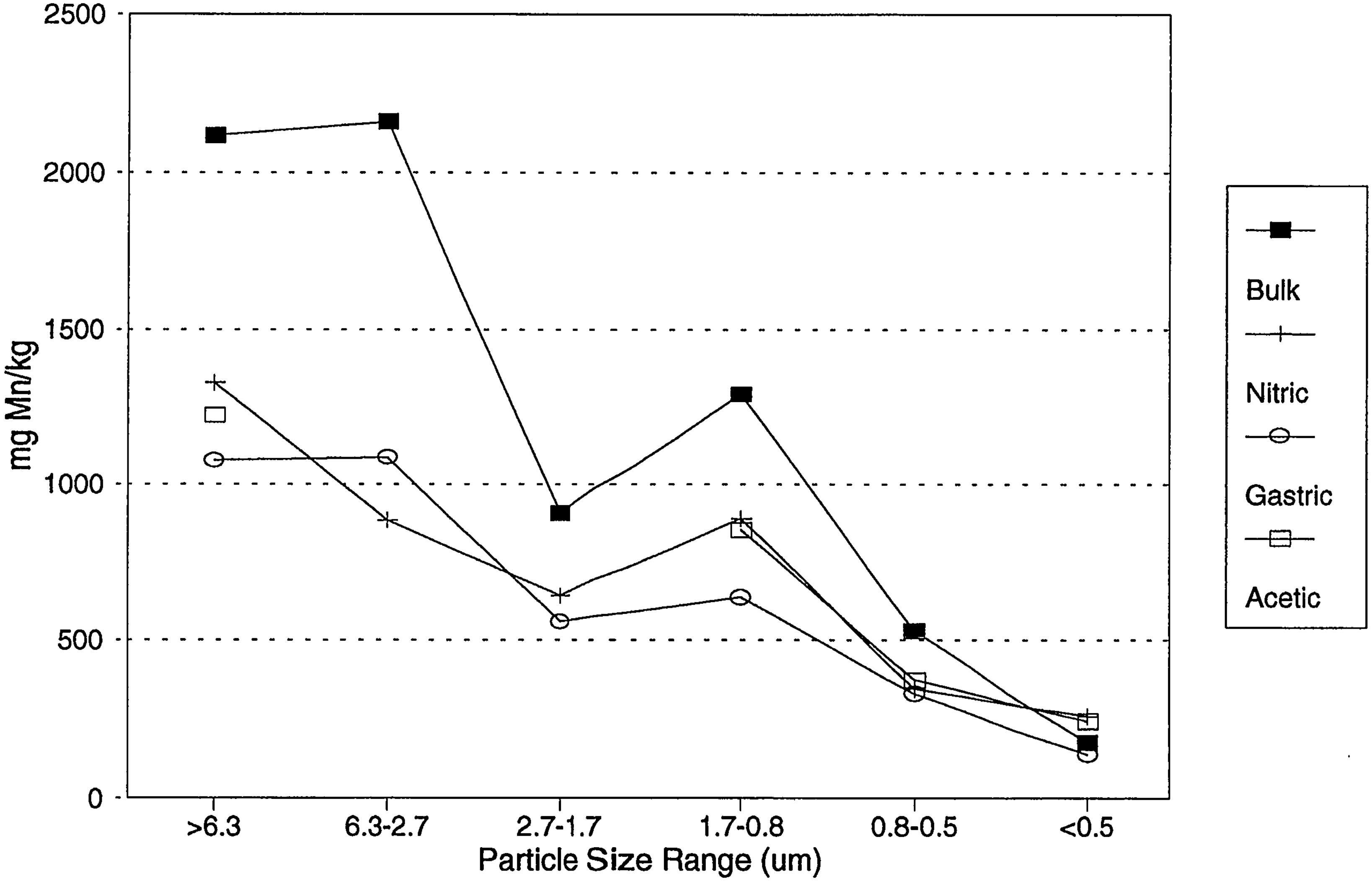
Phase I

Lead Concentration



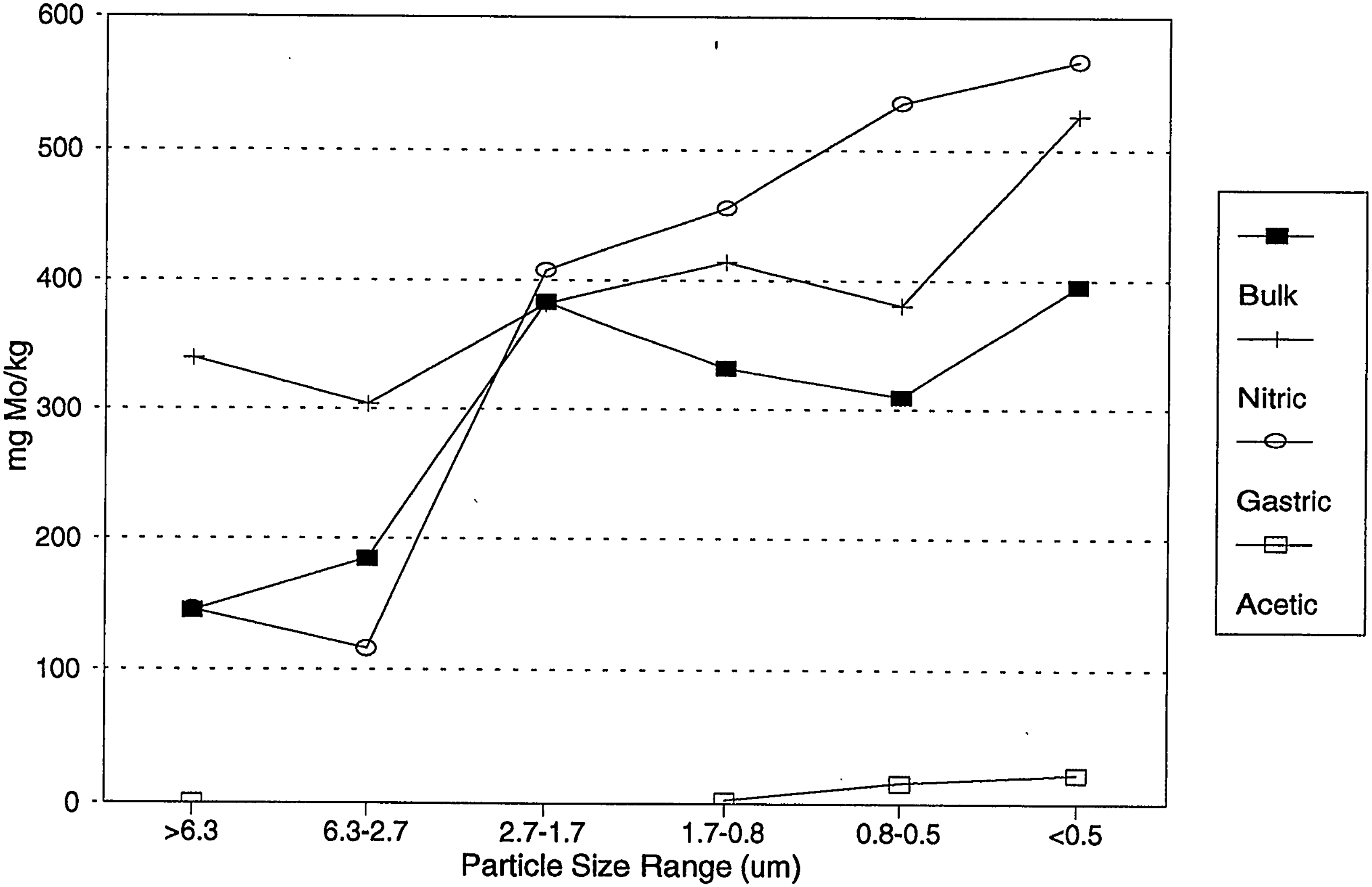
Phase I

Manganese Concentration

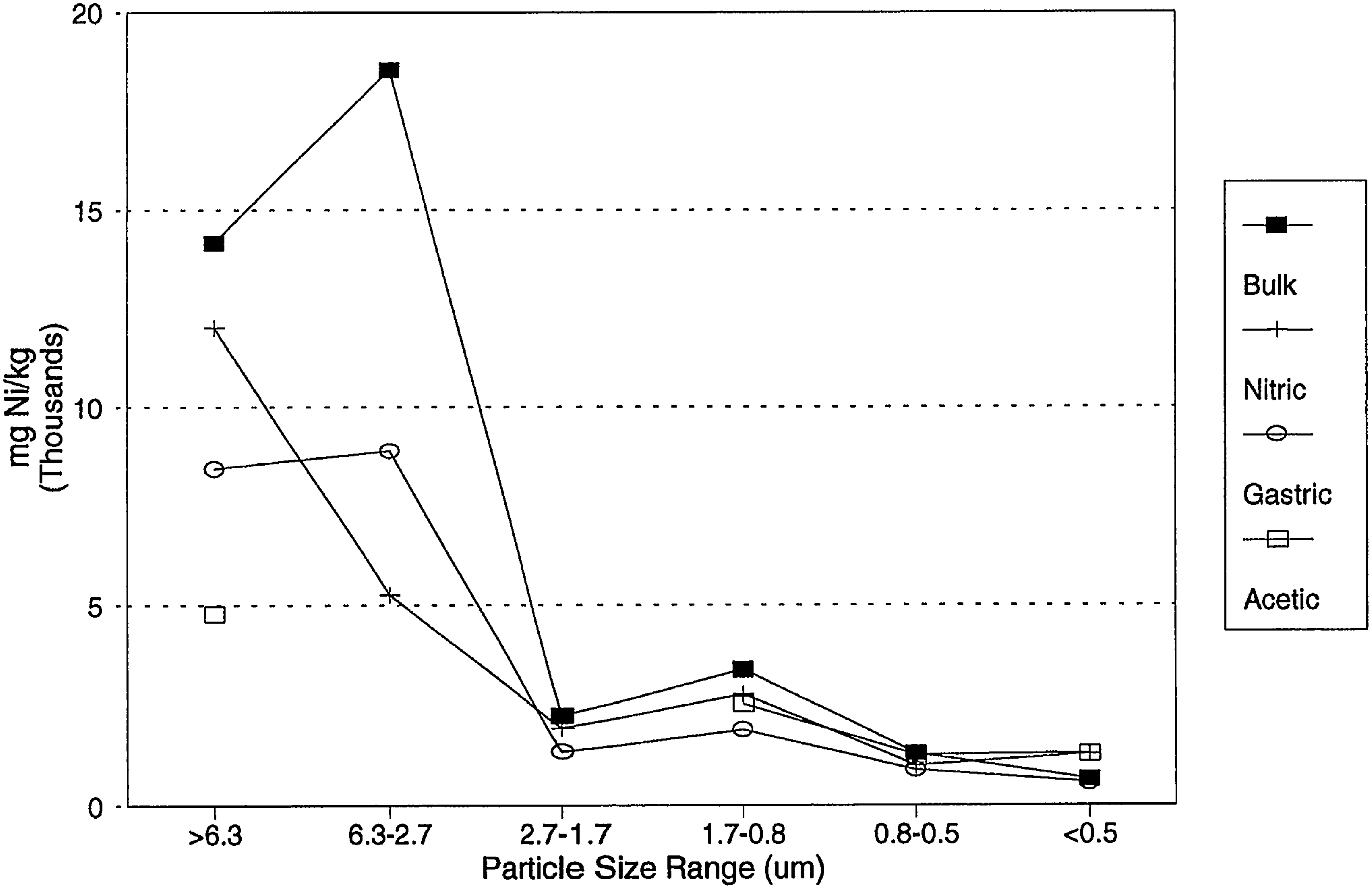


Phase I

Molybdenum Concentration

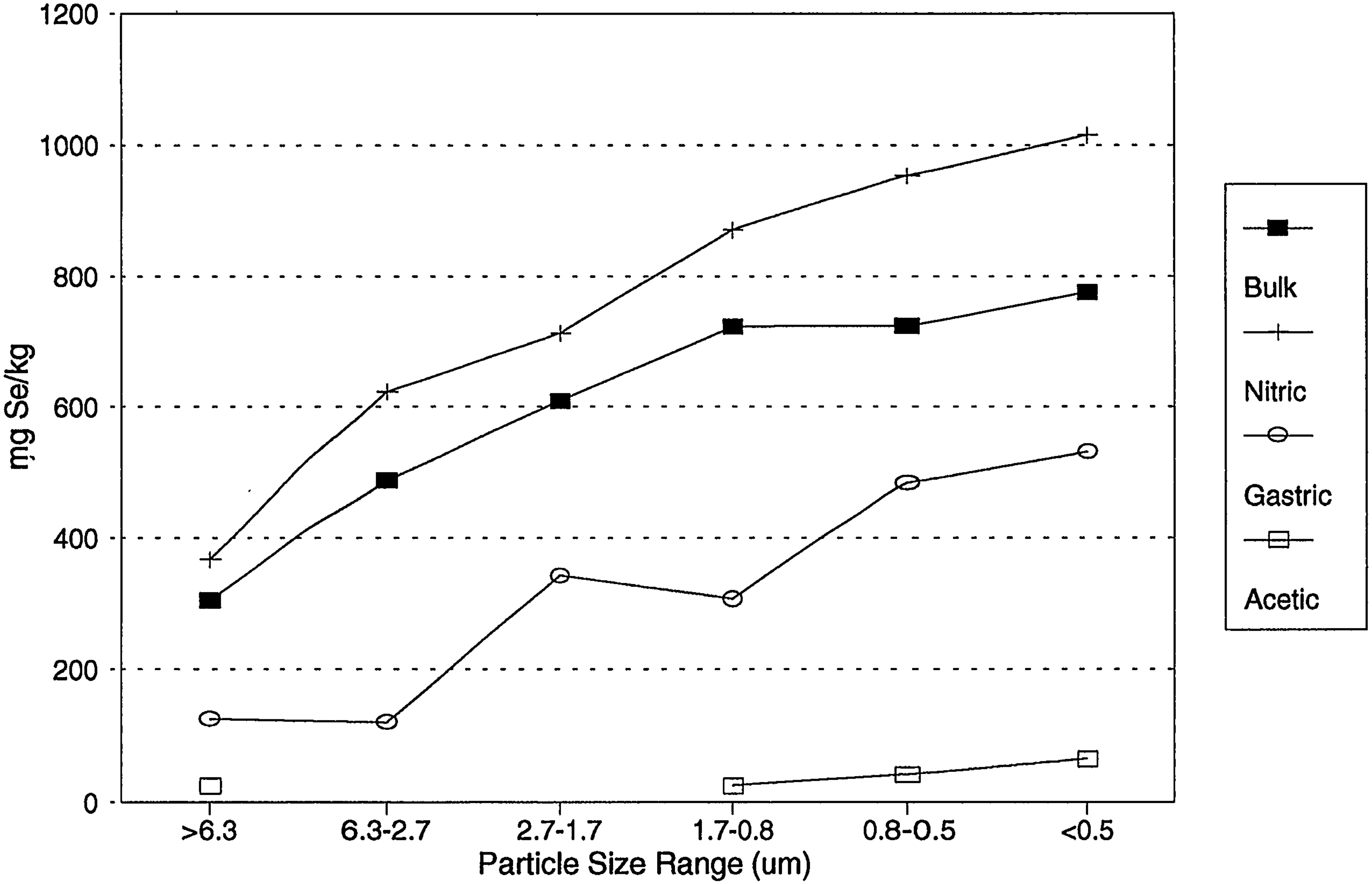


Phase I
Nickel Concentration



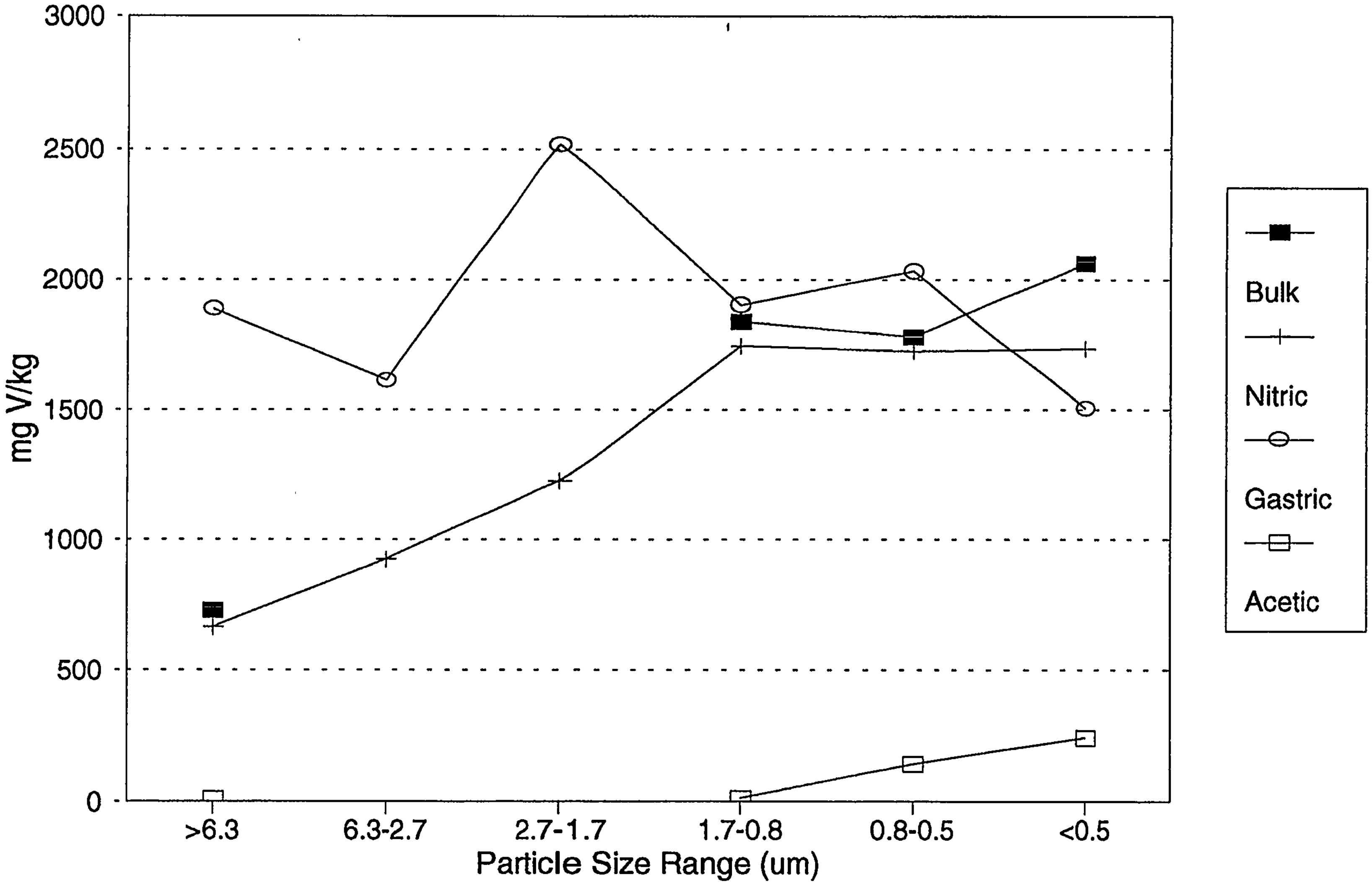
Phase I

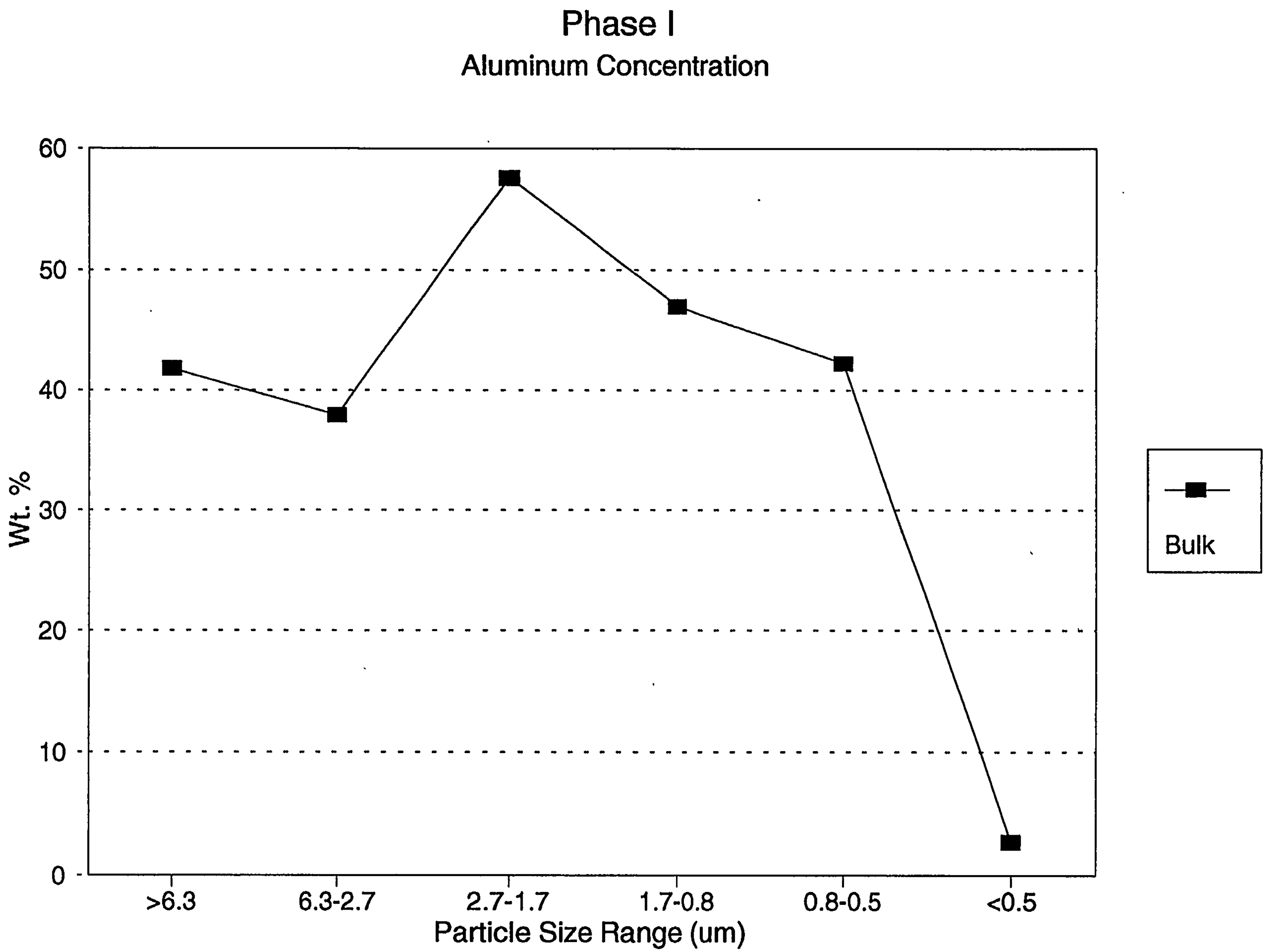
Selenium Concentration



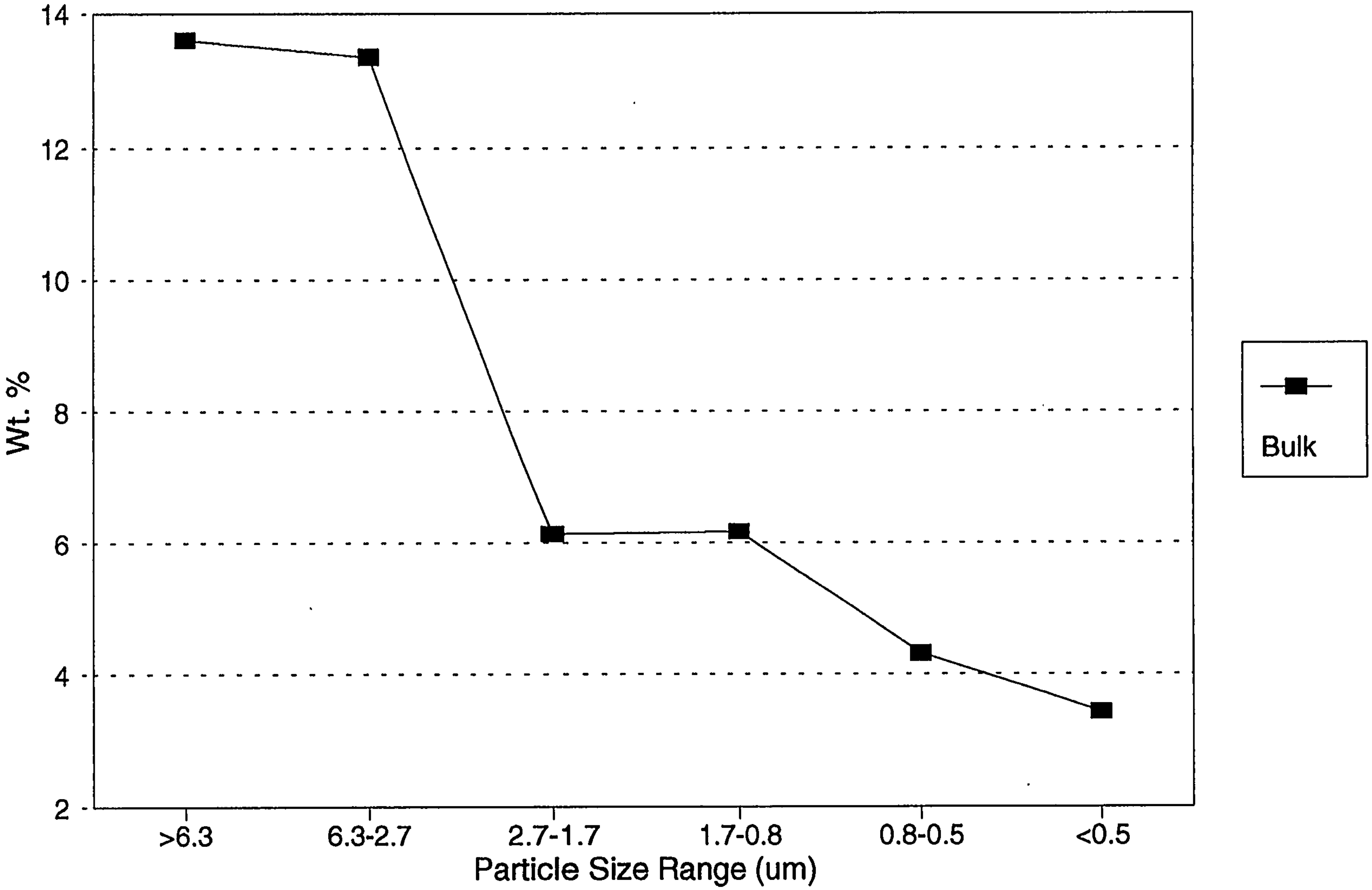
Phase I

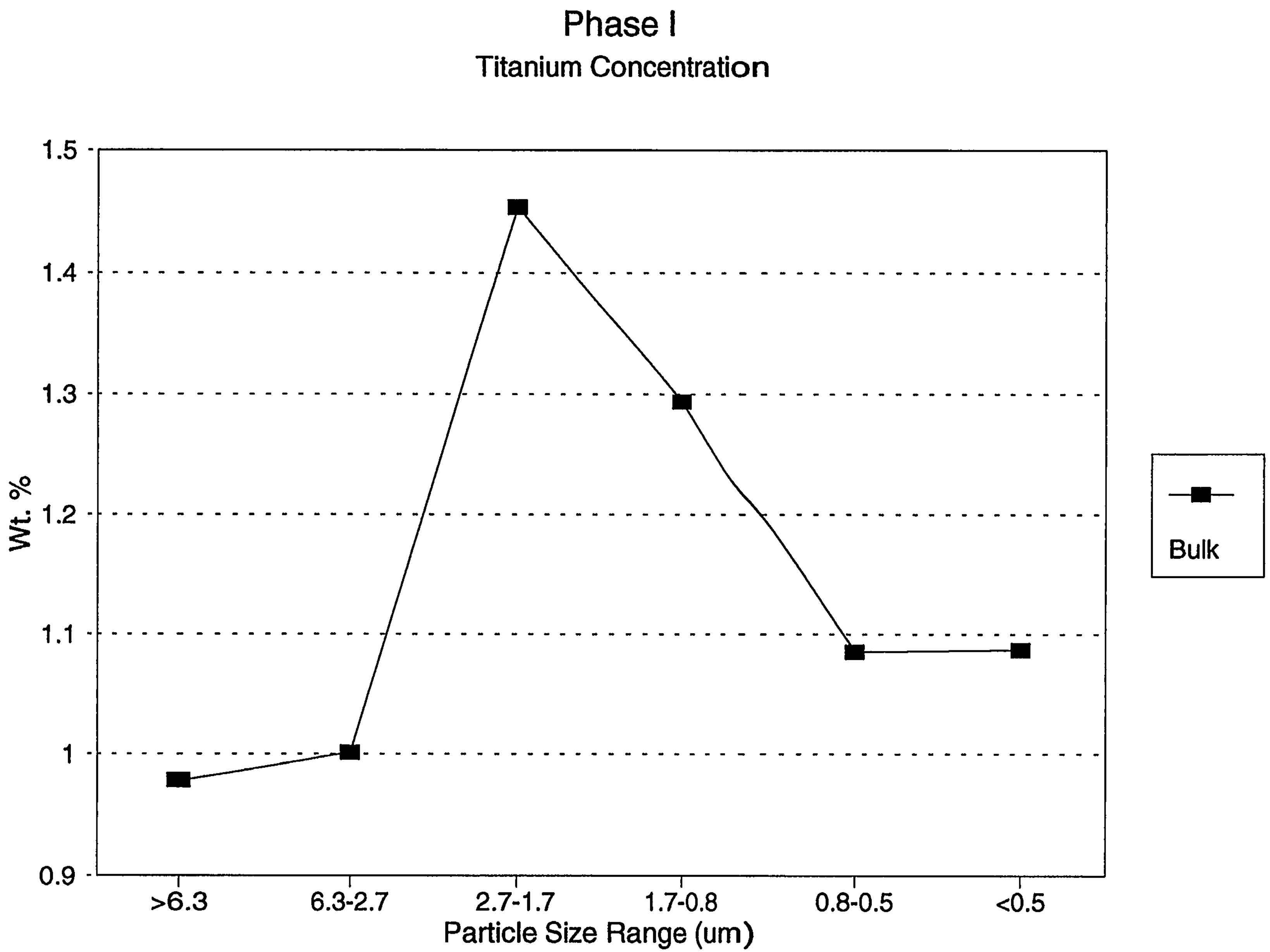
Vanadium Concentration

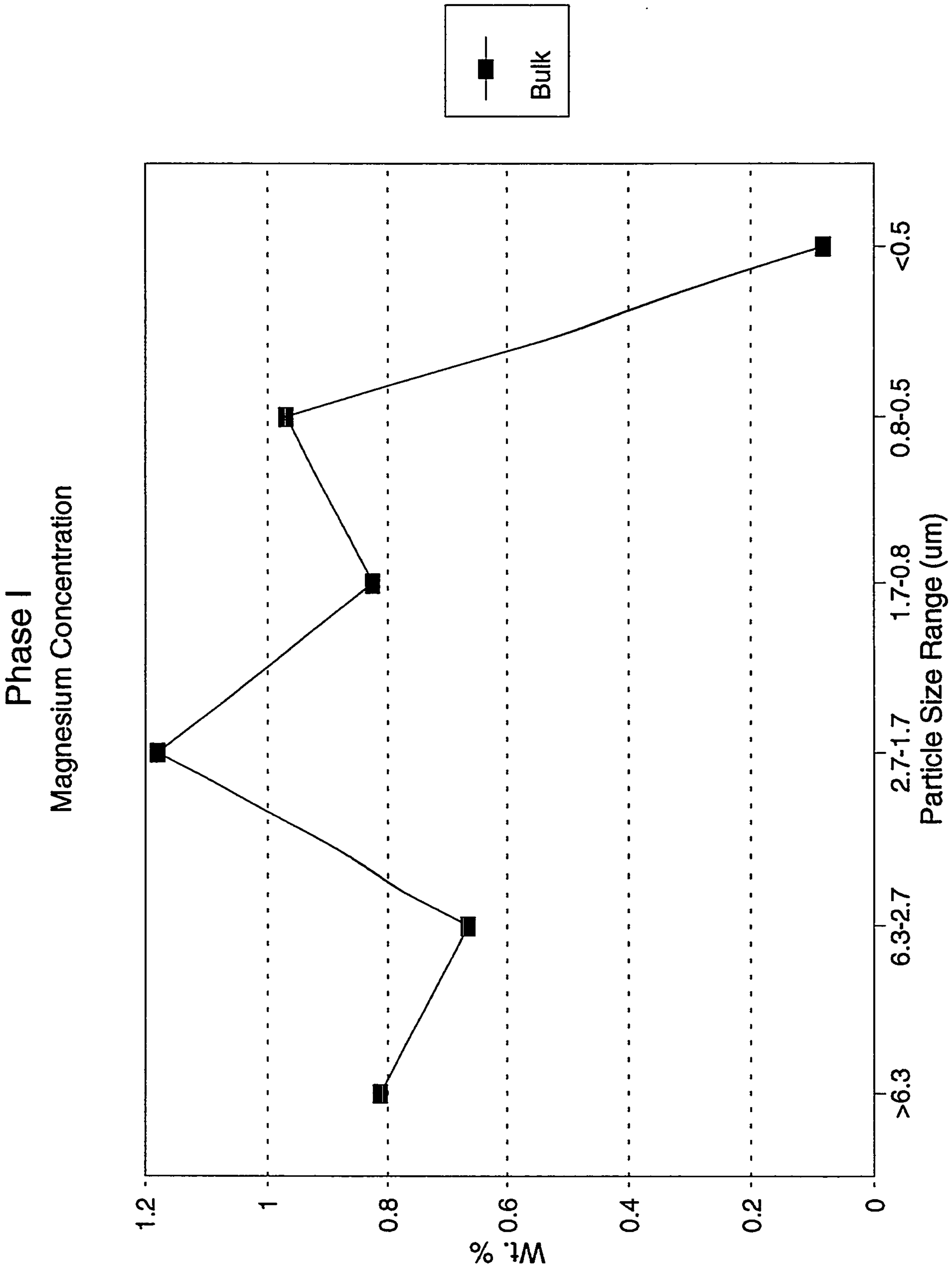



Phase I
Aluminum Concentration
Wt. %
60
50
40
30
20
10
0
>6.3
6.3-2.7
2.7-1.7
1.7-0.8
0.8-0.5
<0.5
Particle Size Range (um)
Bulk

Phase I
Iron Concentration

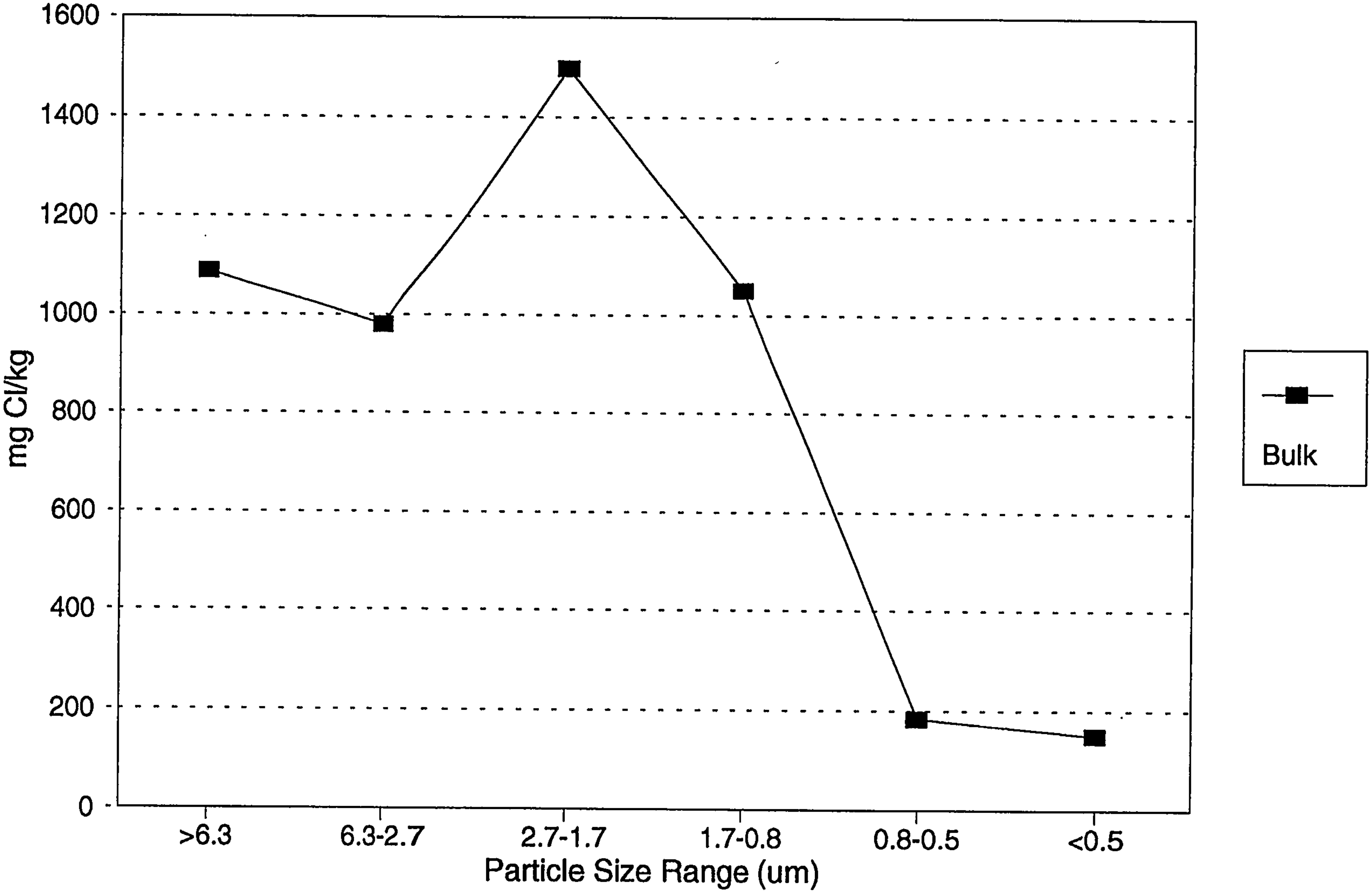



Phase I
Titanium Concentration
Wt. %
1.5
1.4
1.3
1.2
1.1
1
0.9
>6.3
6.3-2.7
2.7-1.7
1.7-0.8
0.8-0.5
<0.5
Particle Size Range (um)
Bulk


Phase I
Magnesium Concentration
Wt. %
1.2
1
0.8
0.6
0.4
0.2
0
>6.3
6.3-2.7
2.7-1.7
1.7-0.8
0.8-0.5
<0.5
Particle Size Range (um)
Bulk

Phase I

Chloride Concentration



APPENDIX B: PHASE II QC RESULTS

Table B-1. Quality Control Sample Results - INAA/GDMS

Sample	Element	Analysis	Data Quality Objective Bias (%Recovery)	Data Quality Objective Precision (%RSD)	Bias Measurements SRM (%Recovery)	Bias Measurements SRM Certification	Precision Measurement Replicate Analysis (%RSD)
Brammer (IRNT 12-1-02)	Aluminum	GDMS	75 - 125	20	96	C	5.3
	Aluminum	INAA	75 - 125	20	105	C	4.0
	Antimony	GDMS	75 - 125	20	ND Q	I	NA
	Antimony	INAA	75 - 125	20	108	I	8.9
	Arsenic	GDMS	75 - 125	20	75	C	18.6
	Arsenic	INAA	75 - 125	20	111	C	6.8
	Barium	GDMS	75 - 125	20	88	C	12.9
	Barium	INAA	75 - 125	20	119	C	6.1
	Beryllium	GDMS	75 - 125	20	ND Q	I	NA
	Cadmium	GDMS	75 - 125	20	ND Q	I	NA
	Cadmium	INAA	75 - 125	20	3214 Q	I	6.8
	Calcium	GDMS	75 - 125	20	58 Q	C	86.5 Q
	Calcium	INAA	75 - 125	20	233 Q	I	6.4
	Chlorine	GDMS	75 - 125	20	621 Q	NC	94.5 Q
	Chlorine	INAA	75 - 125	20	1789 Q	NC	6.7
	Chromium	GDMS	75 - 125	20	80	C	3.9
	Chromium	INAA	75 - 125	20	108	C	0.5
	Cobalt	GDMS	75 - 125	20	68 Q	C	14.4
	Cobalt	INAA	75 - 125	20	110	C	1.6
	Copper	GDMS	75 - 125	20	51 Q	C	50.9 Q
	Copper	INAA	75 - 125	20	147 Q	C	44.0 Q
	Fluorine	GDMS	75 - 125	20	ND Q	NC	NA
	Iron	GDMS	75 - 125	20	101	C	12.7
	Iron	INAA	75 - 125	20	106	C	0.3
	Lead	GDMS	75 - 125	20	93	C	13.7
	Magnesium	GDMS	75 - 125	20	92	C	1.7
	Magnesium	INAA	75 - 125	20	81	I	10.6
	Manganese	GDMS	75 - 125	20	104	C	10.8
	Manganese	INAA	75 - 125	20	101	C	6.5
	Mercury	GDMS	75 - 125	20	ND Q	NC	NA
	Mercury	INAA	75 - 125	20	34648 Q	NC	28.9 Q
	Molybdenum	GDMS	75 - 125	20	174 Q	NC	8.6
	Molybdenum	INAA	75 - 125	20	1207 Q	NC	64.4 Q
	Nickel	GDMS	75 - 125	20	85	I	5.4

Table B-1. (Continued)

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RSD)	SRM (%Recovery)	SRM Certification	Replicate Analysis (%RSD)
Brammer (IRNT 12-1-02)	Nickel	INAA	75 - 125	20	237 Q	I	80.5 Q
	Phosphorus	GDMS	75 - 125	20	97	NC	4.6
	Potassium	GDMS	75 - 125	20	96	C	46.0 Q
	Potassium	INAA	75 - 125	20	194 Q	C	6.4
	Selenium	GDMS	75 - 125	20	147 Q	NC	27.6 Q
	Selenium	INAA	75 - 125	20	191 Q	NC	0.9
	Silicon	GDMS	75 - 125	20	116	C	3.7
	Sodium	GDMS	75 - 125	20	99	C	56.8 Q
	Sodium	INAA	75 - 125	20	94	I	0.7
	Strontium	GDMS	75 - 125	20	121	I	12.0
	Strontium	INAA	75 - 125	20	67 Q	I	29.7 Q
	Titanium	GDMS	75 - 125	20	77	C	14.3
	Titanium	INAA	75 - 125	20	104	C	2.9
	Vanadium	GDMS	75 - 125	20	78	C	11.6
	Vanadium	INAA	75 - 125	20	105	C	4.7
	Zinc	GDMS	75 - 125	20	33 Q	C	71.0 Q
	Zinc	INAA	75 - 125	20	174 Q	C	48.0 Q
NIST 1633a	Aluminum	GDMS	75 - 125	20	94	C	6.0
	Aluminum	ICP	75 - 125	20	83	C	2.4
	Aluminum	INAA	75 - 125	20	87	C	3.9
	Antimony	GDMS	75 - 125	20	ND Q	C	NA
	Antimony	INAA	75 - 125	20	92	C	7.9
	Arsenic	GDMS	75 - 125	20	103	C	20.0
	Arsenic	INAA	75 - 125	20	86	C	3.9
	Barium	GDMS	75 - 125	20	96	NC	48.2 Q
	Barium	ICP	75 - 125	20	79	NC	1.3
	Barium	INAA	75 - 125	20	82	I	5.5
	Beryllium	GDMS	75 - 125	20	ND Q	NC	NA
	Beryllium	ICP	75 - 125	20	105	NC	0.0
	Cadmium	GDMS	75 - 125	20	ND Q	C	NA
	Cadmium	INAA	75 - 125	20	6646 Q	C	13.3
	Calcium	GDMS	75 - 125	20	90	C	0.0
	Calcium	ICP	75 - 125	20	84	C	1.2
	Calcium	INAA	75 - 125	20	85	C	0.7

Table B-1. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RSD)	SRM (%Recovery)	SRM Certification	Replicate Analysis (%RSD)
NIST 1633a	Chromium	GDMS	75 - 125	20	75	C	3.9
	Chromium	ICP	75 - 125	20	95	C	0.0
	Chromium	INAA	75 - 125	20	86	C	5.0
	Cobalt	GDMS	75 - 125	20	59 Q	NC	4.2
	Cobalt	ICP	75 - 125	20	81	I	15.0
	Cobalt	INAA	75 - 125	20	80	I	2.5
	Copper	GDMS	75 - 125	20	59 Q	C	4.4
	Copper	ICP	75 - 125	20	87	C	2.3
	Copper	INAA	75 - 125	20	282 Q	C	13.3
	Iron	GDMS	75 - 125	20	99	C	11.5
	Iron	ICP	75 - 125	20	92	C	1.1
	Iron	INAA	75 - 125	20	84	C	2.4
	Lead	GDMS	75 - 125	20	115	C	18.3
	Lead	GFAA	75 - 125	20	97	C	1.0
	Magnesium	GDMS	75 - 125	20	78	C	3.5
	Magnesium	ICP	75 - 125	20	69 Q	C	5.8
	Magnesium	INAA	75 - 125	20	88	C	6.5
	Manganese	GDMS	75 - 125	20	89	C	28.6 Q
	Manganese	ICP	75 - 125	20	88	C	1.1
	Manganese	INAA	75 - 125	20	87	C	0.7
	Mercury	GDMS	75 - 125	20	ND Q	C	NA
	Mercury	INAA	75 - 125	20	3116 Q	C	13.3
	Molybdenum	GDMS	75 - 125	20	123	NC	15.4
	Molybdenum	INAA	75 - 125	20	90	I	2.7
	Nickel	GDMS	75 - 125	20	87	C	0.0
	Nickel	ICP	75 - 125	20	106	C	16.0
	Nickel	INAA	75 - 125	20	90	C	5.6
	Potassium	GDMS	75 - 125	20	115	C	15.4
	Potassium	ICP	75 - 125	20	90	C	5.6
	Potassium	INAA	75 - 125	20	85	C	6.3
	Selenium	GDMS	75 - 125	20	153 Q	C	40.7 Q
	Selenium	INAA	75 - 125	20	87	C	1.3
	Silicon	GDMS	75 - 125	20	107	C	4.8
	Sodium	GDMS	75 - 125	20	191 Q	C	12.6

Table B-1. (Continued)

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RSD)	SRM (%Recovery)	SRM Certification	Replicate Analysis (%RSD)
NIST 1633a	Sodium	ICP	75 - 125	20	94	C	1.1
	Sodium	INAA	75 - 125	20	87	C	8.1
	Strontium	GDMS	75 - 125	20	82	C	14.0
	Strontium	ICP	75 - 125	20	83	C	1.2
	Strontium	INAA	75 - 125	20	88	C	5.2
	Titanium	GDMS	75 - 125	20	86	NC	11.0
	Titanium	ICP	75 - 125	20	101	NC	1.0
	Titanium	INAA	75 - 125	20	90	I	1.6
	Vanadium	GDMS	75 - 125	20	72 Q	C	9.8
	Vanadium	ICP	75 - 125	20	99	C	1.0
	Vanadium	INAA	75 - 125	20	87	C	7.2
	Zinc	GDMS	75 - 125	20	56 Q	C	4.7
	Zinc	ICP	75 - 125	20	91	C	1.1
	Zinc	INAA	75 - 125	20	87	C	5.5

INAA = Instrumental Neutron Activation Analysis.
GDMS = Glow Discharge Mass Spectrometry.
SRM = Standard Reference Material.
RSD = Relative Standard Deviation.
C = SRM value certified.
Q = Value exceeds data quality objective.
I = SRM value is informational only (not fully certified).
NC = SRM value is not certified and not recommended as a standard.

Table B-2. Quality Control Sample Results - Nitric Acid Digestates

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Blank (Pre-digestion spike)	Aluminum	ICP	75 - 125	20	NS		
	Antimony	ICP	75 - 125	20	NS		
	Antimony	ICP/MS	75 - 125	20	NS		
	Arsenic	GFAA	75 - 125	20	108		
	Arsenic	ICP/MS	75 - 125	20	85		
	Barium	ICP	75 - 125	20	87		
	Barium	ICP/MS	75 - 125	20	81		
	Beryllium	ICP	75 - 125	20	93		
	Beryllium	ICP/MS	75 - 125	20	72 Q		
	Cadmium	ICP/MS	75 - 125	20	91		
	Calcium	ICP	75 - 125	20	NS		
	Chromium	ICP	75 - 125	20	134 Q		
	Chromium	ICP/MS	75 - 125	20	95		
	Cobalt	ICP	75 - 125	20	76		
	Cobalt	ICP/MS	75 - 125	20	81		
	Copper	ICP	75 - 125	20	124		
	Copper	ICP/MS	75 - 125	20	122		
	Iron	ICP	75 - 125	20	NS		
	Lead	ICP/MS	75 - 125	20	231 Q		
	Magnesium	ICP	75 - 125	20	NS		
	Manganese	ICP	75 - 125	20	81		
	Manganese	ICP/MS	75 - 125	20	72 Q		
	Mercury	CVAA	75 - 125	20	NS		
	Mercury	ICP/MS	75 - 125	20	NS		
	Molybdenum	ICP	75 - 125	20	NS		
	Molybdenum	ICP/MS	75 - 125	20	NS		
	Nickel	ICP	75 - 125	20	196 Q		
	Nickel	ICP/MS	75 - 125	20	213 Q		
	Phosphorus	ICP	75 - 125	20	NS		
	Potassium	ICP	75 - 125	20	NS		
	Selenium	GFAA	75 - 125	20	120		
	Selenium	ICP/MS	75 - 125	20	94		
	Sodium	ICP	75 - 125	20	NS		
	Titanium	ICP	75 - 125	20	NS		

Table B-2. (Continued)

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Blank (Pre-digestion spike)	Vanadium	ICP	75 - 125	20	72 Q		
	Vanadium	ICP/MS	75 - 125	20	70 Q		
	Zinc	ICP	75 - 125	20	NS		
Blank (Post-digestion spike)	Antimony	ICP/MS	75 - 125	20	NS		
	Arsenic	ICP/MS	75 - 125	20	88		
	Barium	ICP/MS	75 - 125	20	81		
	Beryllium	ICP/MS	75 - 125	20	79		
	Cadmium	ICP/MS	75 - 125	20	92		
	Chromium	ICP/MS	75 - 125	20	71 Q		
	Cobalt	ICP/MS	75 - 125	20	85		
	Copper	ICP/MS	75 - 125	20	89		
	Lead	ICP/MS	75 - 125	20	94		
	Manganese	ICP/MS	75 - 125	20	78		
	Mercury	ICP/MS	75 - 125	20	90		
	Molybdenum	ICP/MS	75 - 125	20	NS		
	Nickel	ICP/MS	75 - 125	20	89		
	Selenium	ICP/MS	75 - 125	20	79		
	Vanadium	ICP/MS	75 - 125	20	74 Q		
Stage 1 - High Load	Antimony	ICP/MS	75 - 125	20	NS		2.3
	Arsenic	ICP/MS	75 - 125	20	80		1.7
	Barium	ICP/MS	75 - 125	20	87		0.4
	Beryllium	ICP/MS	75 - 125	20	77		32.4 Q
	Cadmium	ICP/MS	75 - 125	20	85		13.2
	Chromium	ICP/MS	75 - 125	20	70 Q		1.6
	Cobalt	ICP/MS	75 - 125	20	84		4.2
	Copper	ICP/MS	75 - 125	20	84		2.8
	Lead	ICP/MS	75 - 125	20	93		0.2
	Manganese	ICP/MS	75 - 125	20	78		1.2
	Mercury	ICP/MS	75 - 125	20	141 Q		0.0
	Molybdenum	ICP/MS	75 - 125	20	NS		1.5
	Nickel	ICP/MS	75 - 125	20	81		2.4
	Selenium	ICP/MS	75 - 125	20	89		4.9
	Vanadium	ICP/MS	75 - 125	20	77		0.1
Stage 2 - High Load	Aluminum	ICP	75 - 125	20	87	89	2.3

Table B-2. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 2 - High Load	Antimony	ICP	75 - 125	20	84	87	3.5
	Antimony	ICP/MS	75 - 125	20	NS		1.1
	Arsenic	ICP/MS	75 - 125	20	104		3.1
	Barium	ICP	75 - 125	20	91	92	1.1
	Barium	ICP/MS	75 - 125	20	135 Q		2.8
	Beryllium	ICP	75 - 125	20	92	92	0
	Beryllium	ICP/MS	75 - 125	20	78		2.9
	Cadmium	ICP/MS	75 - 125	20	91		0.5
	Calcium	ICP	75 - 125	20	94	95	1.1
	Chromium	ICP	75 - 125	20	90	92	2.2
	Chromium	ICP/MS	75 - 125	20	98		6.4
	Cobalt	ICP	75 - 125	20	90	90	0
	Cobalt	ICP/MS	75 - 125	20	87		4.2
	Copper	ICP	75 - 125	20	91	92	1.1
	Copper	ICP/MS	75 - 125	20	88		1.5
	Iron	ICP	75 - 125	20	91	91	0
	Lead	ICP/MS	75 - 125	20	100		0.3
	Magnesium	ICP	75 - 125	20	89	90	1.1
	Manganese	ICP	75 - 125	20	90	90	0
	Manganese	ICP/MS	75 - 125	20	86		0.2
	Mercury	CVAA	75 - 125	20	100	102	2.0
	Mercury	ICP/MS	75 - 125	20	101		0.0
	Molybdenum	ICP	75 - 125	20	85	85	0
	Molybdenum	ICP/MS	75 - 125	20	NS		3.5
	Nickel	ICP	75 - 125	20	92	94	2.2
	Nickel	ICP/MS	75 - 125	20	93		0.2
	Phosphorus	ICP	75 - 125	20	103	103	0
	Potassium	ICP	75 - 125	20	87	95	8.8
	Selenium	ICP/MS	75 - 125	20	84		1.5
	Sodium	ICP	75 - 125	20	89	89	0
	Titanium	ICP	75 - 125	20	89	89	0
	Vanadium	ICP	75 - 125	20	90	92	2.2
	Vanadium	ICP/MS	75 - 125	20	101		2.7
	Zinc	ICP	75 - 125	20	89	90	1.1

Table B-2. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 3 - High Load	Antimony	ICP/MS	75 - 125	20	NS		0.7
	Arsenic	ICP/MS	75 - 125	20	102		5.1
	Barium	ICP/MS	75 - 125	20	115		2.8
	Beryllium	ICP/MS	75 - 125	20	76		12.7
	Cadmium	ICP/MS	75 - 125	20	98		4.9
	Chromium	ICP/MS	75 - 125	20	98		7.8
	Cobalt	ICP/MS	75 - 125	20	81		5.6
	Copper	ICP/MS	75 - 125	20	86		4.8
	Lead	ICP/MS	75 - 125	20	95		3.6
	Manganese	ICP/MS	75 - 125	20	78		5.4
	Mercury	ICP/MS	75 - 125	20	127 Q		0.0
	Molybdenum	ICP/MS	75 - 125	20	NS		5.2
	Nickel	ICP/MS	75 - 125	20	79		8.2
	Selenium	ICP/MS	75 - 125	20	89		5.3
	Vanadium	ICP/MS	75 - 125	20	97		6.7
Stage 1 - Low Load	Antimony	ICP/MS	75 - 125	20	NS		8.4
	Arsenic	ICP/MS	75 - 125	20	92		1.0
	Barium	ICP/MS	75 - 125	20	109		2.9
	Beryllium	ICP/MS	75 - 125	20	83		28.6 Q
	Cadmium	ICP/MS	75 - 125	20	92		14.0
	Chromium	ICP/MS	75 - 125	20	277 Q		4.7
	Cobalt	ICP/MS	75 - 125	20	90		6.6
	Copper	ICP/MS	75 - 125	20	85		4.7
	Lead	ICP/MS	75 - 125	20	102		6.2
	Manganese	ICP/MS	75 - 125	20	90		4.2
	Mercury	ICP/MS	75 - 125	20	112		0.0
	Molybdenum	ICP/MS	75 - 125	20	NS		1.1
	Nickel	ICP/MS	75 - 125	20	165 Q		4.0
	Selenium	ICP/MS	75 - 125	20	81		8.4
	Vanadium	ICP/MS	75 - 125	20	88		3.6
Stage 3 - Low Load	Antimony	ICP/MS	75 - 125	20	NS		4.1
	Arsenic	ICP/MS	75 - 125	20	95		1.0
	Barium	ICP/MS	75 - 125	20	110		0.3
	Beryllium	ICP/MS	75 - 125	20	80		5.6

Table B-2. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 3 - Low Load	Cadmium	ICP/MS	75 - 125	20	85		1.4
	Chromium	ICP/MS	75 - 125	20	79		0.5
	Cobalt	ICP/MS	75 - 125	20	84		1.9
	Copper	ICP/MS	75 - 125	20	84		3.5
	Lead	ICP/MS	75 - 125	20	97		1.9
	Manganese	ICP/MS	75 - 125	20	84		1.4
	Mercury	ICP/MS	75 - 125	20	120		0.0
	Molybdenum	ICP/MS	75 - 125	20	NS		0.3
	Nickel	ICP/MS	75 - 125	20	86		0.4
	Selenium	ICP/MS	75 - 125	20	95		5.9
	Vanadium	ICP/MS	75 - 125	20	85		0.6
Stage 3 - FGD Inlet	Antimony	ICP/MS	75 - 125	20	NS		13.5
	Arsenic	ICP/MS	75 - 125	20	100		2.6
	Barium	ICP/MS	75 - 125	20	13 Q		1.0
	Beryllium	ICP/MS	75 - 125	20	95		5.6
	Cadmium	ICP/MS	75 - 125	20	92		2.4
	Chromium	ICP/MS	75 - 125	20	71 Q		0.7
	Cobalt	ICP/MS	75 - 125	20	97		2.4
	Copper	ICP/MS	75 - 125	20	93		1.6
Stage 3 - FGD Inlet	Lead	ICP/MS	75 - 125	20	84		1.5
	Manganese	ICP/MS	75 - 125	20	92		1.2
	Mercury	ICP/MS	75 - 125	20	92		0.0
	Mercury	CVAA	75 - 125	20	94	94	0.0
	Molybdenum	ICP/MS	75 - 125	20	NS		3.8
	Nickel	ICP/MS	75 - 125	20	88		2.3
	Selenium	ICP/MS	75 - 125	20	55 Q		18.9
	Vanadium	ICP/MS	75 - 125	20	89		0.6

MS = Matrix spike.
MSD = Matrix spike duplicate.
RPD = Relative percent difference.
ICP = Inductively coupled plasma emission spectrophotometry
NS = Not spiked
ICP/MS = Inductively coupled plasma mass spectrometry

GFAA = Graphite furnace atomic absorption spectrophotometry
Q = Value exceeds data quality objective.
CVAA = Cold vapor atomic absorption spectrophotometry

Table B-3. Quality Control Sample Results - Gastric Fluid Leachates

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Blank (Pre-digestion spike)	Aluminum	ICP	75 - 125	20	NS		
	Antimony	ICP	75 - 125	20	NS		
	Antimony	ICP/MS	75 - 125	20	NS		
	Arsenic	GFAA	75 - 125	20	100		
	Arsenic	ICP/MS	75 - 125	20	ND Q		
	Barium	ICP	75 - 125	20	93		
	Barium	ICP/MS	75 - 125	20	84		
	Beryllium	ICP	75 - 125	20	101		
	Beryllium	ICP/MS	75 - 125	20	74 Q		
	Cadmium	ICP/MS	75 - 125	20	104		
	Calcium	ICP	75 - 125	20	NS		
	Chromium	ICP	75 - 125	20	106		
	Chromium	ICP/MS	75 - 125	20	8 Q		
	Cobalt	ICP	75 - 125	20	84		
	Cobalt	ICP/MS	75 - 125	20	77		
	Copper	ICP	75 - 125	20	103		
	Copper	ICP/MS	75 - 125	20	60 Q		
	Iron	ICP	75 - 125	20	NS		
	Lead	ICP/MS	75 - 125	20	120		
	Magnesium	ICP	75 - 125	20	77		
	Manganese	ICP	75 - 125	20	92		
	Manganese	ICP/MS	75 - 125	20	21 Q		
	Mercury	CVAA	75 - 125	20	246 Q		
	Mercury	ICP/MS	75 - 125	20	190 Q		
	Molybdenum	ICP	75 - 125	20	NS		
	Molybdenum	ICP/MS	75 - 125	20	NS		
	Nickel	ICP	75 - 125	20	74 Q		
	Nickel	ICP/MS	75 - 125	20	64 Q		
	Phosphorus	ICP	75 - 125	20	NS		
	Potassium	ICP	75 - 125	20	NS		
	Selenium	GFAA	75 - 125	20	105		
	Selenium	ICP/MS	75 - 125	20	45 Q		
	Titanium	ICP	75 - 125	20	NS		
	Vanadium	ICP	75 - 125	20	84		

Table B-3. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Blank (Pre-digestion spike)	Vanadium	ICP/MS	75 - 125	20	ND Q		
	Zinc	ICP	75 - 125	20	NS		
Blank (Post-digestion spike)	Antimony	ICP/MS	75 - 125	20	NS		
	Arsenic	ICP/MS	75 - 125	20	39		
	Barium	ICP/MS	75 - 125	20	106		
	Beryllium	ICP/MS	75 - 125	20	79		
	Cadmium	ICP/MS	75 - 125	20	106		
	Chromium	ICP/MS	75 - 125	20	74		
	Cobalt	ICP/MS	75 - 125	20	79		
	Copper	ICP/MS	75 - 125	20	81		
	Lead	ICP/MS	75 - 125	20	115		
	Manganese	ICP/MS	75 - 125	20	67		
	Mercury	ICP/MS	75 - 125	20	158		
	Molybdenum	ICP/MS	75 - 125	20	NS		
	Nickel	ICP/MS	75 - 125	20	79		
	Selenium	ICP/MS	75 - 125	20	74		
	Vanadium	ICP/MS	75 - 125	20	ND		
Stage 1 - High Load	Antimony	ICP/MS	75 - 125	20	NS		6.4
	Arsenic	ICP/MS	75 - 125	20	89		58.5 Q
	Barium	ICP/MS	75 - 125	20	96		0.6
	Beryllium	ICP/MS	75 - 125	20	71 Q		42.7 Q
	Cadmium	ICP/MS	75 - 125	20	100		7.2
	Chromium	ICP/MS	75 - 125	20	84		19.3
	Cobalt	ICP/MS	75 - 125	20	72 Q		15.8
	Copper	ICP/MS	75 - 125	20	78		9.1
	Lead	ICP/MS	75 - 125	20	103		4.8
	Manganese	ICP/MS	75 - 125	20	74 Q		12.2
	Mercury	ICP/MS	75 - 125	20	101		72.9 Q
	Molybdenum	ICP/MS	75 - 125	20	NS Q		11.4
	Nickel	ICP/MS	75 - 125	20	78		2.1
	Selenium	ICP/MS	75 - 125	20	79		16.0
	Vanadium	ICP/MS	75 - 125	20	ND Q		0.0
Stage 2 - High Load	Antimony	ICP/MS	75 - 125	20	NS		0.0
	Arsenic	ICP/MS	75 - 125	20	80		17.7

Table B-3. (Continued)

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 2 - High Load	Barium	ICP/MS	75 - 125	20	99		12.1
	Beryllium	ICP/MS	75 - 125	20	76		37.2 Q
	Cadmium	ICP/MS	75 - 125	20	100		11.5
	Chromium	ICP/MS	75 - 125	20	85		27.9 Q
	Cobalt	ICP/MS	75 - 125	20	77		3.9
	Copper	ICP/MS	75 - 125	20	84		7.8
	Lead	ICP/MS	75 - 125	20	102		5.5
	Manganese	ICP/MS	75 - 125	20	75		7.9
	Mercury	ICP/MS	75 - 125	20	99		77.9 Q
	Molybdenum	ICP/MS	75 - 125	20	NS		1.8
	Nickel	ICP/MS	75 - 125	20	76		7.0
	Selenium	ICP/MS	75 - 125	20	83		12.4
	Vanadium	ICP/MS	75 - 125	20	13 Q		0.0
Stage 3 - High Load	Antimony	ICP/MS	75 - 125	20	NS		10.6
	Arsenic	ICP/MS	75 - 125	20	89		31.7 Q
	Barium	ICP/MS	75 - 125	20	96		1.9
	Beryllium	ICP/MS	75 - 125	20	74 Q		44.3 Q
	Cadmium	ICP/MS	75 - 125	20	96		5.4
	Chromium	ICP/MS	75 - 125	20	86		0.5
	Cobalt	ICP/MS	75 - 125	20	72 Q		27.8 Q
	Copper	ICP/MS	75 - 125	20	77		8.4
	Lead	ICP/MS	75 - 125	20	102		3.6
	Manganese	ICP/MS	75 - 125	20	71 Q		29.8 Q
	Mercury	ICP/MS	75 - 125	20	108		66.7 Q
	Mercury	CVAA	75 - 125	20	87	90	3.4
	Molybdenum	ICP/MS	75 - 125	20	NS		16.8
	Nickel	ICP/MS	75 - 125	20	76		14.5
	Selenium	ICP/MS	75 - 125	20	79		1.3
	Vanadium	ICP/MS	75 - 125	20	60 Q		0.0
Stage 1 - Low Load	Antimony	ICP/MS	75 - 125	20	NS		12.0
	Arsenic	ICP/MS	75 - 125	20	59 Q		194.4 Q
	Barium	ICP/MS	75 - 125	20	91		1.1
	Beryllium	ICP/MS	75 - 125	20	72 Q		83.3 Q
	Cadmium	ICP/MS	75 - 125	20	94		1.7

Table B-3. (Continued)

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 1 - Low Load	Chromium	ICP/MS	75 - 125	20	45 Q		31.8 Q
	Cobalt	ICP/MS	75 - 125	20	71 Q		20.6 Q
	Copper	ICP/MS	75 - 125	20	75		10.2
	Lead	ICP/MS	75 - 125	20	100		3.4
	Manganese	ICP/MS	75 - 125	20	72 Q		21.3 Q
	Mercury	ICP/MS	75 - 125	20	93		76.7 Q
	Molybdenum	ICP/MS	75 - 125	20	NS		24.5 Q
	Nickel	ICP/MS	75 - 125	20	121		14.0
	Selenium	ICP/MS	75 - 125	20	72 Q		1.3
	Vanadium	ICP/MS	75 - 125	20	ND Q		0.0
Stage 2 - Low Load	Antimony	ICP/MS	75 - 125	20	NS		13.7
	Arsenic	ICP/MS	75 - 125	20	84		70.3 Q
	Barium	ICP/MS	75 - 125	20	81		26.9 Q
	Beryllium	ICP/MS	75 - 125	20	74 Q		33.1 Q
	Cadmium	ICP/MS	75 - 125	20	98		5.5
	Chromium	ICP/MS	75 - 125	20	69 Q		8.0
	Cobalt	ICP/MS	75 - 125	20	72 Q		17.1
	Copper	ICP/MS	75 - 125	20	78		4.0
	Lead	ICP/MS	75 - 125	20	103		5.5
	Manganese	ICP/MS	75 - 125	20	73 Q		19.4
	Mercury	ICP/MS	75 - 125	20	89		150.2 Q
	Mercury	CVAA	75 - 125	20	100	90	10.0
	Molybdenum	ICP/MS	75 - 125	20	NS		14.2
	Nickel	ICP/MS	75 - 125	20	63 Q		12.5
	Selenium	ICP/MS	75 - 125	20	82		4.2
	Vanadium	ICP/MS	75 - 125	20	ND Q		0.0
Stage 3 - Low Load	Antimony	ICP/MS	75 - 125	20	NS		8.0
	Arsenic	ICP/MS	75 - 125	20	73 Q		17.1
	Barium	ICP/MS	75 - 125	20	100		23.6 Q
	Beryllium	ICP/MS	75 - 125	20	74 Q		68.3 Q
	Cadmium	ICP/MS	75 - 125	20	101		8.2
	Chromium	ICP/MS	75 - 125	20	70 Q		4.3
	Cobalt	ICP/MS	75 - 125	20	71 Q		29.8 Q
	Copper	ICP/MS	75 - 125	20	75		12.2

Table B-3. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 3 - Low Load	Lead	ICP/MS	75 - 125	20	108		13.2
	Manganese	ICP/MS	75 - 125	20	72 Q		47.9 Q
	Mercury	ICP/MS	75 - 125	20	108		79.1 Q
	Molybdenum	ICP/MS	75 - 125	20	NS		19.8
	Nickel	ICP/MS	75 - 125	20	69 Q		25.6 Q
	Selenium	ICP/MS	75 - 125	20	69 Q		4.9
	Vanadium	ICP/MS	75 - 125	20	16 Q		0.0
Stage 2 - FGD Inlet	Aluminum	ICP	75 - 125	20	85	85	0
	Antimony	ICP	75 - 125	20	89	92	3.3
	Barium	ICP	75 - 125	20	90	91	1.1
	Beryllium	ICP	75 - 125	20	96	95	1.0
	Calcium	ICP	75 - 125	20	94	93	1.1
	Chromium	ICP	75 - 125	20	92	92	0
	Cobalt	ICP	75 - 125	20	92	92	0
	Copper	ICP	75 - 125	20	94	94	0
	Iron	ICP	75 - 125	20	91	91	0
	Magnesium	ICP	75 - 125	20	91	89	2.2
	Manganese	ICP	75 - 125	20	93	92	1.1
	Molybdenum	ICP	75 - 125	20	88	86	2.3
	Nickel	ICP	75 - 125	20	95	94	1.1
	Phosphorus	ICP	75 - 125	20	106	107	0.94
	Potassium	ICP	75 - 125	20	92	86	6.7
	Titanium	ICP	75 - 125	20	89	89	0
	Vanadium	ICP	75 - 125	20	91	90	1.1
	Zinc	ICP	75 - 125	20	91	91	0
Stage 3 - FGD Inlet	Antimony	ICP/MS	75 - 125	20	NS		10.4
	Arsenic	ICP/MS	75 - 125	20	103		59.6 Q
	Barium	ICP/MS	75 - 125	20	127 Q		28.6 Q
	Beryllium	ICP/MS	75 - 125	20	73 Q		28.0 Q
	Cadmium	ICP/MS	75 - 125	20	101		6.5
	Chromium	ICP/MS	75 - 125	20	127 Q		8.8
	Cobalt	ICP/MS	75 - 125	20	78		18.3
	Copper	ICP/MS	75 - 125	20	82		4.3
	Lead	ICP/MS	75 - 125	20	116		6.5

Table B-3. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 3 - FGD Inlet	Manganese	ICP/MS	75 - 125	20	89		20.3 Q
	Mercury	ICP/MS	75 - 125	20	99		78.5 Q
	Molybdenum	ICP/MS	75 - 125	20	NS		12.9
	Nickel	ICP/MS	75 - 125	20	98		15.1
	Selenium	ICP/MS	75 - 125	20	83		8.7
	Vanadium	ICP/MS	75 - 125	20	ND Q		ND

MS = Matrix spike.
MSD = Matrix spike duplicate.
RPD = Relative percent difference.
ICP = Inductively coupled plasma emission spectrophotometry
NS = Not spiked
ND = Not detected
ICP/MS = Inductively coupled plasma mass spectrometry
GFAA = Graphite furnace atomic absorption spectrophotometry
Q = Value exceeds data quality objective.
CVAA = Cold vapor atomic absorption spectrophotometry

Table B-4. Quality Control Sample Results - Acetic Acid Leachates

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Blank (Pre-digestion spike)	Aluminum	ICP	75 - 125	20	NS		
	Antimony	ICP	75 - 125	20	NS		
	Antimony	ICP/MS	75 - 125	20	NS		
	Arsenic	GFAA	75 - 125	20	100		
	Arsenic	ICP/MS	75 - 125	20	104		
	Barium	ICP	75 - 125	20	93		
	Barium	ICP/MS	75 - 125	20	88		
	Beryllium	ICP	75 - 125	20	101		
	Beryllium	ICP/MS	75 - 125	20	114		
	Cadmium	ICP/MS	75 - 125	20	95		
	Calcium	ICP	75 - 125	20	NS		
	Chromium	ICP	75 - 125	20	106		
	Chromium	ICP/MS	75 - 125	20	74 Q		
	Cobalt	ICP	75 - 125	20	84		
	Cobalt	ICP/MS	75 - 125	20	95		
	Copper	ICP	75 - 125	20	103		
	Copper	ICP/MS	75 - 125	20	123		
	Iron	ICP	75 - 125	20	NS		
	Lead	ICP/MS	75 - 125	20	90		
	Magnesium	ICP	75 - 125	20	NS		
	Manganese	ICP	75 - 125	20	92		
	Manganese	ICP/MS	75 - 125	20	100		
	Mercury	CVAA	75 - 125	20	48 Q		
	Mercury	ICP/MS	75 - 125	20	51 Q		
	Molybdenum	ICP	75 - 125	20	NS		
	Molybdenum	ICP/MS	75 - 125	20	NS		
	Nickel	ICP	75 - 125	20	74 Q		
	Nickel	ICP/MS	75 - 125	20	22 Q		
	Phosphorus	ICP	75 - 125	20	NC		
	Potassium	ICP	75 - 125	20	NC		
	Selenium	GFAA	75 - 125	20	93		
	Selenium	ICP/MS	75 - 125	20	70 Q		
	Sodium	ICP	75 - 125	20	NS		
	Titanium	ICP	75 - 125	20	NS		

Table B-4. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Blank (Pre-digestion spike)	Vanadium	ICP	75 - 125	20	84		
	Vanadium	ICP/MS	75 - 125	20	84		
	Zinc	ICP	75 - 125	20	NS		
Blank (Post-digestion spike)	Antimony	ICP/MS	75 - 125	20	NS		
	Arsenic	ICP/MS	75 - 125	20	108		
	Barium	ICP/MS	75 - 125	20	90		
	Beryllium	ICP/MS	75 - 125	20	115		
	Cadmium	ICP/MS	75 - 125	20	90		
	Chromium	ICP/MS	75 - 125	20	95		
	Cobalt	ICP/MS	75 - 125	20	96		
	Copper	ICP/MS	75 - 125	20	95		
	Lead	ICP/MS	75 - 125	20	87		
	Manganese	ICP/MS	75 - 125	20	97		
	Mercury	ICP/MS	75 - 125	20	66 Q		
	Molybdenum	ICP/MS	75 - 125	20	NS		
	Nickel	ICP/MS	75 - 125	20	102		
	Selenium	ICP/MS	75 - 125	20	97		
	Vanadium	ICP/MS	75 - 125	20	102		
Stage 1 - High Load	Antimony	ICP/MS	75 - 125	20	NS		8.4
	Arsenic	ICP/MS	75 - 125	20	166 Q		30.7 Q
	Barium	ICP/MS	75 - 125	20	127 Q		7.0
	Beryllium	ICP/MS	75 - 125	20	108		45.6 Q
	Cadmium	ICP/MS	75 - 125	20	107		22.6 Q
	Chromium	ICP/MS	75 - 125	20	128 Q		11.6
	Cobalt	ICP/MS	75 - 125	20	96		37.5 Q
	Copper	ICP/MS	75 - 125	20	102		22.0 Q
	Lead	ICP/MS	75 - 125	20	119		12.4
	Manganese	ICP/MS	75 - 125	20	105		34.5 Q
	Mercury	ICP/MS	75 - 125	20	70 Q		144.9 Q
	Molybdenum	ICP/MS	75 - 125	20	NS		0.3
	Nickel	ICP/MS	75 - 125	20	138 Q		37.1 Q
	Selenium	ICP/MS	75 - 125	20	118		27.9 Q
	Vanadium	ICP/MS	75 - 125	20	157 Q		11.4

Table B-4. (Continued)

			Data Quality Objective		Bias Measurements		Precision Measurement
Sample	Element	Analysis	Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 2 - High Load	Aluminum	ICP	75 - 125	20	91	87	4.5
	Antimony	ICP	75 - 125	20	88	90	2.2
	Antimony	ICP/MS	75 - 125	20	NS		60.6 Q
	Arsenic	ICP/MS	75 - 125	20	96		138.2 Q
	Barium	ICP	75 - 125	20	89	86	3.4
	Barium	ICP/MS	75 - 125	20	67 Q		1.4
	Beryllium	ICP/MS	75 - 125	20	88		49.8 Q
	Beryllium	ICP	75 - 125	20	92	89	3.3
	Cadmium	ICP/MS	75 - 125	20	47 Q		22.1 Q
	Calcium	ICP	75 - 125	20	92	87	5.6
	Chromium	ICP/MS	75 - 125	20	71 Q		1.1
	Chromium	ICP	75 - 125	20	92	88	4.4
	Cobalt	ICP/MS	75 - 125	20	77		43.3 Q
	Cobalt	ICP	75 - 125	20	89	87	2.3
	Copper	ICP/MS	75 - 125	20	75		40.7 Q
	Copper	ICP	75 - 125	20	92	89	3.3
	Iron	ICP	75 - 125	20	89	97	5.9
	Lead	ICP/MS	75 - 125	20	19 Q		21.8 Q
	Magnesium	ICP	75 - 125	20	89	86	3.4
	Manganese	ICP/MS	75 - 125	20	78		31.3 Q
	Manganese	ICP	75 - 125	20	89	86	3.4
	Mercury	ICP/MS	75 - 125	20	118		65.3 Q
	Molybdenum	ICP	75 - 125	20	85	84	1.2
	Molybdenum	ICP/MS	75 - 125	20	NS		71.5 Q
	Nickel	ICP	75 - 125	20	91	89	2.2
	Nickel	ICP/MS	75 - 125	20	70 Q		41.7 Q
	Phosphorus	ICP	75 - 125	20	113	114	0.9
	Potassium	ICP	75 - 125	20	91	89	2.2
	Selenium	ICP/MS	75 - 125	20	78		9.5
	Sodium	ICP	75 - 125	20	68 Q	34 Q	67.0 Q
	Titanium	ICP	75 - 125	20	91	87	4.5
	Vanadium	ICP	75 - 125	20	95	90	5.4
	Vanadium	ICP/MS	75 - 125	20	103		42.4 Q
	Zinc	ICP	75 - 125	20	90	87	3.4

Table B-4. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 3 - High Load	Antimony	ICP/MS	75 - 125	20	NS		6.2
	Arsenic	ICP/MS	75 - 125	20	97		26.2 Q
	Barium	ICP/MS	75 - 125	20	84		5.9
	Beryllium	ICP/MS	75 - 125	20	75		42.1 Q
	Cadmium	ICP/MS	75 - 125	20	80		19.4
	Chromium	ICP/MS	75 - 125	20	67 Q		9.3
	Cobalt	ICP/MS	75 - 125	20	68 Q		42.9 Q
	Copper	ICP/MS	75 - 125	20	63 Q		21.1 Q
	Lead	ICP/MS	75 - 125	20	98		121.6 Q
	Manganese	ICP/MS	75 - 125	20	70 Q		37.3 Q
	Mercury	ICP/MS	75 - 125	20	92		98.8 Q
	Mercury	CVAA	75 - 125	20	99	100	1.0
	Molybdenum	ICP/MS	75 - 125	20	NS		2.3
	Nickel	ICP/MS	75 - 125	20	53 Q		44.1 Q
	Selenium	ICP/MS	75 - 125	20	80		81.5 Q
	Vanadium	ICP/MS	75 - 125	20	86		3.7
Stage 1 - Low Load	Antimony	ICP/MS	75 - 125	20	NS		23.3 Q
	Arsenic	ICP/MS	75 - 125	20	80		21.7 Q
	Barium	ICP/MS	75 - 125	20	75		8.1
	Beryllium	ICP/MS	75 - 125	20	83		59.3 Q
	Cadmium	ICP/MS	75 - 125	20	82		10.5
	Chromium	ICP/MS	75 - 125	20	42 Q		10.2
	Cobalt	ICP/MS	75 - 125	20	72 Q		45.5 Q
	Copper	ICP/MS	75 - 125	20	70 Q		29.6 Q
	Lead	ICP/MS	75 - 125	20	97		15.2
	Manganese	ICP/MS	75 - 125	20	76		40.0 Q
	Mercury	ICP/MS	75 - 125	20	71 Q		81.3 Q
	Molybdenum	ICP/MS	75 - 125	20	NS		26.0 Q
	Nickel	ICP/MS	75 - 125	20	72 Q		2.0
	Selenium	ICP/MS	75 - 125	20	74 Q		94.7 Q
	Vanadium	ICP/MS	75 - 125	20	85		18.1
Stage 2 - Low Load	Antimony	ICP/MS	75 - 125	20	NS		9.5
	Arsenic	ICP/MS	75 - 125	20	113		32.8 Q
	Barium	ICP/MS	75 - 125	20	118		7.2

Table B-4. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 2 - Low Load	Beryllium	ICP/MS	75 - 125	20	90		29.4 Q
	Cadmium	ICP/MS	75 - 125	20	94		20.2
	Chromium	ICP/MS	75 - 125	20	162 Q		8.5
	Cobalt	ICP/MS	75 - 125	20	81		38.2 Q
	Copper	ICP/MS	75 - 125	20	84		23.8 Q
	Lead	ICP/MS	75 - 125	20	110		6.9
	Manganese	ICP/MS	75 - 125	20	93		37.1 Q
	Mercury	ICP/MS	75 - 125	20	88		200.0 Q
	Molybdenum	ICP/MS	75 - 125	20	NS		23.5 Q
	Nickel	ICP/MS	75 - 125	20	172 Q		34.0 Q
	Selenium	ICP/MS	75 - 125	20	104		41.9 Q
	Vanadium	ICP/MS	75 - 125	20	120		2.6
Stage 3 - Low Load	Antimony	ICP/MS	75 - 125	20	NS		7.3
	Arsenic	ICP/MS	75 - 125	20	125		36.7 Q
	Barium	ICP/MS	75 - 125	20	85		0.3
	Beryllium	ICP/MS	75 - 125	20	85		34.3 Q
	Cadmium	ICP/MS	75 - 125	20	84		15.4
	Chromium	ICP/MS	75 - 125	20	82		16.0
	Cobalt	ICP/MS	75 - 125	20	74 Q		34.6 Q
	Copper	ICP/MS	75 - 125	20	78		14.0
	Lead	ICP/MS	75 - 125	20	92		24.0 Q
	Manganese	ICP/MS	75 - 125	20	78		26.9 Q
	Mercury	ICP/MS	75 - 125	20	81		158.5 Q
	Molybdenum	ICP/MS	75 - 125	20	NS		1.6
	Nickel	ICP/MS	75 - 125	20	88		30.3 Q
	Selenium	ICP/MS	75 - 125	20	99		12.0
	Vanadium	ICP/MS	75 - 125	20	104		10.7
Stage 3 - FGD Inlet	Antimony	ICP/MS	75 - 125	20	NS		8.2
	Arsenic	ICP/MS	75 - 125	20	81		64.1 Q
	Barium	ICP/MS	75 - 125	20	75		2.7
	Beryllium	ICP/MS	75 - 125	20	83		44.7 Q
	Cadmium	ICP/MS	75 - 125	20	84		8.1
	Chromium	ICP/MS	75 - 125	20	78		12.9
	Cobalt	ICP/MS	75 - 125	20	73 Q		31.1 Q

Table B-4. (Continued)

Sample	Element	Analysis	Data Quality Objective		Bias Measurements		Precision Measurement
			Bias (%Recovery)	Precision (%RPD)	MS (%Recovery)	MSD (%Recovery)	Duplicate Analysis (%RPD)
Stage 3 - FGD Inlet	Copper	ICP/MS	75 - 125	20	79		8.4
	Lead	ICP/MS	75 - 125	20	91		179.3 Q
	Manganese	ICP/MS	75 - 125	20	74 Q		28.7 Q
	Mercury	ICP/MS	75 - 125	20	114		168.9 Q
	Mercury	CVAA	75 - 125	20	100	104	3.9
	Molybdenum	ICP/MS	75 - 125	20	NS		2.0
	Nickel	ICP/MS	75 - 125	20	73 Q		30.9 Q
	Selenium	ICP/MS	75 - 125	20	54 Q		95.0 Q
	Vanadium	ICP/MS	75 - 125	20	73 Q		188.9 Q

MS = Matrix spike.
MSD = Matrix spike duplicate.
RPD = Relative percent difference.
ICP = Inductively coupled plasma emission spectrophotometry
NS = Not spiked
ICP/MS = Inductively coupled plasma mass spectrometry
GFAA = Graphite furnace atomic absorption spectrophotometry
Q = Value exceeds data quality objective.
CVAA = Cold vapor atomic absorption spectrophotometry

APPENDIX C: PHASE II ANALYTICAL RESULTS

Table C-1. FGD Inlet - Bulk Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	INAA	Y	143,228					143,228			
> 6.4 um	Aluminum	ICP	N	137,000					137,000			
> 6.4 um	Antimony	INAA	Y	7.57					7.57			
> 6.4 um	Antimony	ICP	N	< 54.8					< 54.8			
> 6.4 um	Arsenic	INAA	Y	72.9					72.9			
> 6.4 um	Barium	INAA	Y	1,733					1,733			
> 6.4 um	Barium	ICP	N	1,450					1,450			
> 6.4 um	Beryllium	ICP	Y	18.80					18.80			
> 6.4 um	Cadmium	INAA	Y	73.7					73.7			
> 6.4 um	Calcium	INAA	N	13,800					13,800			
> 6.4 um	Calcium	ICP	Y	13,200					13,200			
> 6.4 um	Chlorine	INAA	Y	1,801					1,801			
> 6.4 um	Chromium	INAA	Y	197					197			
> 6.4 um	Chromium	ICP	N	188					188			
> 6.4 um	Cobalt	INAA	Y	67.5					67.5			
> 6.4 um	Cobalt	ICP	N	60.2					60.2			
> 6.4 um	Copper	INAA	N	< 321					< 321			
> 6.4 um	Copper	ICP	Y	207					207			
> 6.4 um	Iron	INAA	Y	60,228					60,228			
> 6.4 um	Iron	ICP	N	55,900					55,900			
> 6.4 um	Lead	ICP	Y	117					117			
> 6.4 um	Magnesium	INAA	Y	3,895					3,895			
> 6.4 um	Magnesium	ICP	N	4,910					4,910			
> 6.4 um	Manganese	INAA	Y	174					174			
> 6.4 um	Manganese	ICP	N	171					171			
> 6.4 um	Mercury	INAA	N	< 4.81					< 4.81			
> 6.4 um	Mercury	CVAA	Y	0.225					0.225			
> 6.4 um	Molybdenum	INAA	Y	48.7					48.7			
> 6.4 um	Molybdenum	ICP	N	27.2					27.2			
> 6.4 um	Nickel	INAA	N	< 321					< 321			
> 6.4 um	Nickel	ICP	Y	133					133			
> 6.4 um	Potassium	INAA	N	19,524					19,524			
> 6.4 um	Potassium	ICP	Y	19,000					19,000			
> 6.4 um	Selenium	INAA	Y	26.5					26.5			
> 6.4 um	Sodium	INAA	Y	2,491					2,491			
> 6.4 um	Sodium	ICP	N	2,730					2,730			

Table C-1. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Strontium	INAA	Y	324					324			
> 6.4 um	Strontium	ICP	N	1,240					1,240			
> 6.4 um	Titanium	INAA	Y	9,784					9,784			
> 6.4 um	Titanium	ICP	N	9,020					9,020			
> 6.4 um	Vanadium	INAA	Y	351					351			
> 6.4 um	Vanadium	ICP	N	364					364			
> 6.4 um	Zinc	INAA	Y	5,297					5,297			
> 6.4 um	Zinc	ICP	N	2,110					2,110			
6.4-0.8 um	Aluminum	INAA	Y	144,831					144,831			
6.4-0.8 um	Aluminum	ICP	N	130,000					130,000			
6.4-0.8 um	Antimony	INAA	Y	23.1					23.1			
6.4-0.8 um	Antimony	ICP	N	< 50.9					< 50.9			
6.4-0.8 um	Arsenic	INAA	Y	225					225			
6.4-0.8 um	Barium	INAA	Y	2,382					2,382			
6.4-0.8 um	Barium	ICP	N	1,710					1,710			
6.4-0.8 um	Beryllium	ICP	Y	28.4					28.4			
6.4-0.8 um	Cadmium	INAA	Y	112					112			
6.4-0.8 um	Calcium	INAA	N	13,007					13,007			
6.4-0.8 um	Calcium	ICP	Y	12,100					12,100			
6.4-0.8 um	Chlorine	INAA	Y	1,724					1,724			
6.4-0.8 um	Chromium	INAA	Y	405					405			
6.4-0.8 um	Chromium	ICP	N	399					399			
6.4-0.8 um	Cobalt	INAA	Y	121					121			
6.4-0.8 um	Cobalt	ICP	N	114					114			
6.4-0.8 um	Copper	INAA	N	606					606			
6.4-0.8 um	Copper	ICP	Y	391					391			
6.4-0.8 um	Iron	INAA	Y	57,782					57,782			
6.4-0.8 um	Iron	ICP	N	52,700					52,700			
6.4-0.8 um	Lead	ICP	Y	323					323			
6.4-0.8 um	Magnesium	INAA	Y	5,470					5,470			
6.4-0.8 um	Magnesium	ICP	N	4,720					4,720			
6.4-0.8 um	Manganese	INAA	Y	271					271			
6.4-0.8 um	Manganese	ICP	N	240					240			
6.4-0.8 um	Mercury	INAA	N	< 6.86					< 6.86			
6.4-0.8 um	Mercury	CVAA	Y	1.10					1.10			
6.4-0.8 um	Molybdenum	INAA	Y	126					126			

Table C-1. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Molybdenum	ICP	N	73.3					73.3			
6.4-0.8 um	Nickel	INAA	N	154					154			
6.4-0.8 um	Nickel	ICP	Y	320					320			
6.4-0.8 um	Potassium	INAA	N	18,072					18,072			
6.4-0.8 um	Potassium	ICP	Y	22,000					22,000			
6.4-0.8 um	Selenium	INAA	Y	51.94					51.94			
6.4-0.8 um	Sodium	INAA	Y	3,424					3,424			
6.4-0.8 um	Sodium	ICP	N	3,520					3,520			
6.4-0.8 um	Strontium	INAA	Y	477					477			
6.4-0.8 um	Strontium	ICP	N	1,070					1,070			
6.4-0.8 um	Titanium	INAA	Y	9,878					9,878			
6.4-0.8 um	Titanium	ICP	N	9,480					9,480			
6.4-0.8 um	Vanadium	INAA	Y	593					593			
6.4-0.8 um	Vanadium	ICP	N	620					620			
6.4-0.8 um	Zinc	INAA	Y	1,045					1,045			
6.4-0.8 um	Zinc	ICP	N	885					885			
< 0.8 um	Aluminum	INAA	Y	152,413					152,413			
< 0.8 um	Aluminum	ICP	N	122,000					122,000			
< 0.8 um	Antimony	INAA	Y	24.2					24.2			
< 0.8 um	Antimony	ICP	N	< 179					< 179			
< 0.8 um	Arsenic	INAA	Y	213					213			
< 0.8 um	Barium	INAA	Y	2,288					2,288			
< 0.8 um	Barium	ICP	N	1,610					1,610			
< 0.8 um	Beryllium	ICP	Y	29.5					29.5			
< 0.8 um	Cadmium	INAA	Y	137					137			
< 0.8 um	Calcium	INAA	N	14,003					14,003			
< 0.8 um	Calcium	ICP	Y	11,200					11,200			
< 0.8 um	Chlorine	INAA	Y	12,830					12,830			
< 0.8 um	Chromium	INAA	Y	953					953			
< 0.8 um	Chromium	ICP	N	975					975			
< 0.8 um	Cobalt	INAA	Y	131					131			
< 0.8 um	Cobalt	ICP	N	124					124			
< 0.8 um	Copper	INAA	N	733					733			
< 0.8 um	Copper	ICP	Y	323					323			
< 0.8 um	Iron	INAA	Y	62,980					62,980			
< 0.8 um	Iron	ICP	N	57,300					57,300			

Table C-1. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Lead	ICP	Y	318					318			
< 0.8 um	Magnesium	INAA	Y	5,083					5,083			
< 0.8 um	Magnesium	ICP	N	4,020					4,020			
< 0.8 um	Manganese	INAA	Y	309					309			
< 0.8 um	Manganese	ICP	N	300					300			
< 0.8 um	Mercury	INAA	N	< 7.67					< 7.67			
< 0.8 um	Mercury	CVAA	Y	1.10					1.10			
< 0.8 um	Molybdenum	INAA	Y	166					166			
< 0.8 um	Molybdenum	ICP	N	36.5					36.5			
< 0.8 um	Nickel	INAA	N	163					163			
< 0.8 um	Nickel	ICP	Y	350					350			
< 0.8 um	Potassium	INAA	N	21,353					21,353			
< 0.8 um	Potassium	ICP	Y	20,400					20,400			
< 0.8 um	Selenium	INAA	Y	57.9					57.9			
< 0.8 um	Sodium	INAA	Y	4,030					4,030			
< 0.8 um	Sodium	ICP	N	3,450					3,450			
< 0.8 um	Strontium	INAA	Y	543					543			
< 0.8 um	Strontium	ICP	N	1,030					1,030			
< 0.8 um	Titanium	INAA	Y	10,807					10,807			
< 0.8 um	Titanium	ICP	N	9,530					9,530			
< 0.8 um	Vanadium	INAA	Y	579					579			
< 0.8 um	Vanadium	ICP	N	614					614			
< 0.8 um	Zinc	INAA	Y	1,184					1,184			
< 0.8 um	Zinc	ICP	N	845					845			

Table C-2. High Load Stack Emissions - Bulk Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	INAA	Y	42,568	41,496				42,032	758	1.8	6,814
> 6.4 um	Aluminum	ICP	N	32,300					32,300			
> 6.4 um	Aluminum	GDMS	N	68,803	35,460	30,167			44,810	20,946	46.7	52,001
> 6.4 um	Antimony	INAA	Y	138	144				141	4	3.1	39
> 6.4 um	Antimony	ICP	N	< 107					< 107			
> 6.4 um	Antimony	GDMS	N	< 38.0	< 65.0	< 34.0			< 65.0	NA	NA	NA
> 6.4 um	Arsenic	INAA	Y	1,810	1,880				1,845	49	2.7	445
> 6.4 um	Arsenic	GDMS	N	2,000	2,000	1,600			1,867	231	12.4	573
> 6.4 um	Barium	INAA	Y	6,953	6,990				6,971	26	0.4	237
> 6.4 um	Barium	ICP	N	5,240					5,240			
> 6.4 um	Barium	GDMS	N	4,800	5,600	3,400			4,600	1,114	24.2	2,765
> 6.4 um	Beryllium	ICP	Y	16.8					16.8			
> 6.4 um	Beryllium	GDMS	N	< 0.012	< 0.029	< 0.004			< 0.029	NA	NA	NA
> 6.4 um	Cadmium	INAA	Y	271	270				270	1	0.4	9
> 6.4 um	Cadmium	GDMS	N	< 54.0	< 35.0	< 40.0			< 54.0	NA	NA	NA
> 6.4 um	Calcium	INAA	N	18,620	16,943				17,782	1,186	6.7	10,657
> 6.4 um	Calcium	ICP	Y	36,900					36,900			
> 6.4 um	Calcium	GDMS	N	44,311	38,594	20,726			34,544	12,303	35.6	30,544
> 6.4 um	Chlorine	INAA	Y	1,299	1,157				1,228	100	8.2	900
> 6.4 um	Chlorine	GDMS	N	1,400	1,900	1,500			1,600	265	16.5	657
> 6.4 um	Chromium	INAA	Y	4,548	4,137				4,343	291	6.7	2,611
> 6.4 um	Chromium	ICP	N	6,440					6,440			
> 6.4 um	Chromium	GDMS	N	1,200	1,600	9,800			4,200	4,854	115.6	12,050
> 6.4 um	Cobalt	INAA	Y	94.5	86.7				90.6	5.5	6.1	49.6
> 6.4 um	Cobalt	ICP	N	209					209			
> 6.4 um	Cobalt	GDMS	N	41.0	35.0	99.0			58.3	35.3	60.6	87.7
> 6.4 um	Copper	INAA	N	541	415				478	89	18.6	797
> 6.4 um	Copper	ICP	Y	439					439			
> 6.4 um	Copper	GDMS	N	220	270	360			283	71	25.0	176
> 6.4 um	Fluorine	GDMS	Y	< 37.0	< 31.0	< 58.0			< 58.0	NA	NA	NA
> 6.4 um	Iron	INAA	Y	85,765	85,785				85,775	14	0.0	130
> 6.4 um	Iron	ICP	N	93,400					93,400			
> 6.4 um	Iron	GDMS	N	76,938	37,769	65,047			59,918	20,082	33.5	49,855
> 6.4 um	Lead	ICP	Y	247					247			
> 6.4 um	Lead	GDMS	N	210	160	120			163	45	27.6	112
> 6.4 um	Magnesium	INAA	Y	2,103	1,854				1,979	176	8.9	1,586

Table C-2. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Magnesium	ICP	N	2,780					2,780			
> 6.4 um	Magnesium	GDMS	N	2,111	2,473	1,809			2,131	332	15.6	825
> 6.4 um	Manganese	INAA	N	600	589				595	8	1.4	74
> 6.4 um	Manganese	ICP	Y	697					697			
> 6.4 um	Manganese	GDMS	N	390	450	390			410	35	8.4	86
> 6.4 um	Mercury	INAA	N	< 7.48	< 7.23				< 7.48	NA	NA	NA
> 6.4 um	Mercury	GDMS	N	< 0.005	< 0.220	< 0.009			< 0.220	NA	NA	NA
> 6.4 um	Mercury	CVAA	Y	2.11					2.11			
> 6.4 um	Molybdenum	INAA	Y	539	535				537	3	0.6	29
> 6.4 um	Molybdenum	ICP	N	360					360			
> 6.4 um	Molybdenum	GDMS	N	420	530	460			470	56	11.8	138
> 6.4 um	Nickel	INAA	N	1,380	1,407				1,393	19	1.4	175
> 6.4 um	Nickel	ICP	Y	4,540					4,540			
> 6.4 um	Nickel	GDMS	N	1,600	1,500	6,100			3,067	2,627	85.7	6,523
> 6.4 um	Phosphorus	GDMS	Y	3,900	2,900	1,800			2,867	1,050	36.6	2,608
> 6.4 um	Potassium	INAA	N	9,306	8,645				8,975	468	5.2	4,204
> 6.4 um	Potassium	ICP	Y	5,140					5,140			
> 6.4 um	Potassium	GDMS	N	183	29	51			87	83	95.1	206
> 6.4 um	Selenium	INAA	Y	1,028	1,057				1,042	21	2.0	187
> 6.4 um	Selenium	GDMS	N	300	620	580			500	174	34.9	433
> 6.4 um	Silicon	GDMS	Y	88,813	93,488	74,790			85,697	9,731	11.4	24,157
> 6.4 um	Sodium	INAA	Y	1,526	1,474				1,500	37	2.4	329
> 6.4 um	Sodium	ICP	N	1,220					1,220			
> 6.4 um	Sodium	GDMS	N	453	14	47			171	244	142.7	606
> 6.4 um	Strontium	INAA	N	< 349	< 337				< 349	NA	NA	NA
> 6.4 um	Strontium	ICP	Y	549					549			
> 6.4 um	Strontium	GDMS	N	410	370	250			343	83	24.3	207
> 6.4 um	Titanium	INAA	Y	5,490	5,774				5,632	201	3.6	1,805
> 6.4 um	Titanium	ICP	N	2,970					2,970			
> 6.4 um	Titanium	GDMS	N	2,700	3,100	2,100			2,633	503	19.1	1,250
> 6.4 um	Vanadium	INAA	Y	2,120	2,073				2,096	33	1.6	294
> 6.4 um	Vanadium	ICP	N	1,600					1,600			
> 6.4 um	Vanadium	GDMS	N	1,200	1,500	990			1,230	256	20.8	636
> 6.4 um	Zinc	INAA	Y	1,042	1,137				1,090	67	6.2	605
> 6.4 um	Zinc	ICP	N	600					600			
> 6.4 um	Zinc	GDMS	N	510	540	480			510	30	5.9	74

Table C-2. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Aluminum	INAA	Y	55,571	56,177	57,236			56,328	842	1.5	2,091
6.4-0.8 um	Aluminum	ICP	N	43,500					43,500			
6.4-0.8 um	Aluminum	GDMS	N	52	43,399	100,558			48,003	50,411	105.0	125,150
6.4-0.8 um	Antimony	INAA	Y	172	156	152			160	11	6.7	26
6.4-0.8 um	Antimony	ICP	N	36.3 J					36.3			
6.4-0.8 um	Antimony	GDMS	N	78.0	< 25.0	< 49.0			< 49.0	NA	NA	NA
6.4-0.8 um	Arsenic	INAA	Y	2,307	2,213	2,176			2,232	68	3.0	168
6.4-0.8 um	Arsenic	GDMS	N	4,700	2,500	4,000			3,733	1,124	30.1	2,790
6.4-0.8 um	Barium	INAA	Y	8,899	8,322	7,895			8,372	504	6.0	1,251
6.4-0.8 um	Barium	ICP	N	6,020					6,020			
6.4-0.8 um	Barium	GDMS	N	11,000	4,000	12,000			9,000	4,359	48.4	10,821
6.4-0.8 um	Beryllium	ICP	Y	20.9					20.9			
6.4-0.8 um	Beryllium	GDMS	N	< 0.010	< 0.035	< 0.004			< 0.035	NA	NA	NA
6.4-0.8 um	Cadmium	INAA	Y	1,539	1,855	1,703			1,699	158	9.3	392
6.4-0.8 um	Cadmium	GDMS	N	1,100	330	610			680	390	57.3	968
6.4-0.8 um	Calcium	INAA	N	43,562	40,767	36,656			40,328	3,474	8.6	8,625
6.4-0.8 um	Calcium	ICP	Y	27,600					27,600			
6.4-0.8 um	Calcium	GDMS	N	34,306	192,969	27,159			84,811	93,736	110.5	232,709
6.4-0.8 um	Chlorine	INAA	Y	< 1,654	< 1,638	< 1,599			< 1,654	NA	NA	NA
6.4-0.8 um	Chlorine	GDMS	N	760	350	810			640	252	39.4	627
6.4-0.8 um	Chromium	INAA	Y	829	880	850			853	26	3.0	64
6.4-0.8 um	Chromium	ICP	N	536					536			
6.4-0.8 um	Chromium	GDMS	N	1,700	710	880			1,097	529	48.3	1,314
6.4-0.8 um	Cobalt	INAA	Y	57.7	58.6	56.8			57.7	0.9	1.6	2.2
6.4-0.8 um	Cobalt	ICP	N	40.8					40.8			
6.4-0.8 um	Cobalt	GDMS	N	91.0	41.0	65.0			65.7	25.0	38.1	62.1
6.4-0.8 um	Copper	INAA	N	< 551	< 546	< 533			< 551	NA	NA	NA
6.4-0.8 um	Copper	ICP	Y	252					252			
6.4-0.8 um	Copper	GDMS	N	870	120	220			403	407	101.0	1,011
6.4-0.8 um	Fluorine	GDMS	Y	< 68.0	< 47.0	< 86.0			< 86.0	NA	NA	NA
6.4-0.8 um	Iron	INAA	Y	40,797	42,118	41,482			41,466	661	1.6	1,640
6.4-0.8 um	Iron	ICP	N	33,600					33,600			
6.4-0.8 um	Iron	GDMS	N	90,926	23,081	49,660			54,556	34,186	62.7	84,872
6.4-0.8 um	Lead	ICP	Y	167					167			
6.4-0.8 um	Lead	GDMS	N	1,300	380	1,200			960	505	52.6	1,253
6.4-0.8 um	Magnesium	INAA	Y	2,941	3,091	3,216			3,082	138	4.5	342

Table C-2. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Magnesium	ICP	N	2,920					2,920			
6.4-0.8 um	Magnesium	GDMS	N	5,780	3,558	6,031			5,126	1,363	26.6	3,385
6.4-0.8 um	Manganese	INAA	N	235	266	281			261	23	8.9	58
6.4-0.8 um	Manganese	ICP	Y	219					219			
6.4-0.8 um	Manganese	GDMS	N	560	280	340			393	147	37.5	366
6.4-0.8 um	Mercury	INAA	N	< 8.27	< 8.19	< 8.00			< 8.27	NA	NA	NA
6.4-0.8 um	Mercury	GDMS	N	< 0.018	< 0.016	< 0.009			< 0.018	NA	NA	NA
6.4-0.8 um	Mercury	CVAA	Y	0.393					0.393			
6.4-0.8 um	Molybdenum	INAA	Y	524	549	531			535	13	2.4	32
6.4-0.8 um	Molybdenum	ICP	N	326					326			
6.4-0.8 um	Molybdenum	GDMS	N	1,100	430	740			757	335	44.3	832
6.4-0.8 um	Nickel	INAA	N	199	282	270			251	45	18.0	112
6.4-0.8 um	Nickel	ICP	Y	714					714			
6.4-0.8 um	Nickel	GDMS	N	1,400	380	790			857	513	59.9	1,274
6.4-0.8 um	Phosphorus	GDMS	Y	6,700	4,300	6,000			5,667	1,234	21.8	3,064
6.4-0.8 um	Potassium	INAA	N	10,303	11,941	< 7,463			8,658	4,345	50.2	10,787
6.4-0.8 um	Potassium	ICP	Y	7,080					7,080			
6.4-0.8 um	Potassium	GDMS	N	199	14,943	232			5,125	8,503	165.9	21,109
6.4-0.8 um	Selenium	INAA	Y	807	796	783			795	12	1.5	30
6.4-0.8 um	Selenium	GDMS	N	820	210	740			590	332	56.2	823
6.4-0.8 um	Silicon	GDMS	Y	182,301	102,837	149,581			144,906	39,938	27.6	99,150
6.4-0.8 um	Sodium	INAA	Y	2,105	2,093	1,875			2,024	130	6.4	322
6.4-0.8 um	Sodium	ICP	N	1,400					1,400			
6.4-0.8 um	Sodium	GDMS	N	82	10	274			122	137	112.3	340
6.4-0.8 um	Strontium	INAA	N	1,186	1,158	< 533			870	523	60.1	1,299
6.4-0.8 um	Strontium	ICP	Y	762					762			
6.4-0.8 um	Strontium	GDMS	N	1,200	500	990			897	359	40.1	892
6.4-0.8 um	Titanium	INAA	Y	6,888	7,436	6,544			6,956	450	6.5	1,117
6.4-0.8 um	Titanium	ICP	N	3,790					3,790			
6.4-0.8 um	Titanium	GDMS	N	7,400	3,100	5,900			5,467	2,183	39.9	5,418
6.4-0.8 um	Vanadium	INAA	Y	2,484	2,558	2,531			2,524	38	1.5	93
6.4-0.8 um	Vanadium	ICP	N	2,110					2,110			
6.4-0.8 um	Vanadium	GDMS	N	3,100	1,600	2,500			2,400	755	31.5	1,874
6.4-0.8 um	Zinc	INAA	Y	1,029	1,000	1,007			1,012	15	1.5	37
6.4-0.8 um	Zinc	ICP	N	688					688			
6.4-0.8 um	Zinc	GDMS	N	1,700	840	1,100			1,213	441	36.4	1,095

Table C-2. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Aluminum	INAA	Y	28,933	29,185	27,475			28,531	923	3.2	2,292
< 0.8 um	Aluminum	ICP	N	27,800					27,800			
< 0.8 um	Aluminum	GDMS	N	34	174,653	121,728			98,805	89,538	90.6	222,286
< 0.8 um	Antimony	INAA	Y	229	235	229			231	3	1.4	8
< 0.8 um	Antimony	ICP	N	92.4					92.4			
< 0.8 um	Antimony	GDMS	N	150	330	300			260	96	37.1	239
< 0.8 um	Arsenic	INAA	Y	3,011	3,035	2,960			3,002	38	1.3	95
< 0.8 um	Arsenic	GDMS	N	1,600	2,800	1,300			1,900	794	41.8	1,971
< 0.8 um	Barium	INAA	Y	11,413	11,946	11,361			11,573	324	2.8	804
< 0.8 um	Barium	ICP	N	10,400					10,400			
< 0.8 um	Barium	GDMS	N	14,000	53,000	45,000			37,333	20,599	55.2	51,140
< 0.8 um	Beryllium	ICP	Y	24.8					24.8			
< 0.8 um	Beryllium	GDMS	N	< 0.043	< 0.010	< 0.032			< 0.043	NA	NA	NA
< 0.8 um	Cadmium	INAA	Y	323	301	295			306	15	4.9	37
< 0.8 um	Cadmium	GDMS	N	600	1,300	1,700			1,200	557	46.4	1,382
< 0.8 um	Calcium	INAA	N	20,858	16,758	17,074			18,230	2,281	12.5	5,663
< 0.8 um	Calcium	ICP	Y	37,500					37,500			
< 0.8 um	Calcium	GDMS	N	429	157,234	929			52,864	90,388	171.0	224,397
< 0.8 um	Chlorine	INAA	Y	< 1,369	< 1,174	< 1,245			< 1,369	NA	NA	NA
< 0.8 um	Chlorine	GDMS	N	1,300	240	150			563	640	113.5	1,588
< 0.8 um	Chromium	INAA	Y	1,642	1,694	1,636			1,657	32	1.9	80
< 0.8 um	Chromium	ICP	N	1,600					1,600			
< 0.8 um	Chromium	GDMS	N	6,600	13,000	14,000			11,200	4,015	35.8	9,968
< 0.8 um	Cobalt	INAA	Y	37.7	41.0	37.5			38.7	2.0	5.1	4.9
< 0.8 um	Cobalt	ICP	N	37.8					37.8			
< 0.8 um	Cobalt	GDMS	N	59.0	100.0	150.0			103.0	45.6	44.2	113.1
< 0.8 um	Copper	INAA	N	808	396	454			553	223	40.4	554
< 0.8 um	Copper	ICP	Y	294					294			
< 0.8 um	Copper	GDMS	N	1,100	1,400	1,700			1,400	300	21.4	745
< 0.8 um	Fluorine	GDMS	Y	< 29.0	< 28.0	< 31.0			< 31.0	NA	NA	NA
< 0.8 um	Iron	INAA	Y	33,578	34,331	32,141			33,350	1,113	3.3	2,762
< 0.8 um	Iron	ICP	N	31,400					31,400			
< 0.8 um	Iron	GDMS	N	60,151	90,926	97,921			82,999	20,094	24.2	49,885
< 0.8 um	Lead	ICP	Y	162					162			
< 0.8 um	Lead	GDMS	N	470	810	2,200			1,160	917	79.0	2,275
< 0.8 um	Magnesium	INAA	Y	1,043	2,269	2,159			1,823	678	37.2	1,684

Table C-2. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Magnesium	ICP	N	2,050					2,050			
< 0.8 um	Magnesium	GDMS	N	0	15,078	36,789			17,289	18,494	107.0	45,914
< 0.8 um	Manganese	INAA	N	252	270	322			281	37	13.0	91
< 0.8 um	Manganese	ICP	Y	243					243			
< 0.8 um	Manganese	GDMS	N	1,400	1,600	4,400			2,467	1,677	68.0	4,164
< 0.8 um	Mercury	INAA	N	< 6.84	< 5.87	< 6.22			< 6.84	NA	NA	NA
< 0.8 um	Mercury	GDMS	N	0.330	0.490	< 0.034			0.279	0.241	86.2	0.597
< 0.8 um	Mercury	CVAA	Y	0.179					0.179			
< 0.8 um	Molybdenum	INAA	Y	1,046	985	1,001			1,011	31	3.1	78
< 0.8 um	Molybdenum	ICP	N	987					987			
< 0.8 um	Molybdenum	GDMS	N	1,100	1,300	600			1,000	361	36.1	895
< 0.8 um	Nickel	INAA	N	640	557	612			603	42	7.0	105
< 0.8 um	Nickel	ICP	Y	1,280					1,280			
< 0.8 um	Nickel	GDMS	N	3,300	5,600	7,000			5,300	1,868	35.2	4,638
< 0.8 um	Phosphorus	GDMS	Y	2,600	880	330			1,270	1,184	93.2	2,940
< 0.8 um	Potassium	INAA	N	< 6,387	24,125	26,688			18,002	12,889	71.6	31,997
< 0.8 um	Potassium	ICP	Y	4,000					4,000			
< 0.8 um	Potassium	GDMS	N	664	166	1,494			775	671	86.6	1,666
< 0.8 um	Selenium	INAA	Y	792	821	817			810	16	1.9	39
< 0.8 um	Selenium	GDMS	N	260	1,200	480			647	492	76.0	1,221
< 0.8 um	Silicon	GDMS	Y	7,012	51,418	4,113			20,848	26,514	127.2	65,825
< 0.8 um	Sodium	INAA	Y	981	1,015	1,126			1,041	76	7.3	188
< 0.8 um	Sodium	ICP	N	972					972			
< 0.8 um	Sodium	GDMS	N	1,113	742	631			828	252	30.5	627
< 0.8 um	Strontium	INAA	N	< 456	< 313	< 332			< 456	NA	NA	NA
< 0.8 um	Strontium	ICP	Y	716					716			
< 0.8 um	Strontium	GDMS	N	350	2,600	5,600			2,850	2,634	92.4	6,539
< 0.8 um	Titanium	INAA	Y	4,333	3,773	4,152			4,086	286	7.0	710
< 0.8 um	Titanium	ICP	N	2,920					2,920			
< 0.8 um	Titanium	GDMS	N	760	770	640			723	72	10.0	180
< 0.8 um	Vanadium	INAA	Y	2,978	2,971	2,769			2,906	119	4.1	294
< 0.8 um	Vanadium	ICP	N	2,870					2,870			
< 0.8 um	Vanadium	GDMS	N	1,300	1,200	310			937	545	58.2	1,353
< 0.8 um	Zinc	INAA	Y	994	1,108	1,142			1,081	78	7.2	193
< 0.8 um	Zinc	ICP	N	669					669			
< 0.8 um	Zinc	GDMS	N	5,400	5,000	8,800			6,400	2,088	32.6	5,184

Table C-3. Low Load Stack Emissions - Bulk Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	INAA	Y	23,193	22,708	23,359			23,087	338	1.5	840
> 6.4 um	Aluminum	ICP	N	13,700					13,700			
> 6.4 um	Aluminum	GDMS	N	20,112	31,755	35,989			29,285	8,222	28.1	20,412
> 6.4 um	Antimony	INAA	Y	64.2	63.0	67.8			65.0	2.5	3.8	6.1
> 6.4 um	Antimony	ICP	N	< 57.6					< 57.6			
> 6.4 um	Antimony	GDMS	N	< 20.0	< 29.0	< 22.0			< 29.0	NA	NA	NA
> 6.4 um	Arsenic	INAA	Y	846	840	903			863	35	4.0	86
> 6.4 um	Arsenic	GDMS	N	720	1,400	1,100			1,073	341	31.8	846
> 6.4 um	Barium	INAA	Y	3,730	3,596	4,200			3,842	317	8.2	787
> 6.4 um	Barium	ICP	N	1,610					1,610			
> 6.4 um	Barium	GDMS	N	1,400	2,200	2,500			2,033	569	28.0	1,412
> 6.4 um	Beryllium	ICP	Y	5.40					5.40			
> 6.4 um	Beryllium	GDMS	N	< 0.029	< 0.038	< 0.100			< 0.100	NA	NA	NA
> 6.4 um	Cadmium	INAA	Y	121	138	154			138	17	12.1	41
> 6.4 um	Cadmium	GDMS	N	< 14.0	< 23.0	< 17.0			< 23.0	NA	NA	NA
> 6.4 um	Calcium	INAA	N	9,212	8,839	6,135			8,062	1,679	20.8	4,168
> 6.4 um	Calcium	ICP	Y	6,920					6,920			
> 6.4 um	Calcium	GDMS	N	6,003	8,576	9,291			7,957	1,729	21.7	4,293
> 6.4 um	Chlorine	INAA	Y	2,074	2,754	3,178			2,669	557	20.9	1,382
> 6.4 um	Chlorine	GDMS	N	2,100	2,300	5,300			3,233	1,793	55.4	4,450
> 6.4 um	Chromium	INAA	Y	48,732	54,101	55,667			52,833	3,637	6.9	9,030
> 6.4 um	Chromium	ICP	N	47,500					47,500			
> 6.4 um	Chromium	GDMS	N	36,000	42,000	55,000			44,333	9,713	21.9	24,112
> 6.4 um	Cobalt	INAA	Y	646	659	580			628	42	6.7	105
> 6.4 um	Cobalt	ICP	N	431					431			
> 6.4 um	Cobalt	GDMS	N	200	300	380			293	90	30.7	224
> 6.4 um	Copper	INAA	N	686	752	821			753	67	9.0	167
> 6.4 um	Copper	ICP	Y	419					419			
> 6.4 um	Copper	GDMS	N	330	650	490			490	160	32.7	397
> 6.4 um	Fluorine	GDMS	Y	< 42	< 290	< 29			< 290	NA	NA	NA
> 6.4 um	Iron	INAA	Y	150,542	160,504	168,144			159,730	8,827	5.5	21,913
> 6.4 um	Iron	ICP	N	125,000					125,000			
> 6.4 um	Iron	GDMS	N	65,747	104,915	153,875			108,179	44,155	40.8	109,619
> 6.4 um	Lead	ICP	Y	189					189			
> 6.4 um	Lead	GDMS	N	41.0	90.0	85.0			72.0	27.0	37.4	66.9
> 6.4 um	Magnesium	INAA	Y	< 5,112	< 5,252	1,133			< 5,252	NA	NA	NA

Table C-3. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Magnesium	ICP	N	706					706			
> 6.4 um	Magnesium	GDMS	N	1,086	2,051	1,628			1,588	484	30.5	1,201
> 6.4 um	Manganese	INAA	N	1,089	1,166	1,031			1,095	68	6.2	169
> 6.4 um	Manganese	ICP	Y	1,040					1,040			
> 6.4 um	Manganese	GDMS	N	470	1,000	1,100			857	339	39.5	841
> 6.4 um	Mercury	INAA	N	10.5	12.5	8.5			10.5	2.0	18.9	4.9
> 6.4 um	Mercury	GDMS	N	< 0.017	0.130	< 0.061			0.056	0.065	114.9	0.161
> 6.4 um	Mercury	CVAA	Y	7.47					7.47			
> 6.4 um	Molybdenum	INAA	Y	367	375	316			352	32	9.1	80
> 6.4 um	Molybdenum	ICP	N	260					260			
> 6.4 um	Molybdenum	GDMS	N	200	340	460			333	130	39.0	323
> 6.4 um	Nickel	INAA	N	14,610	15,169	13,725			14,502	728	5.0	1,808
> 6.4 um	Nickel	ICP	Y	22,700					22,700			
> 6.4 um	Nickel	GDMS	N	16,000	25,000	29,000			23,333	6,658	28.5	16,530
> 6.4 um	Phosphorus	GDMS	Y	900	1,700	1,700			1,433	462	32.2	1,147
> 6.4 um	Potassium	INAA	N	7,414	6,848	8,596			7,619	892	11.7	2,214
> 6.4 um	Potassium	ICP	Y	2,610					2,610			
> 6.4 um	Potassium	GDMS	N	55.6	398.5	215.8			223.3	171.6	76.8	425.9
> 6.4 um	Selenium	INAA	Y	929	941	876			915	35	3.8	86
> 6.4 um	Selenium	GDMS	N	510	440	410			453	51	11.3	127
> 6.4 um	Silicon	GDMS	Y	43,004	70,116	93,488			68,869	25,265	36.7	62,723
> 6.4 um	Sodium	INAA	Y	815	1,033	1,021			957	122	12.8	304
> 6.4 um	Sodium	ICP	N	694					694			
> 6.4 um	Sodium	GDMS	N	119	356	245			240	119	49.5	295
> 6.4 um	Strontium	INAA	N	< 1,278	< 1,313	< 761			< 1,313	NA	NA	NA
> 6.4 um	Strontium	ICP	Y	184					184			
> 6.4 um	Strontium	GDMS	N	100	190	210			167	59	35.2	145
> 6.4 um	Titanium	INAA	Y	3,278	3,035	3,577			3,297	271	8.2	673
> 6.4 um	Titanium	ICP	N	1,150					1,150			
> 6.4 um	Titanium	GDMS	N	1,200	1,900	2,400			1,833	603	32.9	1,496
> 6.4 um	Vanadium	INAA	Y	783	769	817			790	24	3.1	61
> 6.4 um	Vanadium	ICP	N	411					411			
> 6.4 um	Vanadium	GDMS	N	400	620	720			580	164	28.2	406
> 6.4 um	Zinc	INAA	N	< 1,431	< 1,523	497			< 1,523	NA	NA	NA
> 6.4 um	Zinc	ICP	Y	180					180			
> 6.4 um	Zinc	GDMS	N	170	350	320			280	96	34.4	239

Table C-3. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Aluminum	INAA	Y	61,783					61,783			
6.4-0.8 um	Aluminum	ICP	N	103,000					103,000			
6.4-0.8 um	Aluminum	GDMS	N	42,869					42,869			
6.4-0.8 um	Antimony	INAA	Y	119					119			
6.4-0.8 um	Antimony	ICP	N	< 875					< 875			
6.4-0.8 um	Antimony	GDMS	N	< 26.0					< 26.0			
6.4-0.8 um	Arsenic	INAA	Y	1,763					1,763			
6.4-0.8 um	Arsenic	GDMS	N	1,100					1,100			
6.4-0.8 um	Barium	INAA	Y	8,686					8,686			
6.4-0.8 um	Barium	ICP	N	13,200					13,200			
6.4-0.8 um	Barium	GDMS	N	2,800					2,800			
6.4-0.8 um	Beryllium	ICP	Y	41.9					41.9			
6.4-0.8 um	Beryllium	GDMS	N	< 0.050					< 0.050			
6.4-0.8 um	Cadmium	INAA	Y	229					229			
6.4-0.8 um	Cadmium	GDMS	N	< 39.0					< 39.0			
6.4-0.8 um	Calcium	INAA	N	9,655					9,655			
6.4-0.8 um	Calcium	ICP	Y	43,200					43,200			
6.4-0.8 um	Calcium	GDMS	N	10,006					10,006			
6.4-0.8 um	Chlorine	INAA	Y	983					983			
6.4-0.8 um	Chlorine	GDMS	N	360					360			
6.4-0.8 um	Chromium	INAA	Y	8,466					8,466			
6.4-0.8 um	Chromium	ICP	N	26,600					26,600			
6.4-0.8 um	Chromium	GDMS	N	3,100					3,100			
6.4-0.8 um	Cobalt	INAA	Y	137					137			
6.4-0.8 um	Cobalt	ICP	N	388					388			
6.4-0.8 um	Cobalt	GDMS	N	58					58			
6.4-0.8 um	Copper	INAA	N	493					493			
6.4-0.8 um	Copper	ICP	Y	508					508			
6.4-0.8 um	Copper	GDMS	N	370					370			
6.4-0.8 um	Fluorine	GDMS	Y	< 290					< 290			
6.4-0.8 um	Iron	INAA	Y	63,531					63,531			
6.4-0.8 um	Iron	ICP	N	140,000					140,000			
6.4-0.8 um	Iron	GDMS	N	30,775					30,775			
6.4-0.8 um	Lead	ICP	Y	< 3.75					< 3.75			
6.4-0.8 um	Lead	GDMS	N	130					130			
6.4-0.8 um	Magnesium	INAA	Y	1,935					1,935			

Table C-3. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Magnesium	ICP	N	7,110					7,110			
6.4-0.8 um	Magnesium	GDMS	N	2,774					2,774			
6.4-0.8 um	Manganese	INAA	N	398					398			
6.4-0.8 um	Manganese	ICP	Y	1,020					1,020			
6.4-0.8 um	Manganese	GDMS	N	280					280			
6.4-0.8 um	Mercury	INAA	N	< 8.40					< 8.40			
6.4-0.8 um	Mercury	GDMS	N	< 0.012					< 0.012			
6.4-0.8 um	Mercury	CVAA	Y	4.78					4.78			
6.4-0.8 um	Molybdenum	INAA	Y	372					372			
6.4-0.8 um	Molybdenum	ICP	N	297					297			
6.4-0.8 um	Molybdenum	GDMS	N	200					200			
6.4-0.8 um	Nickel	INAA	N	1,761					1,761			
6.4-0.8 um	Nickel	ICP	Y	18,900					18,900			
6.4-0.8 um	Nickel	GDMS	N	3,200					3,200			
6.4-0.8 um	Phosphorus	GDMS	Y	2,800					2,800			
6.4-0.8 um	Potassium	INAA	N	12,655					12,655			
6.4-0.8 um	Potassium	ICP	Y	13,200					13,200			
6.4-0.8 um	Potassium	GDMS	N	133					133			
6.4-0.8 um	Selenium	INAA	Y	117					117			
6.4-0.8 um	Selenium	GDMS	N	410					410			
6.4-0.8 um	Silicon	GDMS	Y	79,465					79,465			
6.4-0.8 um	Sodium	INAA	Y	2,140					2,140			
6.4-0.8 um	Sodium	ICP	N	4,250					4,250			
6.4-0.8 um	Sodium	GDMS	N	71.2					71.2			
6.4-0.8 um	Strontium	INAA	N	< 840					< 840			
6.4-0.8 um	Strontium	ICP	Y	1,650					1,650			
6.4-0.8 um	Strontium	GDMS	N	260					260			
6.4-0.8 um	Titanium	INAA	Y	6,484					6,484			
6.4-0.8 um	Titanium	ICP	N	8,590					8,590			
6.4-0.8 um	Titanium	GDMS	N	3,000					3,000			
6.4-0.8 um	Vanadium	INAA	Y	1,760					1,760			
6.4-0.8 um	Vanadium	ICP	N	3,230					3,230			
6.4-0.8 um	Vanadium	GDMS	N	880					880			
6.4-0.8 um	Zinc	INAA	N	783					783			
6.4-0.8 um	Zinc	ICP	Y	1,270					1,270			
6.4-0.8 um	Zinc	GDMS	N	450					450			

Table C-3. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Aluminum	INAA	Y	33,304	31,853	31,453			32,203	974	3.0	2,418
< 0.8 um	Aluminum	ICP	N	35,300					35,300			
< 0.8 um	Aluminum	GDMS	N	48,691	84,680	211,700			115,024	85,636	74.5	212,601
< 0.8 um	Antimony	INAA	Y	256	224	250			243	17	6.9	42
< 0.8 um	Antimony	ICP	N	233					233			
< 0.8 um	Antimony	GDMS	N	< 110	< 150	380			170	182	107.1	452
< 0.8 um	Arsenic	INAA	Y	3,457	3,190	3,381			3,343	137	4.1	341
< 0.8 um	Arsenic	GDMS	N	4,600	7,000	1,900			4,500	2,551	56.7	6,334
< 0.8 um	Barium	INAA	Y	18,850	18,475	18,936			18,753	245	1.3	609
< 0.8 um	Barium	ICP	N	17,200					17,200			
< 0.8 um	Barium	GDMS	N	24,000	42,000	76,000			47,333	26,407	55.8	65,558
< 0.8 um	Beryllium	ICP	Y	29.3					29.3			
< 0.8 um	Beryllium	GDMS	N	< 0.280	< 0.170	< 0.058			< 0.280	NA	NA	NA
< 0.8 um	Cadmium	INAA	Y	365	374	298			346	41	12.0	103
< 0.8 um	Cadmium	GDMS	N	< 150	< 280	2,200			805	1,209	150.1	3,000
< 0.8 um	Calcium	INAA	N	17,519	18,016	12,593			16,043	2,998	18.7	7,442
< 0.8 um	Calcium	ICP	Y	31,100					31,100			
< 0.8 um	Calcium	GDMS	N	21,441	38,594	171,528			77,188	82,150	106.4	203,947
< 0.8 um	Chlorine	INAA	Y	545	240	497			427	164	38.5	408
< 0.8 um	Chlorine	GDMS	N	500	120	61			227	238	105.0	592
< 0.8 um	Chromium	INAA	Y	2,248	2,108	2,242			2,199	79	3.6	195
< 0.8 um	Chromium	ICP	N	2,280					2,280			
< 0.8 um	Chromium	GDMS	N	2,900	3,800	19,000			8,567	9,047	105.6	22,459
< 0.8 um	Cobalt	INAA	Y	55.6	57.5	56.6			56.6	1.0	1.7	2.4
< 0.8 um	Cobalt	ICP	N	61.2					61.2			
< 0.8 um	Cobalt	GDMS	N	40	70	170			93	68	72.9	169
< 0.8 um	Copper	INAA	N	723	862	583			723	140	19.3	346
< 0.8 um	Copper	ICP	Y	456					456			
< 0.8 um	Copper	GDMS	N	450	610	2,600			1,220	1,198	98.2	2,974
< 0.8 um	Fluorine	GDMS	Y	< 58	< 48	< 100			< 100	NA	NA	NA
< 0.8 um	Iron	INAA	Y	29,693	28,266	31,581			29,847	1,663	5.6	4,129
< 0.8 um	Iron	ICP	N	30,700					30,700			
< 0.8 um	Iron	GDMS	N	28,677	41,966	111,909			60,851	44,715	73.5	111,009
< 0.8 um	Lead	ICP	Y	152					152			
< 0.8 um	Lead	GDMS	N	190	320	2,200			903	1,125	124.5	2,792
< 0.8 um	Magnesium	INAA	Y	1,552	1,568	1,447			1,522	65	4.3	162

Table C-3. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Magnesium	ICP	N	2,430					2,430			
< 0.8 um	Magnesium	GDMS	N	2,593	6,031	21,712			10,112	10,192	100.8	25,302
< 0.8 um	Manganese	INAA	N	278	250	270			266	15	5.5	36
< 0.8 um	Manganese	ICP	Y	270					270			
< 0.8 um	Manganese	GDMS	N	260	510	3,000			1,257	1,515	120.6	3,761
< 0.8 um	Mercury	INAA	N	< 7.27	< 7.40	< 6.42			< 7.40	NA	NA	NA
< 0.8 um	Mercury	GDMS	N	< 0.098	< 0.041	< 0.096			< 0.098	NA	NA	NA
< 0.8 um	Mercury	CVAA	Y	0.203					0.203			
< 0.8 um	Molybdenum	INAA	Y	769	817	733			773	42	5.5	105
< 0.8 um	Molybdenum	ICP	N	779					779			
< 0.8 um	Molybdenum	GDMS	N	910	1,300	540			917	380	41.5	943
< 0.8 um	Nickel	INAA	N	799	816	786			801	15	1.9	37
< 0.8 um	Nickel	ICP	Y	1,710					1,710			
< 0.8 um	Nickel	GDMS	N	1,700	2,500	7,400			3,867	3,086	79.8	7,661
< 0.8 um	Phosphorus	GDMS	Y	5,000	7,600	440			4,347	3,624	83.4	8,998
< 0.8 um	Potassium	INAA	N	10,670	12,002	12,266			11,646	856	7.3	2,125
< 0.8 um	Potassium	ICP	Y	5,020					5,020			
< 0.8 um	Potassium	GDMS	N	125	68	1,660			618	903	146.3	2,243
< 0.8 um	Selenium	INAA	Y	1,810	1,679	1,760			1,749	66	3.8	164
< 0.8 um	Selenium	GDMS	N	1,300	530	280			703	532	75.6	1,320
< 0.8 um	Silicon	GDMS	Y	98,162	158,929	7,012			88,034	76,464	86.9	189,829
< 0.8 um	Sodium	INAA	Y	962	1,164	928			1,018	128	12.5	317
< 0.8 um	Sodium	ICP	N	1,050					1,050			
< 0.8 um	Sodium	GDMS	N	215	58	890			388	442	114.0	1,098
< 0.8 um	Strontium	INAA	N	< 727	< 740	< 257			< 740	NA	NA	NA
< 0.8 um	Strontium	ICP	Y	1,130					1,130			
< 0.8 um	Strontium	GDMS	N	860	1,600	5,500			2,653	2,493	94.0	6,189
< 0.8 um	Titanium	INAA	Y	5,701	5,146	4,558			5,135	572	11.1	1,419
< 0.8 um	Titanium	ICP	N	3,560					3,560			
< 0.8 um	Titanium	GDMS	N	3,400	5,600	320			3,107	2,652	85.4	6,584
< 0.8 um	Vanadium	INAA	Y	2,321	2,217	2,184			2,241	72	3.2	178
< 0.8 um	Vanadium	ICP	N	2,430					2,430			
< 0.8 um	Vanadium	GDMS	N	1,900	2,600	430			1,643	1,108	67.4	2,750
< 0.8 um	Zinc	INAA	N	444	481	476			467	20	4.3	50
< 0.8 um	Zinc	ICP	Y	494					494			
< 0.8 um	Zinc	GDMS	N	460	910	5,600			2,323	2,847	122.5	7,067

Table C-4. FGD Inlet - Nitric Acid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	35,714					35,714			
> 6.4 um	Antimony	ICP/MS	Y	0.88					0.88			
> 6.4 um	Antimony	ICP	N	< 23.0					< 23.0			
> 6.4 um	Arsenic	ICP/MS	Y	77.0					77.0			
> 6.4 um	Arsenic	GFAA	N	108					108			
> 6.4 um	Barium	ICP/MS	Y	884					884			
> 6.4 um	Barium	ICP	N	917					917			
> 6.4 um	Beryllium	ICP/MS	Y	8.43					8.43			
> 6.4 um	Beryllium	ICP	N	9.07					9.07			
> 6.4 um	Cadmium	ICP/MS	Y	4.31					4.31			
> 6.4 um	Calcium	ICP	Y	10,286					10,286			
> 6.4 um	Chromium	ICP/MS	N	98.6					98.6			
> 6.4 um	Chromium	ICP	Y	97.1					97.1			
> 6.4 um	Coalt	ICP/MS	Y	30.5					30.5			
> 6.4 um	Coalt	ICP	N	27.4					27.4			
> 6.4 um	Copper	ICP/MS	Y	65.0					65.0			
> 6.4 um	Copper	ICP	N	124					124			
> 6.4 um	Iron	ICP	Y	27,810					27,810			
> 6.4 um	Lead	ICP/MS	Y	119					119			
> 6.4 um	Magnesium	ICP	Y	2,352					2,352			
> 6.4 um	Manganese	ICP/MS	Y	110					110			
> 6.4 um	Manganese	ICP	N	98.1					98.1			
> 6.4 um	Mercury	ICP/MS	N	3.14					3.14			
> 6.4 um	Mercury	CVAA	Y	< 0.09					< 0.09			
> 6.4 um	Molydenum	ICP/MS	Y	37.1					37.1			
> 6.4 um	Molydenum	ICP	N	31.9					31.9			
> 6.4 um	Nickel	ICP/MS	Y	76.5					76.5			
> 6.4 um	Nickel	ICP	N	76.4					76.4			
> 6.4 um	Phosphorus	ICP	Y	1,162					1,162			
> 6.4 um	Potassium	ICP	Y	5,238					5,238			
> 6.4 um	Selenium	ICP/MS	N	16.0					16.0			
> 6.4 um	Selenium	GFAA	Y	20.0					20.0			
> 6.4 um	Sodium	ICP	Y	1,581					1,581			
> 6.4 um	Titanium	ICP	Y	2,390					2,390			
> 6.4 um	Vanadium	ICP/MS	Y	190					190			
> 6.4 um	Vanadium	ICP	N	192					192			

Table C-4. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Zinc	ICP	Y	2,286					2,286			
6.4-0.8 um	Aluminum	ICP	Y	73,892					73,892			
6.4-0.8 um	Antimony	ICP/MS	Y	2.73					2.73			
6.4-0.8 um	Antimony	ICP	N	< 23.7					< 23.7			
6.4-0.8 um	Arsenic	ICP/MS	Y	241					241			
6.4-0.8 um	Arsenic	GFAA	N	286					286			
6.4-0.8 um	Barium	ICP/MS	Y	1,774					1,774			
6.4-0.8 um	Barium	ICP	N	1,823					1,823			
6.4-0.8 um	Beryllium	ICP/MS	Y	21.9					21.9			
6.4-0.8 um	Beryllium	ICP	N	22.6					22.6			
6.4-0.8 um	Cadmium	ICP/MS	Y	10.4					10.4			
6.4-0.8 um	Calcium	ICP	Y	11,133					11,133			
6.4-0.8 um	Chromium	ICP/MS	N	275					275			
6.4-0.8 um	Chromium	ICP	Y	296					296			
6.4-0.8 um	Coalt	ICP/MS	Y	87.0					87.0			
6.4-0.8 um	Coalt	ICP	N	90.6					90.6			
6.4-0.8 um	Copper	ICP/MS	Y	297					297			
6.4-0.8 um	Copper	ICP	N	318					318			
6.4-0.8 um	Iron	ICP	Y	38,522					38,522			
6.4-0.8 um	Lead	ICP/MS	Y	247					247			
6.4-0.8 um	Magnesium	ICP	Y	4,709					4,709			
6.4-0.8 um	Manganese	ICP/MS	Y	199					199			
6.4-0.8 um	Manganese	ICP	N	195					195			
6.4-0.8 um	Mercury	ICP/MS	N	< 0.08					< 0.08			
6.4-0.8 um	Mercury	CVAA	Y	0.10					0.10			
6.4-0.8 um	Molydenum	ICP/MS	Y	85.3					85.3			
6.4-0.8 um	Molydenum	ICP	N	79.4					79.4			
6.4-0.8 um	Nickel	ICP/MS	Y	208					208			
6.4-0.8 um	Nickel	ICP	N	231					231			
6.4-0.8 um	Phosphorus	ICP	Y	3,586					3,586			
6.4-0.8 um	Potassium	ICP	Y	13,695					13,695			
6.4-0.8 um	Selenium	ICP/MS	N	62.3					62.3			
6.4-0.8 um	Selenium	GFAA	Y	23.3					23.3			
6.4-0.8 um	Sodium	ICP	Y	2,897					2,897			
6.4-0.8 um	Titanium	ICP	Y	3,872					3,872			
6.4-0.8 um	Vanadium	ICP/MS	Y	464					464			

Table C-4. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Vanadium	ICP	N	481					481			
6.4-0.8 um	Zinc	ICP	Y	701					701			
< 0.8 um	Aluminum	ICP	Y	59,900					59,900			
< 0.8 um	Antimony	ICP/MS	Y	2.78			2.43	13.5	2.78			
< 0.8 um	Antimony	ICP	N	8.66 J					8.66 J			
< 0.8 um	Arsenic	ICP/MS	Y	204			210	2.6	204			
< 0.8 um	Arsenic	GFAA	N	258					258			
< 0.8 um	Barium	ICP/MS	Y	1,246			1,234	1.0	1,246			
< 0.8 um	Barium	ICP	N	1,240					1,240			
< 0.8 um	Beryllium	ICP/MS	Y	18.1			19.2	5.6	18.1			
< 0.8 um	Beryllium	ICP	N	19.4					19.4			
< 0.8 um	Cadmium	ICP/MS	Y	10.6			10.4	2.4	10.6			
< 0.8 um	Calcium	ICP	Y	10,900					10,900			
< 0.8 um	Chromium	ICP/MS	N	719			724	0.7	719			
< 0.8 um	Chromium	ICP	Y	764					764			
< 0.8 um	Coalt	ICP/MS	Y	74.3			76.1	2.4	74.3			
< 0.8 um	Coalt	ICP	N	80.0					80.0			
< 0.8 um	Copper	ICP/MS	Y	258			< 262	1.6	258			
< 0.8 um	Copper	ICP	N	269					269			
< 0.8 um	Iron	ICP	Y	39,200					39,200			
< 0.8 um	Lead	ICP/MS	Y	212			209	1.5	212			
< 0.8 um	Magnesium	ICP	Y	3,730					3,730			
< 0.8 um	Manganese	ICP/MS	Y	249			253	1.2	249			
< 0.8 um	Manganese	ICP	N	244					244			
< 0.8 um	Mercury	ICP/MS	N	< 0.09			0.09	0.0	< 0.09			
< 0.8 um	Mercury	CVAA	Y	0.08 J					0.08 J			
< 0.8 um	Molydenum	ICP/MS	Y	100			96	3.8	100			
< 0.8 um	Molydenum	ICP	N	83.4					83.4			
< 0.8 um	Nickel	ICP/MS	Y	252			258	2.3	252			
< 0.8 um	Nickel	ICP	N	264					264			
< 0.8 um	Phosphorus	ICP	Y	2,810					2,810			
< 0.8 um	Potassium	ICP	Y	10,000					10,000			
< 0.8 um	Selenium	ICP/MS	N	78.2			64.7	18.9	78.2			
< 0.8 um	Selenium	GFAA	Y	52.5					52.5			
< 0.8 um	Sodium	ICP	Y	2,490					2,490			
< 0.8 um	Titanium	ICP	Y	2,850					2,850			

Table C-4. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Vanadium	ICP/MS	Y	436			438	0.6	436			
< 0.8 um	Vanadium	ICP	N	434					434			
< 0.8 um	Zinc	ICP	Y	638					638			

Table C-5. High Load Stack Emissions - Nitric Acid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	31,610					31,610			
> 6.4 um	Antimony	ICP/MS	Y	76.9	82.9	64.4	62.9	2.3	74.7	9.4	12.6	23.4
> 6.4 um	Antimony	ICP	N	< 204					< 204			
> 6.4 um	Arsenic	ICP/MS	Y	1,793	1,588	1,682	1,653	1.7	1,688	103	6.1	255
> 6.4 um	Arsenic	GFAA	N	1,760	1,680	1,710			1,717	40	2.4	100
> 6.4 um	Barium	ICP/MS	Y	5,526	5,328	6,111	6,090	0.4	5,655	407	7.2	1,010
> 6.4 um	Barium	ICP	N	6,059					6,059			
> 6.4 um	Beryllium	ICP/MS	Y	20.1	12.6	18.2	13.1	32.4	17.0	3.9	23.0	9.7
> 6.4 um	Beryllium	ICP	N	24.8					24.8			
> 6.4 um	Cadmium	ICP/MS	Y	84.1	81.2	77.8	88.8	13.2	81.0	3.2	3.9	7.9
> 6.4 um	Calcium	ICP	Y	42,966					42,966			
> 6.4 um	Chromium	ICP/MS	Y	3,216	3,971	3,546	3,602	1.6	3,578	378	10.6	940
> 6.4 um	Chromium	ICP	N	3,695					3,695			
> 6.4 um	Coalt	ICP/MS	Y	68.0	72.9	76.9	73.7	4.2	72.6	4.5	6.1	11.1
> 6.4 um	Coalt	ICP	N	33.6					33.6			
> 6.4 um	Copper	ICP/MS	Y	401	428	401	390	2.8	410	15	3.8	38
> 6.4 um	Copper	ICP	N	412					412			
> 6.4 um	Iron	ICP	Y	74,322					74,322			
> 6.4 um	Lead	ICP/MS	Y	182	187	175	174	0.2	181	6	3.5	16
> 6.4 um	Magnesium	ICP	Y	3,068					3,068			
> 6.4 um	Manganese	ICP/MS	Y	523	784	556	549	1.2	621	142	22.9	353
> 6.4 um	Manganese	ICP	N	538					538			
> 6.4 um	Mercury	ICP/MS	N	< 0.73	< 0.74	< 0.73	< 0.73	0.0	< 0.74	NA	NA	NA
> 6.4 um	Mercury	CVAA	Y	< 0.81	< 0.82	< 0.81			< 0.82	NA	NA	NA
> 6.4 um	Molydenum	ICP/MS	Y	469	455	471	464	1.5	465	9	1.9	21
> 6.4 um	Molydenum	ICP	N	431					431			
> 6.4 um	Nickel	ICP/MS	Y	2,557	2,951	2,285	2,231	2.4	2,598	335	12.9	831
> 6.4 um	Nickel	ICP	N	2,695					2,695			
> 6.4 um	Phosphorus	ICP	Y	108 J					108 J			
> 6.4 um	Potassium	ICP	Y	3,686					3,686			
> 6.4 um	Selenium	ICP/MS	Y	1,008	1,186	1,006	958	4.9	1,067	104	9.7	257
> 6.4 um	Selenium	GFAA	N	1,352	1,479	1,436			1,422	65	4.5	160
> 6.4 um	Sodium	ICP	Y	7,381					7,381			
> 6.4 um	Titanium	ICP	Y	2,864					2,864			
> 6.4 um	Vanadium	ICP/MS	Y	1,777	1,594	1,709	1,707	0.1	1,693	93	5.5	230
> 6.4 um	Vanadium	ICP	N	1,932					1,932			

Table C-5. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Zinc	ICP	Y	1,000					1,000			
6.4-0.8 um	Aluminum	ICP	Y	44,327					44,327			
6.4-0.8 um	Antimony	ICP/MS	Y	60.1	70.6	66.3	65.5	1.1	65.6	5.3	8.0	13.1
6.4-0.8 um	Antimony	ICP	N	209 J					209 J			
6.4-0.8 um	Arsenic	ICP/MS	Y	1,687	1,696	1,834	1,892	3.1	1,739	83	4.7	205
6.4-0.8 um	Arsenic	GFAA	N	2,080	2,050	2,230			2,120	96	4.5	239
6.4-0.8 um	Barium	ICP/MS	Y	6,331	7,520	6,546	6,733	2.8	6,799	634	9.3	1,574
6.4-0.8 um	Barium	ICP	N	7,365					7,365			
6.4-0.8 um	Beryllium	ICP/MS	Y	19.5	16.2	16.7	16.3	2.9	17.5	1.8	10.1	4.4
6.4-0.8 um	Beryllium	ICP	N	35.2					35.2			
6.4-0.8 um	Cadmium	ICP/MS	Y	2,144	922	887	891	0.5	1,318	716	54.3	1,777
6.4-0.8 um	Calcium	ICP	Y	33,077					33,077			
6.4-0.8 um	Chromium	ICP/MS	Y	660	544	585	623	6.4	596	59	9.9	146
6.4-0.8 um	Chromium	ICP	N	913					913			
6.4-0.8 um	Coalt	ICP/MS	Y	35.8	33.3	41.7	40.0	4.2	37.0	4.3	11.7	10.7
6.4-0.8 um	Coalt	ICP	N	< 32.7					< 32.7			
6.4-0.8 um	Copper	ICP/MS	Y	269	257	273	277	1.5	266	8	3.1	20
6.4-0.8 um	Copper	ICP	N	327					327			
6.4-0.8 um	Iron	ICP	Y	44,904					44,904			
6.4-0.8 um	Lead	ICP/MS	Y	5,320	1,767	1,024	1,026	0.3	2,704	2,296	84.9	5,701
6.4-0.8 um	Magnesium	ICP	Y	3,548					3,548			
6.4-0.8 um	Manganese	ICP/MS	Y	264	200	221	220	0.2	228	33	14.5	82
6.4-0.8 um	Manganese	ICP	N	338					338			
6.4-0.8 um	Mercury	ICP/MS	N	< 0.83	< 0.84	< 0.84	< 0.84	0.0	< 0.84	NA	NA	NA
6.4-0.8 um	Mercury	CVAA	Y	3.08	< 0.94	< 0.93			1.34	1.51	112.6	3.74
6.4-0.8 um	Molydenum	ICP/MS	Y	395	404	401	416	3.5	400	5	1.2	12
6.4-0.8 um	Molydenum	ICP	N	390					390			
6.4-0.8 um	Nickel	ICP/MS	Y	451	404	425	426	0.2	427	23	5.4	58
6.4-0.8 um	Nickel	ICP	N	700					700			
6.4-0.8 um	Phosphorus	ICP	Y	1,990					1,990			
6.4-0.8 um	Potassium	ICP	Y	< 3,558					< 3,558			
6.4-0.8 um	Selenium	ICP/MS	Y	737	662	841	854	1.5	747	90	12.0	223
6.4-0.8 um	Selenium	GFAA	N	1,091	1,294	1,442			1,276	176	13.8	437
6.4-0.8 um	Sodium	ICP	Y	8,048					8,048			
6.4-0.8 um	Titanium	ICP	Y	3,529					3,529			
6.4-0.8 um	Vanadium	ICP/MS	Y.	1,810	1,879	1,889	1,941	2.7	1,859	43	2.3	107

Table C-5. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Vanadium	ICP	N	2,404					2,404			
6.4-0.8 um	Zinc	ICP	Y	981					981			
<0.8 um	Aluminum	ICP	Y	27,196					27,196			
<0.8 um	Antimony	ICP/MS	Y	120	138	107	106	0.7	121	16	12.8	39
<0.8 um	Antimony	ICP	N	380					380			
<0.8 um	Arsenic	ICP/MS	Y	2,437	2,430	2,206	2,323	5.1	2,358	131	5.6	326
<0.8 um	Arsenic	GFAA	N	2,940	2,910	2,600			2,817	188	6.7	467
<0.8 um	Barium	ICP/MS	Y	10,773	10,611	9,063	9,324	2.8	10,149	944	9.3	2,344
<0.8 um	Barium	ICP	N	12,243					12,243			
<0.8 um	Beryllium	ICP/MS	Y	27.6	23.8	20.3	23.0	12.7	23.9	3.7	15.3	9.1
<0.8 um	Beryllium	ICP	N	35.2					35.2			
<0.8 um	Cadmium	ICP/MS	Y	118	107	110	105	4.9	112	6	5.2	14
<0.8 um	Calcium	ICP	Y	36,168					36,168			
<0.8 um	Chromium	ICP/MS	Y	1,433	1,400	1,241	1,341	7.8	1,358	103	7.6	255
<0.8 um	Chromium	ICP	N	1,682					1,682			
<0.8 um	Coalt	ICP/MS	Y	39.5	32.7	30.3	32.0	5.6	34.1	4.8	14.0	11.9
<0.8 um	Coalt	ICP	N	18.6 J					18.6 J			
<0.8 um	Copper	ICP/MS	Y	365	329	232	244	4.8	309	69	22.2	170
<0.8 um	Copper	ICP	N	430					430			
<0.8 um	Iron	ICP	Y	31,495					31,495			
<0.8 um	Lead	ICP/MS	Y	180	166	151	157	3.6	166	14	8.7	36
<0.8 um	Magnesium	ICP	Y	2,215					2,215			
<0.8 um	Manganese	ICP/MS	Y	222	223	212	224	5.4	219	6	2.7	15
<0.8 um	Manganese	ICP	N	261					261			
<0.8 um	Mercury	ICP/MS	N	24.5	< 0.9	< 0.9	< 0.9	0.0	8.5	13.9	164.4	34.5
<0.8 um	Mercury	CVAA	Y	1.87	< 0.95	< 0.96			< 0.96	NA	NA	NA
<0.8 um	Molydenum	ICP/MS	Y	804	850	810	853	5.2	821	25	3.1	63
<0.8 um	Molydenum	ICP	N	972					972			
<0.8 um	Nickel	ICP/MS	Y	956	940	871	945	8.2	922	45	4.9	112
<0.8 um	Nickel	ICP	N	1,542					1,542			
<0.8 um	Phosphorus	ICP	Y	749					749			
<0.8 um	Potassium	ICP	Y	1,551 J					1,551 J			
<0.8 um	Selenium	ICP/MS	Y	826	831	659	695	5.3	772	98	12.7	243
<0.8 um	Selenium	GFAA	N	1,411	1,610	1,720			1,580	157	9.9	389
<0.8 um	Sodium	ICP	Y	3,150					3,150			
<0.8 um	Titanium	ICP	Y	2,645					2,645			

Table C-5. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Vanadium	ICP/MS	Y	2,264	2,332	2,233	2,388	6.7	2,276	51	2.2	126
< 0.8 um	Vanadium	ICP	N	2,785					2,785			
< 0.8 um	Zinc	ICP	Y	778					778			

Table C-6. Low Load Stack Emissions - Nitric Acid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	17,500					17,500			
> 6.4 um	Antimony	ICP/MS	Y	33.5	15.6	20.0	21.8	8.4	23.0	9.3	40.4	23.1
> 6.4 um	Antimony	ICP	N	< 241					< 241			
> 6.4 um	Arsenic	ICP/MS	Y	733	522	743	751	1.0	666	125	18.7	310
> 6.4 um	Arsenic	GFAA	N	886	639	812			779	127	16.3	315
> 6.4 um	Barium	ICP/MS	Y	2,799	2,391	2,931	3,015	2.9	2,707	281	10.4	698
> 6.4 um	Barium	ICP	N	3,170					3,170			
> 6.4 um	Beryllium	ICP/MS	Y	5.25	5.13	7.00	5.25	28.6	5.79	1.05	18.0	2.60
> 6.4 um	Beryllium	ICP	N	11.8					11.8			
> 6.4 um	Cadmium	ICP/MS	Y	31.8	25.0	32.5	28.3	14.0	29.8	4.1	13.9	10.3
> 6.4 um	Calcium	ICP	Y	13,000					13,000			
> 6.4 um	Chromium	ICP/MS	Y	39,514	27,530	38,638	40,492	4.7	35,227	6,680	19.0	16,584
> 6.4 um	Chromium	ICP	N	53,400					53,400			
> 6.4 um	Coalt	ICP/MS	Y	370	256	384	410	6.6	337	70	20.8	174
> 6.4 um	Coalt	ICP	N	402					402			
> 6.4 um	Copper	ICP/MS	Y	1,002	385	417	437	4.7	601	347	57.7	862
> 6.4 um	Copper	ICP	N	1,220					1,220			
> 6.4 um	Iron	ICP	Y	129,000					129,000			
> 6.4 um	Lead	ICP/MS	Y	85.5	155.8	105.3	112.0	6.2	115.5	36.3	31.4	90.0
> 6.4 um	Magnesium	ICP	Y	1,560					1,560			
> 6.4 um	Manganese	ICP/MS	Y	1,029	703	1,112	1,160	4.2	948	216	22.8	537
> 6.4 um	Manganese	ICP	N	1,210					1,210			
> 6.4 um	Mercury	ICP/MS	N	< 0.86	< 0.77	< 0.86	< 0.86	0.0	< 0.86	NA	NA	NA
> 6.4 um	Mercury	CVAA	Y	0.60	J < 0.86	2.00			1.01	0.86	85.4	2.14
> 6.4 um	Molydenum	ICP/MS	Y	329	246	395	391	1.1	323	75	23.2	186
> 6.4 um	Molydenum	ICP	N	266					266			
> 6.4 um	Nickel	ICP/MS	Y	25,523	15,181	18,814	19,589	4.0	19,839	5,247	26.4	13,026
> 6.4 um	Nickel	ICP	N	32,000					32,000			
> 6.4 um	Phosphorus	ICP	Y	< 610					< 610			
> 6.4 um	Potassium	ICP	Y	7,600					7,600			
> 6.4 um	Selenium	ICP/MS	Y	767	628	819	891	8.4	738	99	13.4	245
> 6.4 um	Selenium	GFAA	N	1,060	857	1,020			979	108	11.0	267
> 6.4 um	Sodium	ICP	Y	9,020					9,020			
> 6.4 um	Titanium	ICP	Y	1,460					1,460			
> 6.4 um	Vanadium	ICP/MS	Y	691	487	683	708	3.6	621	115	18.6	287
> 6.4 um	Vanadium	ICP	N	859					859			

Table C-6. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Zinc	ICP	Y	230					230			
6.4-0.8 um	Aluminum	ICP	Y	46,667					46,667			
6.4-0.8 um	Antimony	ICP/MS	Y	38.5			38.5	0.0	38.5			
6.4-0.8 um	Antimony	ICP	N	275					275			
6.4-0.8 um	Arsenic	ICP/MS	Y	1,507			1,485	1.5	1,507			
6.4-0.8 um	Arsenic	GFAA	N	1,680					1,680			
6.4-0.8 um	Barium	ICP/MS	Y	6,398			6,344	0.8	6,398			
6.4-0.8 um	Barium	ICP	N	7,059					7,059			
6.4-0.8 um	Beryllium	ICP/MS	Y	19.1			21.3	10.9	19.1			
6.4-0.8 um	Beryllium	ICP	N	24.5					24.5			
6.4-0.8 um	Cadmium	ICP/MS	Y	117			117	0.2	117			
6.4-0.8 um	Calcium	ICP	Y	24,118					24,118			
6.4-0.8 um	Chromium	ICP/MS	Y	8,800			9,015	2.4	8,800			
6.4-0.8 um	Chromium	ICP	N	11,078					11,078			
6.4-0.8 um	Coalt	ICP/MS	Y	154			156	1.6	154			
6.4-0.8 um	Coalt	ICP	N	173					173			
6.4-0.8 um	Copper	ICP/MS	Y	334			335	0.1	334			
6.4-0.8 um	Copper	ICP	N	408					408			
6.4-0.8 um	Iron	ICP	Y	60,490					60,490			
6.4-0.8 um	Lead	ICP/MS	Y	267			265	0.7	267			
6.4-0.8 um	Magnesium	ICP	Y	3,931					3,931			
6.4-0.8 um	Manganese	ICP/MS	Y	435			437	0.5	435			
6.4-0.8 um	Manganese	ICP	N	490					490			
6.4-0.8 um	Mercury	ICP/MS	N	31.6			< 0.8	189.6	31.6			
6.4-0.8 um	Mercury	CVAA	Y	2.16					2.16			
6.4-0.8 um	Molydenum	ICP/MS	Y	326			319	2.2	326			
6.4-0.8 um	Molydenum	ICP	N	252					252			
6.4-0.8 um	Nickel	ICP/MS	Y	7,075			7,210	1.9	7,075			
6.4-0.8 um	Nickel	ICP	N	8,382					8,382			
6.4-0.8 um	Phosphorus	ICP	Y	737					737			
6.4-0.8 um	Potassium	ICP	Y	11,961					11,961			
6.4-0.8 um	Selenium	ICP/MS	Y	1,073			1,090	1.6	1,073			
6.4-0.8 um	Selenium	GFAA	N	1,460					1,460			
6.4-0.8 um	Sodium	ICP	Y	8,676					8,676			
6.4-0.8 um	Titanium	ICP	Y	3,647					3,647			
6.4-0.8 um	Vanadium	ICP/MS	Y	1,493			1,507	1.0	1,493			

Table C-6. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Vanadium	ICP	N	1,745					1,745			
6.4-0.8 um	Zinc	ICP	Y	649					649			
< 0.8 um	Aluminum	ICP	Y	31,471					31,471			
< 0.8 um	Antimony	ICP/MS	Y	75.2	87.6	85.3	81.9	4.1	82.7	6.6	8.0	16.4
< 0.8 um	Antimony	ICP	N	192 J					192 J			
< 0.8 um	Arsenic	ICP/MS	Y	2,889	2,789	2,937	2,967	1.0	2,872	75	2.6	187
< 0.8 um	Arsenic	GFAA	N	3,300	3,120	3,130			3,183	101	3.2	251
< 0.8 um	Barium	ICP/MS	Y	17,163	16,730	15,503	15,547	0.3	16,465	861	5.2	2,138
< 0.8 um	Barium	ICP	N	18,431					18,431			
< 0.8 um	Beryllium	ICP/MS	Y	33.8	29.0	23.9	22.6	5.6	28.9	5.0	17.1	12.3
< 0.8 um	Beryllium	ICP	N	32.4					32.4			
< 0.8 um	Cadmium	ICP/MS	Y	125	123	112	110	1.4	120	7	6.0	18
< 0.8 um	Calcium	ICP	Y	29,608					29,608			
< 0.8 um	Chromium	ICP/MS	Y	2,058	1,721	2,175	2,164	0.5	1,985	235	11.9	585
< 0.8 um	Chromium	ICP	N	2,333					2,333			
< 0.8 um	Coalt	ICP/MS	Y	50.5	39.6	44.0	44.8	1.9	44.7	5.5	12.3	13.6
< 0.8 um	Coalt	ICP	N	58.0					58.0			
< 0.8 um	Copper	ICP/MS	Y	394	369	386	373	3.5	383	13	3.4	32
< 0.8 um	Copper	ICP	N	486					486			
< 0.8 um	Iron	ICP	Y	29,706					29,706			
< 0.8 um	Lead	ICP/MS	Y	163	141	147	150	1.9	151	12	7.7	29
< 0.8 um	Magnesium	ICP	Y	2,696					2,696			
< 0.8 um	Manganese	ICP/MS	Y	248	237	241	244	1.4	242	5	2.1	13
< 0.8 um	Manganese	ICP	N	275					275			
< 0.8 um	Mercury	ICP/MS	N	< 0.84	< 0.85	< 0.74	< 0.74	0.0	< 0.85	NA	NA	NA
< 0.8 um	Mercury	CVAA	Y	< 0.94	< 0.95	0.17 J			< 0.95	NA	NA	NA
< 0.8 um	Molydenum	ICP/MS	Y	764	730	769	772	0.3	755	21	2.8	53
< 0.8 um	Molydenum	ICP	N	701					701			
< 0.8 um	Nickel	ICP/MS	Y	1,534	1,395	1,592	1,586	0.4	1,507	101	6.7	251
< 0.8 um	Nickel	ICP	N	1,824					1,824			
< 0.8 um	Phosphorus	ICP	Y	1,118					1,118			
< 0.8 um	Potassium	ICP	Y	11,863					11,863			
< 0.8 um	Selenium	ICP/MS	Y	1,904	1,734	1,780	1,677	5.9	1,806	88	4.9	218
< 0.8 um	Selenium	GFAA	N	2,280	2,200	2,270			2,250	44	1.9	108
< 0.8 um	Sodium	ICP	Y	8,235					8,235			
< 0.8 um	Titanium	ICP	Y	3,176					3,176			

Table C-6. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Vanadium	ICP/MS	Y	1,977	1,970	1,980	1,993	0.6	1,976	6	0.3	14
< 0.8 um	Vanadium	ICP	N	2,333					2,333			
< 0.8 um	Zinc	ICP	Y	486					486			

Table C-7. FGD Inlet - Gastric Fluid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	9,940					9,940			
> 6.4 um	Antimony	ICP/MS	Y	0.72					0.72			
> 6.4 um	Antimony	ICP	N	< 24.0					< 24.0			
> 6.4 um	Arsenic	ICP/MS	N	< 0.51					< 0.51			
> 6.4 um	Arsenic	GFAA	Y	54.9					54.9			
> 6.4 um	Barium	ICP/MS	Y	411					411			
> 6.4 um	Barium	ICP	N	443					443			
> 6.4 um	Beryllium	ICP/MS	Y	1.47					1.47			
> 6.4 um	Beryllium	ICP	N	3.04					3.04			
> 6.4 um	Cadmium	ICP/MS	Y	1.22					1.22			
> 6.4 um	Calcium	ICP	Y	7,903					7,903			
> 6.4 um	Chromium	ICP/MS	N	12.8					12.8			
> 6.4 um	Chromium	ICP	Y	38.9					38.9			
> 6.4 um	Cobalt	ICP/MS	Y	5.00					5.00			
> 6.4 um	Cobalt	ICP	N	1.13 J					1.13 J			
> 6.4 um	Copper	ICP/MS	Y	40.6					40.6			
> 6.4 um	Copper	ICP	N	60.3					60.3			
> 6.4 um	Iron	ICP	Y	7,117					7,117			
> 6.4 um	Lead	ICP/MS	Y	18.5					18.5			
> 6.4 um	Magnesium	ICP	Y	2,833					2,833			
> 6.4 um	Manganese	ICP/MS	Y	19.3					19.3			
> 6.4 um	Manganese	ICP	N	45.0					45.0			
> 6.4 um	Mercury	ICP/MS	N	8.57					8.57			
> 6.4 um	Mercury	CVAA	Y	< 0.10					< 0.10			
> 6.4 um	Molybdenum	ICP/MS	Y	15.6					15.6			
> 6.4 um	Molybdenum	ICP	N	17.8					17.8			
> 6.4 um	Nickel	ICP/MS	Y	10.5					10.5			
> 6.4 um	Nickel	ICP	N	23.6					23.6			
> 6.4 um	Phosphorus	ICP	Y	1,243					1,243			
> 6.4 um	Potassium	ICP	Y	1,491					1,491			
> 6.4 um	Selenium	ICP/MS	N	< 0.52					< 0.52			
> 6.4 um	Selenium	GFAA	Y	5.77					5.77			
> 6.4 um	Titanium	ICP	Y	531					531			
> 6.4 um	Vanadium	ICP/MS	N	< 0.48					< 0.48			
> 6.4 um	Vanadium	ICP	Y	96.0					96.0			
> 6.4 um	Zinc	ICP	Y	2,237					2,237			

Table C-7. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Aluminum	ICP	Y	14,898					14,898			
6.4-0.8 um	Antimony	ICP/MS	Y	1.00					1.00			
6.4-0.8 um	Antimony	ICP	N	8.62 J					8.62 J			
6.4-0.8 um	Arsenic	ICP/MS	N	74.3					74.3			
6.4-0.8 um	Arsenic	GFAA	Y	187					187			
6.4-0.8 um	Barium	ICP/MS	Y	590					590			
6.4-0.8 um	Barium	ICP	N	667					667			
6.4-0.8 um	Beryllium	ICP/MS	Y	3.51					3.51			
6.4-0.8 um	Beryllium	ICP	N	5.38					5.38			
6.4-0.8 um	Cadmium	ICP/MS	Y	4.72					4.72			
6.4-0.8 um	Calcium	ICP	Y	7,868					7,868			
6.4-0.8 um	Chromium	ICP/MS	N	107					107			
6.4-0.8 um	Chromium	ICP	Y	157					157			
6.4-0.8 um	Cobalt	ICP/MS	Y	11.9					11.9			
6.4-0.8 um	Cobalt	ICP	N	10.9					10.9			
6.4-0.8 um	Copper	ICP/MS	Y	71.9					71.9			
6.4-0.8 um	Copper	ICP	N	101					101			
6.4-0.8 um	Iron	ICP	Y	7,799					7,799			
6.4-0.8 um	Lead	ICP/MS	Y	57.6					57.6			
6.4-0.8 um	Magnesium	ICP	Y	3,116					3,116			
6.4-0.8 um	Manganese	ICP/MS	Y	30.3					30.3			
6.4-0.8 um	Manganese	ICP	N	59.9					59.9			
6.4-0.8 um	Mercury	ICP/MS	N	4.16					4.16			
6.4-0.8 um	Mercury	CVAA	Y	0.12					0.12			
6.4-0.8 um	Molybdenum	ICP/MS	Y	38.5					38.5			
6.4-0.8 um	Molybdenum	ICP	N	49.3					49.3			
6.4-0.8 um	Nickel	ICP/MS	Y	62.7					62.7			
6.4-0.8 um	Nickel	ICP	N	97.4					97.4			
6.4-0.8 um	Phosphorus	ICP	Y	2,824					2,824			
6.4-0.8 um	Potassium	ICP	Y	2,687					2,687			
6.4-0.8 um	Selenium	ICP/MS	N	3.38					3.38			
6.4-0.8 um	Selenium	GFAA	Y	13.1					13.1			
6.4-0.8 um	Titanium	ICP	Y	672					672			
6.4-0.8 um	Vanadium	ICP/MS	N	< 0.48					< 0.48			
6.4-0.8 um	Vanadium	ICP	Y	240					240			
6.4-0.8 um	Zinc	ICP	Y	315					315			

Table C-7. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Aluminum	ICP	Y	17,211					17,211			
< 0.8 um	Antimony	ICP/MS	Y	1.81			2.00	10.4	1.81			
< 0.8 um	Antimony	ICP	N	< 23.8					< 23.8			
< 0.8 um	Arsenic	ICP/MS	N	62.3			115.3	59.6	62.3			
< 0.8 um	Arsenic	GFAA	Y	171					171			
< 0.8 um	Barium	ICP/MS	Y	542			406	28.6	542			
< 0.8 um	Barium	ICP	N	619					619			
< 0.8 um	Beryllium	ICP/MS	Y	4.18			5.54	28.0	4.18			
< 0.8 um	Beryllium	ICP	N	7.00					7.00			
< 0.8 um	Cadmium	ICP/MS	Y	5.49			5.14	6.5	5.49			
< 0.8 um	Calcium	ICP	Y	8,279					8,279			
< 0.8 um	Chromium	ICP/MS	N	401			367	8.8	401			
< 0.8 um	Chromium	ICP	Y	535					535			
< 0.8 um	Cobalt	ICP/MS	Y	17.8			21.4	18.3	17.8			
< 0.8 um	Cobalt	ICP	N	22.9					22.9			
< 0.8 um	Copper	ICP/MS	Y	73.0			76.2	4.3	73.0			
< 0.8 um	Copper	ICP	N	107					107			
< 0.8 um	Iron	ICP	Y	12,364					12,364			
< 0.8 um	Lead	ICP/MS	Y	60.5			64.5	6.5	60.5			
< 0.8 um	Magnesium	ICP	Y	1,939					1,939			
< 0.8 um	Manganese	ICP/MS	Y	90.2			110.6	20.3	90.2			
< 0.8 um	Manganese	ICP	N	152					152			
< 0.8 um	Mercury	ICP/MS	N	3.12			1.36	78.5	3.12			
< 0.8 um	Mercury	CVAA	Y	< 0.09					< 0.09			
< 0.8 um	Molybdenum	ICP/MS	Y	44.7			50.9	12.9	44.7			
< 0.8 um	Molybdenum	ICP	N	50.1					50.1			
< 0.8 um	Nickel	ICP/MS	Y	101			118	15.1	101			
< 0.8 um	Nickel	ICP	N	158					158			
< 0.8 um	Phosphorus	ICP	Y	2,384					2,384			
< 0.8 um	Potassium	ICP	Y	2,532					2,532			
< 0.8 um	Selenium	ICP/MS	N	11.5			12.5	8.7	11.5			
< 0.8 um	Selenium	GFAA	Y	17.5					17.5			
< 0.8 um	Titanium	ICP	Y	789					789			
< 0.8 um	Vanadium	ICP/MS	N	< 0.48			< 0.48	0.0	< 0.48			
< 0.8 um	Vanadium	ICP	Y	253					253			
< 0.8 um	Zinc	ICP	Y	294					294			

Table C-8. High Load Stack Emissions - Gastric Fluid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	27,500					27,500			
> 6.4 um	Antimony	ICP/MS	Y	26.3	28.8	25.5	27.2	6.4	26.8	1.7	6.4	4.3
> 6.4 um	Antimony	ICP	N	< 241					< 241			
> 6.4 um	Arsenic	ICP/MS	N	630	650	483	882	58.5	587	91	15.5	227
> 6.4 um	Arsenic	GFAA	Y	1,400	1,410	1,380			1,397	15	1.1	38
> 6.4 um	Barium	ICP/MS	Y	2,554	2,037	2,545	2,530	0.6	2,379	296	12.4	735
> 6.4 um	Barium	ICP	N	2,600					2,600			
> 6.4 um	Beryllium	ICP/MS	Y	14.3	11.1	11.1	17.1	42.7	12.1	1.8	15.1	4.6
> 6.4 um	Beryllium	ICP	N	16.2					16.2			
> 6.4 um	Cadmium	ICP/MS	Y	83.3	92.2	351.2	326.9	7.2	175.6	152.2	86.7	377.8
> 6.4 um	Calcium	ICP	Y	48,800					48,800			
> 6.4 um	Chromium	ICP/MS	Y	649	744	934	769	19.3	776	145	18.7	360
> 6.4 um	Chromium	ICP	N	917					< 917			
> 6.4 um	Cobalt	ICP/MS	Y	28.5	31.6	37.7	44.2	15.8	32.6	4.7	14.4	11.7
> 6.4 um	Cobalt	ICP	N	< 34.0					< 34.0			
> 6.4 um	Copper	ICP/MS	Y	178	191	198	181	9.1	189	10	5.5	26
> 6.4 um	Copper	ICP	N	264					264			
> 6.4 um	Iron	ICP	Y	36,200					36,200			
> 6.4 um	Lead	ICP/MS	Y	83.8	56.8	2,109.9	2,214.7	4.8	750.1	1,177.6	157.0	2,923.6
> 6.4 um	Magnesium	ICP	Y	3,560					3,560			
> 6.4 um	Manganese	ICP/MS	Y	132	139	166	188	12.2	146	18	12.6	46
> 6.4 um	Manganese	ICP	N	322					322			
> 6.4 um	Mercury	ICP/MS	N	55.3	34.4	31.5	14.7	72.9	40.4	13.0	32.1	32.2
> 6.4 um	Mercury	CVAA	Y	3.20	< 0.91	< 0.92			1.37	1.58	115.5	3.93
> 6.4 um	Molybdenum	ICP/MS	Y	262	279	220	247	11.4	254	30	11.9	75
> 6.4 um	Molybdenum	ICP	N	299					299			
> 6.4 um	Nickel	ICP/MS	Y	653	850	1,145	1,170	2.1	883	248	28.1	615
> 6.4 um	Nickel	ICP	N	1,050					1,050			
> 6.4 um	Phosphorus	ICP	Y	7,980					7,980			
> 6.4 um	Potassium	ICP	Y	2,280 J					2,280 J			
> 6.4 um	Selenium	ICP/MS	N	656	610	647	551	16.0	638	24	3.8	60
> 6.4 um	Selenium	GFAA	Y	832	885	802			840	42	5.0	104
> 6.4 um	Titanium	ICP	Y	2,200					2,200			
> 6.4 um	Vanadium	ICP/MS	N	< 4.89	< 4.61	< 4.70	< 4.70	0.0	< 4.89	NA	NA	NA
> 6.4 um	Vanadium	ICP	Y	2,040					2,040			
> 6.4 um	Zinc	ICP	Y	796					796			

Table C-8. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Aluminum	ICP	Y	36,154					36,154			
6.4-0.8 um	Antimony	ICP/MS	Y	33.4	43.0	42.5	˙42.5	0.0	39.6	5.4	13.6	13.4
6.4-0.8 um	Antimony	ICP	N	< 232					< 232			
6.4-0.8 um	Arsenic	ICP/MS	N	768	978	973	1,162	17.7	906	120	13.2	298
6.4-0.8 um	Arsenic	GFAA	Y	1,650	1,840	1,780			1,757	97	5.5	241
6.4-0.8 um	Barium	ICP/MS	Y	2,828	3,294	3,329	2,950	12.1	3,150	280	8.9	695
6.4-0.8 um	Barium	ICP	N	3,019					3,019			
6.4-0.8 um	Beryllium	ICP/MS	Y	17.3	14.9	16.5	24.1	37.2	16.2	1.2	7.5	3.0
6.4-0.8 um	Beryllium	ICP	N	28.8					28.8			
6.4-0.8 um	Cadmium	ICP/MS	Y	1,065	1,706	916	816	11.5	1,229	420	34.2	1,042
6.4-0.8 um	Calcium	ICP	Y	37,019					37,019			
6.4-0.8 um	Chromium	ICP/MS	Y	558	445	837	632	27.9	614	201	32.8	500
6.4-0.8 um	Chromium	ICP	N	919					919			
6.4-0.8 um	Cobalt	ICP/MS	Y	26.7	520.0	30.0	31.1	3.9	28.3 a	2.3	8.2	20.8
6.4-0.8 um	Cobalt	ICP	N	7.88 J					7.88 J			
6.4-0.8 um	Copper	ICP/MS	Y	179	201	205	190	7.8	195	14	7.3	35
6.4-0.8 um	Copper	ICP	N	304					304			
6.4-0.8 um	Iron	ICP	Y	31,250					31,250			
6.4-0.8 um	Lead	ICP/MS	Y	1,130	7,218	612	646	5.5	2,986	3,673	123.0	9,120
6.4-0.8 um	Magnesium	ICP	Y	3,971					3,971			
6.4-0.8 um	Manganese	ICP/MS	Y	80.0	92.3	154.5	142.7	7.9	108.9	39.9	36.6	99.1
6.4-0.8 um	Manganese	ICP	N	282					282			
6.4-0.8 um	Mercury	ICP/MS	N	118	49	41	18	77.9	69	43	61.6	106
6.4-0.8 um	Mercury	CVAA	Y	< 0.92	1.15	< 0.91			< 0.92	NA	NA	NA
6.4-0.8 um	Molybdenum	ICP/MS	Y	276	231	297	302	1.8	268	34	12.5	84
6.4-0.8 um	Molybdenum	ICP	N	340					340			
6.4-0.8 um	Nickel	ICP/MS	Y	431	552	521	486	7.0	501	63	12.6	157
6.4-0.8 um	Nickel	ICP	N	820					820			
6.4-0.8 um	Phosphorus	ICP	Y	7,846					7,846			
6.4-0.8 um	Potassium	ICP	Y	7,750					7,750			
6.4-0.8 um	Selenium	ICP/MS	N	519	546	580	512	12.4	549	30	5.5	75
6.4-0.8 um	Selenium	GFAA	Y	706	781	823			770	59	7.7	147
6.4-0.8 um	Titanium	ICP	Y	2,038					2,038			
6.4-0.8 um	Vanadium	ICP/MS	N	< 4.70	< 4.70	< 4.61	< 4.61	0.0	< 4.70	NA	NA	NA
6.4-0.8 um	Vanadium	ICP	Y	2,558					2,558			
6.4-0.8 um	Zinc	ICP	Y	843					843			

Table C-8. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Aluminum	ICP	Y	27,739					27,739			
< 0.8 um	Antimony	ICP/MS	Y	52.8	44.5	47.4	52.6	10.6	48.2	4.2	8.8	10.5
< 0.8 um	Antimony	ICP	N	122 J					122 J			
< 0.8 um	Arsenic	ICP/MS	N	1,395	1,237	1,245	1,713	31.7	1,292	89	6.9	222
< 0.8 um	Arsenic	GFAA	Y	2,280	2,220	2,150			2,217	65	2.9	162
< 0.8 um	Barium	ICP/MS	Y	1,930	1,968	2,292	2,249	1.9	2,063	199	9.7	495
< 0.8 um	Barium	ICP	N	2,104					2,104			
< 0.8 um	Beryllium	ICP/MS	Y	14.6	18.5	15.6	24.5	44.3	16.2	2.0	12.6	5.1
< 0.8 um	Beryllium	ICP	N	33.7					33.7			
< 0.8 um	Cadmium	ICP/MS	Y	107	124	119	113	5.4	117	9	7.4	22
< 0.8 um	Calcium	ICP	Y	43,739					43,739			
< 0.8 um	Chromium	ICP/MS	Y	1,242	1,252	1,260	1,266	0.5	1,252	9	0.7	22
< 0.8 um	Chromium	ICP	N	1,757					1,757			
< 0.8 um	Cobalt	ICP/MS	Y	24.8	20.7	23.1	30.5	27.8	22.8	2.1	9.0	5.1
< 0.8 um	Cobalt	ICP	N	18.3 J					18.3 J			
< 0.8 um	Copper	ICP/MS	Y	192	182	206	224	8.4	193	12	6.2	30
< 0.8 um	Copper	ICP	N	329					329			
< 0.8 um	Iron	ICP	Y	34,261					34,261			
< 0.8 um	Lead	ICP/MS	Y	67.0	101.7	84.6	87.7	3.6	84.4	17.4	20.6	43.1
< 0.8 um	Magnesium	ICP	Y	3,113					3,113			
< 0.8 um	Manganese	ICP/MS	Y	110	159	128	173	29.8	132	25	18.6	61
< 0.8 um	Manganese	ICP	N	297					297			
< 0.8 um	Mercury	ICP/MS	N	46.1	32.7	29.3	14.7	66.7	36.0	8.9	24.6	22.0
< 0.8 um	Mercury	CVAA	Y	1.22	2.88	0.38 J			1.50	1.27	85.1	3.16
< 0.8 um	Molybdenum	ICP/MS	Y	690	738	728	861	16.8	718	26	3.6	63
< 0.8 um	Molybdenum	ICP	N	840					840			
< 0.8 um	Nickel	ICP/MS	Y	1,010	1,014	1,038	1,201	14.5	1,021	15	1.5	37
< 0.8 um	Nickel	ICP	N	1,626					1,626			
< 0.8 um	Phosphorus	ICP	Y	7,913					7,913			
< 0.8 um	Potassium	ICP	Y	11,217					11,217			
< 0.8 um	Selenium	ICP/MS	N	533	493	551	544	1.3	525	30	5.6	74
< 0.8 um	Selenium	GFAA	Y	750	765	779			765	15	1.9	36
< 0.8 um	Titanium	ICP	Y	1,791					1,791			
< 0.8 um	Vanadium	ICP/MS	N	238	< 5	< 5	< 5	0.0	81	136	168.2	338
< 0.8 um	Vanadium	ICP	Y	3,139					3,139			
< 0.8 um	Zinc	ICP	Y	817					817			

Table C-9. Low Load Stack Emissions - Gastric Fluid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	9,722					9,722			
> 6.4 um	Antimony	ICP/MS	Y	9.7	9.5	10.8	9.6	12.0	10.0	0.7	7.0	1.7
> 6.4 um	Antimony	ICP	N	98.1 J					98.1 J			
> 6.4 um	Arsenic	ICP/MS	N	< 4.77	< 5.00	< 5.05	354.17	194.4	< 5.05	NA	NA	NA
> 6.4 um	Arsenic	GFAA	Y	356	402	551			436	102	23.4	253
> 6.4 um	Barium	ICP/MS	Y	1,573	1,841	1,970	1,991	1.1	1,795	202	11.3	502
> 6.4 um	Barium	ICP	N	1,685					1,685			
> 6.4 um	Beryllium	ICP/MS	Y	2.08	0.97	3.43	8.33	83.3	2.16	1.23	57.0	3.06
> 6.4 um	Beryllium	ICP	N	9.54					9.54			
> 6.4 um	Cadmium	ICP/MS	Y	15.4	23.1	28.7	29.2	1.7	22.4	6.7	29.7	16.5
> 6.4 um	Calcium	ICP	Y	11,759					11,759			
> 6.4 um	Chromium	ICP/MS	N	14,000	14,253	11,516	8,355	31.8	13,256	1,513	11.4	3,756
> 6.4 um	Chromium	ICP	Y	25,741					25,741			
> 6.4 um	Cobalt	ICP/MS	Y	271	245	228	281	20.6	248	21	8.7	53
> 6.4 um	Cobalt	ICP	N	344					344			
> 6.4 um	Copper	ICP/MS	Y	249	193	335	371	10.2	259	72	27.6	178
> 6.4 um	Copper	ICP	N	384					384			
> 6.4 um	Iron	ICP	Y	72,130					72,130			
> 6.4 um	Lead	ICP/MS	Y	42.6	41.5	42.6	44.1	3.4	42.2	0.6	1.5	1.6
> 6.4 um	Magnesium	ICP	Y	1,537					1,537			
> 6.4 um	Manganese	ICP/MS	Y	765	873	1,048	1,298	21.3	895	143	16.0	355
> 6.4 um	Manganese	ICP	N	1,185					1,185			
> 6.4 um	Mercury	ICP/MS	N	107	48	25	11	76.7	60	42	70.6	105
> 6.4 um	Mercury	CVAA	Y	2.22	< 0.93	2.35			1.68	1.05	62.7	2.62
> 6.4 um	Molybdenum	ICP/MS	Y	106	173	79	101	24.5	119	48	40.5	120
> 6.4 um	Molybdenum	ICP	N	113					113			
> 6.4 um	Nickel	ICP/MS	Y	12,237	11,987	13,142	15,124	14.0	12,455	608	4.9	1,509
> 6.4 um	Nickel	ICP	N	18,056					18,056			
> 6.4 um	Phosphorus	ICP	Y	2,861					2,861			
> 6.4 um	Potassium	ICP	Y	< 3,426					< 3,426			
> 6.4 um	Selenium	ICP/MS	N	231	283	367	372	1.3	294	69	23.4	171
> 6.4 um	Selenium	GFAA	Y	408	452	545			468	70	14.9	174
> 6.4 um	Titanium	ICP	Y	651					651			
> 6.4 um	Vanadium	ICP/MS	N	< 4.53	< 4.74	< 4.79	< 4.79	0.0	< 4.79	NA	NA	NA
> 6.4 um	Vanadium	ICP	Y	435					435			
> 6.4 um	Zinc	ICP	Y	298					298			

Table C-9. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Aluminum	ICP	Y	31,500					31,500			
6.4-0.8 um	Antimony	ICP/MS	Y	23.8			27.3	13.7	23.8			
6.4-0.8 um	Antimony	ICP	N	117 J					117 J			
6.4-0.8 um	Arsenic	ICP/MS	N	481			1,002	70.3	481			
6.4-0.8 um	Arsenic	GFAA	Y	1,300					1,300			
6.4-0.8 um	Barium	ICP/MS	Y	4,865			3,712	26.9	4,865			
6.4-0.8 um	Barium	ICP	N	5,100					5,100			
6.4-0.8 um	Beryllium	ICP/MS	Y	13.3			18.5	33.1	13.3			
6.4-0.8 um	Beryllium	ICP	N	11.4					11.4			
6.4-0.8 um	Cadmium	ICP/MS	Y	315			299	5.5	315			
6.4-0.8 um	Calcium	ICP	Y	24,200					24,200			
6.4-0.8 um	Chromium	ICP/MS	N	3,818			3,525	8.0	3,818			
6.4-0.8 um	Chromium	ICP	Y	4,580					4,580			
6.4-0.8 um	Cobalt	ICP/MS	Y	739			877	17.1	739			
6.4-0.8 um	Cobalt	ICP	N	975					975			
6.4-0.8 um	Copper	ICP/MS	Y	253			263	4.0	253			
6.4-0.8 um	Copper	ICP	N	366					366			
6.4-0.8 um	Iron	ICP	Y	38,300					38,300			
6.4-0.8 um	Lead	ICP/MS	Y	286			302	5.5	286			
6.4-0.8 um	Magnesium	ICP	Y	3,620					3,620			
6.4-0.8 um	Manganese	ICP/MS	Y	388			471	19.4	388			
6.4-0.8 um	Manganese	ICP	N	667					667			
6.4-0.8 um	Mercury	ICP/MS	N	106			15	150.2	106			
6.4-0.8 um	Mercury	CVAA	Y	< 0.96					< 0.96			
6.4-0.8 um	Molybdenum	ICP/MS	Y	174			201	14.2	174			
6.4-0.8 um	Molybdenum	ICP	N	187					187			
6.4-0.8 um	Nickel	ICP/MS	Y	3,231			3,663	12.5	3,231			
6.4-0.8 um	Nickel	ICP	N	4,410					4,410			
6.4-0.8 um	Phosphorus	ICP	Y	7,510					7,510			
6.4-0.8 um	Potassium	ICP	Y	12,200					12,200			
6.4-0.8 um	Selenium	ICP/MS	N	666			695	4.2	666			
6.4-0.8 um	Selenium	GFAA	Y	922					922			
6.4-0.8 um	Titanium	ICP	Y	1,970					1,970			
6.4-0.8 um	Vanadium	ICP/MS	N	< 4.89			< 4.89	0.0	< 4.89			
6.4-0.8 um	Vanadium	ICP	Y	1,640					1,640			
6.4-0.8 um	Zinc	ICP	Y	538					538			

Table C-9. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Aluminum	ICP	Y	31,553					31,553			
< 0.8 um	Antimony	ICP/MS	Y	47.6	52.2	51.7	56.0	8.0	50.5	2.6	5.1	6.3
< 0.8 um	Antimony	ICP	N	< 234					< 234			
< 0.8 um	Arsenic	ICP/MS	N	1,612	1,645	1,832	2,176	17.1	1,697	119	7.0	295
< 0.8 um	Arsenic	GFAA	Y	2,670	2,800	2,590			2,687	106	3.9	263
< 0.8 um	Barium	ICP/MS	Y	2,929	2,330	3,441	2,714	23.6	2,900	556	19.2	1,380
< 0.8 um	Barium	ICP	N	3,223					3,223			
< 0.8 um	Beryllium	ICP/MS	Y	17.2	16.1	17.7	36.0	68.3	17.0	0.8	4.8	2.0
< 0.8 um	Beryllium	ICP	N	28.6					28.6			
< 0.8 um	Cadmium	ICP/MS	Y	120	120	110	120	8.2	117	6	4.8	14
< 0.8 um	Calcium	ICP	Y	31,553					31,553			
< 0.8 um	Chromium	ICP/MS	N	1,385	1,431	1,523	1,590	4.3	1,446	70	4.9	175
< 0.8 um	Chromium	ICP	Y	2,039					2,039			
< 0.8 um	Cobalt	ICP/MS	Y	31.1	31.2	35.1	47.4	29.8	32.5	2.3	7.1	5.7
< 0.8 um	Cobalt	ICP	N	15.0 J					15.0 J			
< 0.8 um	Copper	ICP/MS	Y	290	282	308	348	12.2	293	13	4.5	33
< 0.8 um	Copper	ICP	N	454					454			
< 0.8 um	Iron	ICP	Y	32,427					32,427			
< 0.8 um	Lead	ICP/MS	Y	40.0	37.6	24.4	27.8	13.2	34.0	8.4	24.8	21.0
< 0.8 um	Magnesium	ICP	Y	3,049					3,049			
< 0.8 um	Manganese	ICP/MS	Y	97.3	106.7	97.8	159.5	47.9	100.6	5.3	5.2	13.1
< 0.8 um	Manganese	ICP	N	328					328			
< 0.8 um	Mercury	ICP/MS	N	44.9	38.4	27.4	11.9	79.1	36.9	8.9	24.0	22.0
< 0.8 um	Mercury	CVAA	Y	1.36	4.55	< 0.83			2.11	2.17	102.9	5.39
< 0.8 um	Molybdenum	ICP/MS	Y	474	526	545	665	19.8	515	37	7.2	91
< 0.8 um	Molybdenum	ICP	N	642					642			
< 0.8 um	Nickel	ICP/MS	Y	1,040	1,067	1,095	1,417	25.6	1,067	28	2.6	69
< 0.8 um	Nickel	ICP	N	1,680					1,680			
< 0.8 um	Phosphorus	ICP	Y	7,738					7,738			
< 0.8 um	Potassium	ICP	Y	6,437					6,437			
< 0.8 um	Selenium	ICP/MS	N	1,064	1,150	1,318	1,254	4.9	1,177	129	11.0	320
< 0.8 um	Selenium	GFAA	Y	1,655	1,614	1,685			1,651	36	2.2	88
< 0.8 um	Titanium	ICP	Y	2,049					2,049			
< 0.8 um	Vanadium	ICP/MS	N	< 4.74	< 4.84	< 4.21	< 4.21	0.0	< 4.84	NA	NA	NA
< 0.8 um	Vanadium	ICP	Y	2,340					2,340			
< 0.8 um	Zinc	ICP	Y	571					571			

Table C-10. FGD Inlet - Acetic Acid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	149					149			
> 6.4 um	Antimony	ICP/MS	Y	0.87					0.87			
> 6.4 um	Antimony	ICP	N	< 23.9					< 23.9			
> 6.4 um	Arsenic	ICP/MS	Y	2.90					2.90			
> 6.4 um	Arsenic	GFAA	N	1.09					1.09			
> 6.4 um	Barium	ICP/MS	Y	40.2					40.2			
> 6.4 um	Barium	ICP	N	44.5					44.5			
> 6.4 um	Beryllium	ICP/MS	Y	0.35					0.35			
> 6.4 um	Beryllium	ICP	N	0.42 J					0.42 J			
> 6.4 um	Cadmium	ICP/MS	Y	0.97					0.97			
> 6.4 um	Calcium	ICP	N	4,149					4,149			
> 6.4 um	Chromium	ICP/MS	N	20.0					20.0			
> 6.4 um	Chromium	ICP	Y	26.2					26.2			
> 6.4 um	Cobalt	ICP/MS	Y	0.94					0.94			
> 6.4 um	Cobalt	ICP	N	< 3.37					< 3.37			
> 6.4 um	Copper	ICP/MS	Y	29.1					29.1			
> 6.4 um	Copper	ICP	N	18.7					18.7			
> 6.4 um	Iron	ICP	Y	62.4					62.4			
> 6.4 um	Lead	ICP/MS	Y	0.82					0.82			
> 6.4 um	Magnesium	ICP	Y	148					148			
> 6.4 um	Manganese	ICP/MS	Y	13.9					13.9			
> 6.4 um	Manganese	ICP	N	18.4					18.4			
> 6.4 um	Mercury	ICP/MS	N	18.4					18.4			
> 6.4 um	Mercury	CVAA	Y	< 0.05					< 0.05			
> 6.4 um	Molybdenum	ICP/MS	Y	5.20					5.20			
> 6.4 um	Molybdenum	ICP	N	2.99 J					2.99 J			
> 6.4 um	Nickel	ICP/MS	Y	15.0					15.0			
> 6.4 um	Nickel	ICP	N	23.8					23.8			
> 6.4 um	Phosphorus	ICP	Y	< 60.4					< 60.4			
> 6.4 um	Potassium	ICP	Y	260 J					260 J			
> 6.4 um	Selenium	ICP/MS	N	< 0.79					< 0.79			
> 6.4 um	Selenium	GFAA	Y	< 1.88					< 1.88			
> 6.4 um	Sodium	ICP	N	131,683					131,683			
> 6.4 um	Titanium	ICP	Y	1.09					1.09			
> 6.4 um	Vanadium	ICP/MS	N	< 0.06					< 0.06			
> 6.4 um	Vanadium	ICP	Y	< 2.34					< 2.34			

Table C-10. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Zinc	ICP	Y	2,079					2,079			
6.4-0.8 um	Aluminum	ICP	Y	1,019					1,019			
6.4-0.8 um	Antimony	ICP/MS	Y	2.27					2.27			
6.4-0.8 um	Antimony	ICP	N	22.7 J					22.7 J			
6.4-0.8 um	Arsenic	ICP/MS	Y	2.80					2.80			
6.4-0.8 um	Arsenic	GFAA	N	3.00					3.00			
6.4-0.8 um	Barium	ICP/MS	Y	121					121			
6.4-0.8 um	Barium	ICP	N	129					129			
6.4-0.8 um	Beryllium	ICP/MS	Y	0.87					0.87			
6.4-0.8 um	Beryllium	ICP	N	0.57					0.57			
6.4-0.8 um	Cadmium	ICP/MS	Y	2.45					2.45			
6.4-0.8 um	Calcium	ICP	N	3,516					3,516			
6.4-0.8 um	Chromium	ICP/MS	N	13.3					13.3			
6.4-0.8 um	Chromium	ICP	Y	21.0					21.0			
6.4-0.8 um	Cobalt	ICP/MS	Y	5.64					5.64			
6.4-0.8 um	Cobalt	ICP	N	4.70					4.70			
6.4-0.8 um	Copper	ICP/MS	Y	45.7					45.7			
6.4-0.8 um	Copper	ICP	N	35.5					35.5			
6.4-0.8 um	Iron	ICP	Y	1,049					1,049			
6.4-0.8 um	Lead	ICP/MS	Y	1.32					1.32			
6.4-0.8 um	Magnesium	ICP	Y	394					394			
6.4-0.8 um	Manganese	ICP/MS	Y	23.3					23.3			
6.4-0.8 um	Manganese	ICP	N	29.3					29.3			
6.4-0.8 um	Mercury	ICP/MS	N	4.77					4.77			
6.4-0.8 um	Mercury	CVAA	Y	< 0.05					< 0.05			
6.4-0.8 um	Molybdenum	ICP/MS	Y	12.0					12.0			
6.4-0.8 um	Molybdenum	ICP	N	1.13 J					1.13 J			
6.4-0.8 um	Nickel	ICP/MS	Y	54.9					54.9			
6.4-0.8 um	Nickel	ICP	N	73.3					73.3			
6.4-0.8 um	Phosphorus	ICP	Y	< 60.9					< 60.9			
6.4-0.8 um	Potassium	ICP	Y	1,518					1,518			
6.4-0.8 um	Selenium	ICP/MS	N	< 0.79					< 0.79			
6.4-0.8 um	Selenium	GFAA	Y	< 1.90					< 1.90			
6.4-0.8 um	Sodium	ICP	N	139,860					139,860			
6.4-0.8 um	Titanium	ICP	Y	2.91					2.91			
6.4-0.8 um	Vanadium	ICP/MS	N	< 0.06					< 0.06			

Table C-10. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Vanadium	ICP	Y	3.29					3.29			
6.4-0.8 um	Zinc	ICP	Y	199					199			
< 0.8 um	Aluminum	ICP	Y	1,028					1,028			
< 0.8 um	Antimony	ICP/MS	Y	1.17			1.27	8.2	1.17			
< 0.8 um	Antimony	ICP	N	< 24.1					< 24.1			
< 0.8 um	Arsenic	ICP/MS	Y	1.30			2.52	64.1	1.30			
< 0.8 um	Arsenic	GFAA	N	4.99					4.99			
< 0.8 um	Barium	ICP/MS	Y	111			114	2.7	111			
< 0.8 um	Barium	ICP	N	131					131			
< 0.8 um	Beryllium	ICP/MS	Y	0.82			1.30	44.7	0.82			
< 0.8 um	Beryllium	ICP	N	0.65					0.65			
< 0.8 um	Cadmium	ICP/MS	Y	3.27			3.54	8.1	3.27			
< 0.8 um	Calcium	ICP	N	4,790					4,790			
< 0.8 um	Chromium	ICP/MS	N	31.6			27.8	12.9	31.6			
< 0.8 um	Chromium	ICP	Y	48.4					48.4			
< 0.8 um	Cobalt	ICP/MS	Y	10.7			14.6	31.1	10.7			
< 0.8 um	Cobalt	ICP	N	11.3					11.3			
< 0.8 um	Copper	ICP/MS	Y	39.4			36.2	8.4	39.4			
< 0.8 um	Copper	ICP	N	34.7					34.7			
< 0.8 um	Iron	ICP	Y	946					946			
< 0.8 um	Lead	ICP/MS	Y	0.55			< 0.03	179.3	0.55			
< 0.8 um	Magnesium	ICP	Y	417					417			
< 0.8 um	Manganese	ICP/MS	Y	93.4			124.8	28.7	93.4			
< 0.8 um	Manganese	ICP	N	127					127			
< 0.8 um	Mercury	ICP/MS	N	2.07			0.17	168.9	2.07			
< 0.8 um	Mercury	CVAA	Y	0.02 J					0.02 J			
< 0.8 um	Molybdenum	ICP/MS	Y	3.69			3.77	2.0	3.69			
< 0.8 um	Molybdenum	ICP	N	< 4.62					< 4.62			
< 0.8 um	Nickel	ICP/MS	Y	90.8			124.0	30.9	90.8			
< 0.8 um	Nickel	ICP	N	141					141			
< 0.8 um	Phosphorus	ICP	Y	< 60.9					< 60.9			
< 0.8 um	Potassium	ICP	Y	950					950			
< 0.8 um	Selenium	ICP/MS	N	< 0.79			2.23	95.0	< 0.79			
< 0.8 um	Selenium	GFAA	Y	< 1.90					< 1.90			
< 0.8 um	Sodium	ICP	N	148,703					148,703			
< 0.8 um	Titanium	ICP	Y	1.84					1.84			

Table C-10. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Vanadium	ICP/MS	N	< 0.06			2.25	188.9	< 0.06			
< 0.8 um	Vanadium	ICP	Y	4.27					4.27			
< 0.8 um	Zinc	ICP	Y	157					157			

Table C-11. High Load Stack Emissions - Acetic Acid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	19,842					19,842			
> 6.4 um	Antimony	ICP/MS	Y	26.8	22.7	22.0	23.9	8.4	23.8	2.6	10.8	6.4
> 6.4 um	Antimony	ICP	N	76.3 J					76.3 J			
> 6.4 um	Arsenic	ICP/MS	Y	669	653	637	869	30.7	653	16	2.4	39
> 6.4 um	Arsenic	GFAA	N	555	514	535			535	21	3.8	51
> 6.4 um	Barium	ICP/MS	Y	807	1,043	961	1,031	7.0	937	120	12.8	297
> 6.4 um	Barium	ICP	N	838					838			
> 6.4 um	Beryllium	ICP/MS	Y	19.0	15.0	14.4	22.9	45.6	16.1	2.5	15.5	6.2
> 6.4 um	Beryllium	ICP	N	15.6					15.6			
> 6.4 um	Cadmium	ICP/MS	Y	91.7	79.7	74.8	93.8	22.6	82.1	8.7	10.6	21.6
> 6.4 um	Calcium	ICP	N	44,269					44,269			
> 6.4 um	Chromium	ICP/MS	Y	718	2,268	881	785	11.6	800 a	115	14.4	1,034
> 6.4 um	Chromium	ICP	N	755					755			
> 6.4 um	Cobalt	ICP/MS	Y	46.6	87.5	96.9	141.6	37.5	77.0	26.7	34.7	66.3
> 6.4 um	Cobalt	ICP	N	37.9					37.9			
> 6.4 um	Copper	ICP/MS	Y	409	361	315	393	22.0	362	47	12.9	116
> 6.4 um	Copper	ICP	N	228					228			
> 6.4 um	Iron	ICP	Y	16,047					16,047			
> 6.4 um	Lead	ICP/MS	Y	39.8	38.8	61.3	54.2	12.4	46.6	12.7	27.3	31.5
> 6.4 um	Magnesium	ICP	Y	3,028					3,028			
> 6.4 um	Manganese	ICP/MS	Y	328	454	404	573	34.5	395	64	16.1	158
> 6.4 um	Manganese	ICP	N	338					338			
> 6.4 um	Mercury	ICP/MS	N	< 0.58	< 0.58	< 0.57	3.57	144.9	< 0.58	NA	NA	NA
> 6.4 um	Mercury	CVAA	Y	< 0.20	< 0.20	< 0.19			< 0.20	NA	NA	NA
> 6.4 um	Molybdenum	ICP/MS	Y	114	102	63	64	0.3	93	27	28.5	66
> 6.4 um	Molybdenum	ICP	N	113					113			
> 6.4 um	Nickel	ICP/MS	Y	1,297	3,748	2,103	3,061	37.1	2,383	1,249	52.4	3,101
> 6.4 um	Nickel	ICP	N	1,411					1,411			
> 6.4 um	Phosphorus	ICP	Y	1,589					1,589			
> 6.4 um	Potassium	ICP	Y	3,917					3,917			
> 6.4 um	Selenium	ICP/MS	N	376	351	321	426	27.9	349	27	7.8	67
> 6.4 um	Selenium	GFAA	Y	418	397	361			392	29	7.4	72
> 6.4 um	Sodium	ICP	N	577,075					577,075			
> 6.4 um	Titanium	ICP	Y	810					810			
> 6.4 um	Vanadium	ICP/MS	Y	801	795	681	607	11.4	759	68	9.0	169
> 6.4 um	Vanadium	ICP	N	759					759			

Table C-11. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Zinc	ICP	Y	692					692			
6.4-0.8 um	Aluminum	ICP	Y	25,647					25,647			
6.4-0.8 um	Antimony	ICP/MS	Y	31.6	31.5	25.1	13.4	60.6	29.4	3.7	12.6	9.2
6.4-0.8 um	Antimony	ICP	N	119					119			
6.4-0.8 um	Arsenic	ICP/MS	Y	641	665	598	109	138.2	635	34	5.3	84
6.4-0.8 um	Arsenic	GFAA	N	527	581	569			559	28	5.1	70
6.4-0.8 um	Barium	ICP/MS	Y	835	967	1,013	1,027	1.4	938	92	9.8	229
6.4-0.8 um	Barium	ICP	N	812					812			
6.4-0.8 um	Beryllium	ICP/MS	Y	20.5	19.7	16.9	28.0	49.8	19.0	1.9	10.0	4.7
6.4-0.8 um	Beryllium	ICP	N	17.7					17.7			
6.4-0.8 um	Cadmium	ICP/MS	Y	969	1,023	2,722	3,398	22.1	1,571	997	63.5	2,475
6.4-0.8 um	Calcium	ICP	N	31,961					31,961			
6.4-0.8 um	Chromium	ICP/MS	Y	439	428	398	402	1.1	422	21	5.0	52
6.4-0.8 um	Chromium	ICP	N	475					475			
6.4-0.8 um	Cobalt	ICP/MS	Y	32.2	31.9	30.9	47.9	43.3	31.6	0.7	2.1	1.7
6.4-0.8 um	Cobalt	ICP	N	26.3					26.3			
6.4-0.8 um	Copper	ICP/MS	Y	279	267	240	362	40.7	262	20	7.7	50
6.4-0.8 um	Copper	ICP	N	232					232			
6.4-0.8 um	Iron	ICP	Y	13,490					13,490			
6.4-0.8 um	Lead	ICP/MS	Y	315	462	2,791	2,243	21.8	1,189	1,389	116.8	3,449
6.4-0.8 um	Magnesium	ICP	Y	2,973					2,973			
6.4-0.8 um	Manganese	ICP/MS	Y	198	196	200	274	31.3	198	2	1.1	6
6.4-0.8 um	Manganese	ICP	N	205					205			
6.4-0.8 um	Mercury	ICP/MS	N	< 0.58	< 0.58	< 0.58	0.29	65.3	< 0.58	NA	NA	NA
6.4-0.8 um	Mercury	CVAA	Y	< 0.20	< 0.20	< 0.20			< 0.20	NA	NA	NA
6.4-0.8 um	Molybdenum	ICP/MS	Y	135	153	115	54	71.5	134	19	14.2	47
6.4-0.8 um	Molybdenum	ICP	N	109					109			
6.4-0.8 um	Nickel	ICP/MS	Y	355	537	358	546	41.7	416	104	25.0	258
6.4-0.8 um	Nickel	ICP	N	408					408			
6.4-0.8 um	Phosphorus	ICP	Y	1,306					1,306			
6.4-0.8 um	Potassium	ICP	Y	3,898					3,898			
6.4-0.8 um	Selenium	ICP/MS	N	220	218	180	164	9.5	206	22	10.8	55
6.4-0.8 um	Selenium	GFAA	Y	284	315	255			285	30	10.5	74
6.4-0.8 um	Sodium	ICP	N	537,255					537,255			
6.4-0.8 um	Titanium	ICP	Y	682					682			
6.4-0.8 um	Vanadium	ICP/MS	Y	921	989	788	512	42.4	900	102	11.4	254

Table C-11. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Vanadium	ICP	N	910					910			
6.4-0.8 um	Zinc	ICP	Y	682					682			
< 0.8 um	Aluminum	ICP	Y	19,087					19,087			
< 0.8 um	Antimony	ICP/MS	Y	27.1	25.9	23.2	24.7	6.2	25.4	2.0	7.8	4.9
< 0.8 um	Antimony	ICP	N	144					144			
< 0.8 um	Arsenic	ICP/MS	Y	611	440	466	607	26.2	506	92	18.2	228
< 0.8 um	Arsenic	GFAA	N	617	429	478			508	98	19.2	242
< 0.8 um	Barium	ICP/MS	Y	576	749	686	727	5.9	670	88	13.1	217
< 0.8 um	Barium	ICP	N	591					591			
< 0.8 um	Beryllium	ICP/MS	Y	22.0	23.2	19.2	29.5	42.1	21.5	2.1	9.5	5.1
< 0.8 um	Beryllium	ICP	N	24.0					24.0			
< 0.8 um	Cadmium	ICP/MS	Y	107.2	115.1	106.0	128.7	19.4	109.4	5.0	4.5	12.3
< 0.8 um	Calcium	ICP	N	37,897					37,897			
< 0.8 um	Chromium	ICP/MS	Y	956	973	881	803	9.3	937	49	5.2	121
< 0.8 um	Chromium	ICP	N	1,131					1,131			
< 0.8 um	Cobalt	ICP/MS	Y	26.8	33.1	26.6	41.1	42.9	28.8	3.7	12.8	9.2
< 0.8 um	Cobalt	ICP	N	20.5					20.5			
< 0.8 um	Copper	ICP/MS	Y	333	335	261	322	21.1	310	42	13.7	105
< 0.8 um	Copper	ICP	N	230					230			
< 0.8 um	Iron	ICP	Y	12,540					12,540			
< 0.8 um	Lead	ICP/MS	Y	21.5	16.2	14.6	60.1	121.6	17.5	3.6	20.7	9.0
< 0.8 um	Magnesium	ICP	Y	2,131					2,131			
< 0.8 um	Manganese	ICP/MS	Y	207	247	204	298	37.3	219	24	10.9	59
< 0.8 um	Manganese	ICP	N	242					242			
< 0.8 um	Mercury	ICP/MS	N	< 0.59	< 0.58	< 0.59	0.20	98.8	< 0.59	NA	NA	NA
< 0.8 um	Mercury	CVAA	Y	0.04 J	< 0.20	0.04 J			< 0.20	NA	NA	NA
< 0.8 um	Molybdenum	ICP/MS	Y	327	256	257	251	2.3	280	41	14.6	102
< 0.8 um	Molybdenum	ICP	N	295					295			
< 0.8 um	Nickel	ICP/MS	Y	1,023	1,172	968	1,515	44.1	1,054	105	10.0	262
< 0.8 um	Nickel	ICP	N	1,349					1,349			
< 0.8 um	Phosphorus	ICP	Y	722					722			
< 0.8 um	Potassium	ICP	Y	2,087					2,087			
< 0.8 um	Selenium	ICP/MS	N	159	118	112	266	81.5	130	25	19.5	63
< 0.8 um	Selenium	GFAA	Y	265	205	206			225	34	15.2	85
< 0.8 um	Sodium	ICP	N	488,095					488,095			
< 0.8 um	Titanium	ICP	Y	437					437			

Table C-11. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Vanadium	ICP/MS	Y	872	569	622	600	3.7	688	162	23.5	402
< 0.8 um	Vanadium	ICP	N	833					833			
< 0.8 um	Zinc	ICP	Y	679					679			

Table C-12. Low Load Stack Emissions - Acetic Acid-Extractable Concentration Results (ug/g)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Aluminum	ICP	Y	4,431					4,431			
> 6.4 um	Antimony	ICP/MS	Y	5.98	3.24	5.65	7.14	23.3	4.96	1.50	30.3	3.72
> 6.4 um	Antimony	ICP	N	116					116			
> 6.4 um	Arsenic	ICP/MS	Y	172	100	191	153	21.7	154	48	30.8	118
> 6.4 um	Arsenic	GFAA	N	191	123	223			179	51	28.5	127
> 6.4 um	Barium	ICP/MS	Y	714	657	798	866	8.1	723	71	9.9	177
> 6.4 um	Barium	ICP	N	678					678			
> 6.4 um	Beryllium	ICP/MS	Y	3.63	3.04	3.77	6.94	59.3	3.48	0.39	11.1	0.96
> 6.4 um	Beryllium	ICP	N	4.35					4.35			
> 6.4 um	Cadmium	ICP/MS	Y	23.3	18.4	25.0	27.8	10.5	22.3	3.4	15.3	8.5
> 6.4 um	Calcium	ICP	N	12,078					12,078			
> 6.4 um	Chromium	ICP/MS	Y	7,859	4,157	4,439	4,008	10.2	5,485	2,061	37.6	5,116
> 6.4 um	Chromium	ICP	N	15,647					15,647			
> 6.4 um	Cobalt	ICP/MS	Y	349	285	225	358	45.5	287	62	21.6	154
> 6.4 um	Cobalt	ICP	N	408					408			
> 6.4 um	Copper	ICP/MS	Y	363	228	247	333	29.6	279	73	26.0	181
> 6.4 um	Copper	ICP	N	300					300			
> 6.4 um	Iron	ICP	Y	23,137					23,137			
> 6.4 um	Lead	ICP/MS	Y	10.6	6.6	7.7	6.6	15.2	8.3	2.1	24.9	5.1
> 6.4 um	Magnesium	ICP	Y	933					933			
> 6.4 um	Manganese	ICP/MS	Y	944	686	671	1,007	40.0	767	153	20.0	381
> 6.4 um	Manganese	ICP	N	1,106					1,106			
> 6.4 um	Mercury	ICP/MS	N	74.8	2.3	< 0.6	1.4	81.3	25.8	42.5	164.7	105.4
> 6.4 um	Mercury	CVAA	Y	0.08 J	< 0.20	< 0.20			< 0.20	NA	NA	NA
> 6.4 um	Molybdenum	ICP/MS	Y	72.5	12.3	37.9	49.2	26.0	40.9	30.3	74.0	75.1
> 6.4 um	Molybdenum	ICP	N	45.5					45.5			
> 6.4 um	Nickel	ICP/MS	Y	15,438	12,645	11,291	11,071	2.0	13,125	2,114	16.1	5,249
> 6.4 um	Nickel	ICP	N	22,745					22,745			
> 6.4 um	Phosphorus	ICP	Y	154 J					154 J			
> 6.4 um	Potassium	ICP	Y	839 J					839 J			
> 6.4 um	Selenium	ICP/MS	N	82.5	< 3.1	67.3	188.2	94.7	50.5	43.0	85.3	106.8
> 6.4 um	Selenium	GFAA	Y	186	77	169			144	59	41.0	146
> 6.4 um	Sodium	ICP	N	549,020					549,020			
> 6.4 um	Titanium	ICP	Y	216					216			
> 6.4 um	Vanadium	ICP/MS	Y	120	46	111	133	18.1	92	40	43.6	100
> 6.4 um	Vanadium	ICP	N	117					117			

Table C-12. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
> 6.4 um	Zinc	ICP	Y	248					248			
6.4-0.8 um	Aluminum	ICP	Y	15,578					15,578			
6.4-0.8 um	Antimony	ICP/MS	Y	17.0			18.7	9.5	17.9			
6.4-0.8 um	Antimony	ICP	N	93.6 J					93.6 J			
6.4-0.8 um	Arsenic	ICP/MS	Y	385			277	32.8	331			
6.4-0.8 um	Arsenic	GFAA	N	414					414			
6.4-0.8 um	Barium	ICP/MS	Y	920			988	7.2	954			
6.4-0.8 um	Barium	ICP	N	996					996			
6.4-0.8 um	Beryllium	ICP/MS	Y	9.26			12.45	29.4	10.86			
6.4-0.8 um	Beryllium	ICP	N	11.1					11.1			
6.4-0.8 um	Cadmium	ICP/MS	Y	99.1			121.3	20.2	110.2			
6.4-0.8 um	Calcium	ICP	N	18,606					18,606			
6.4-0.8 um	Chromium	ICP/MS	Y	2,302			2,114	8.5	2,208			
6.4-0.8 um	Chromium	ICP	N	3,211					3,211			
6.4-0.8 um	Cobalt	ICP/MS	Y	68.3			100.6	38.2	84.5			
6.4-0.8 um	Cobalt	ICP	N	68.5					68.5			
6.4-0.8 um	Copper	ICP/MS	Y	217			275	23.8	246			
6.4-0.8 um	Copper	ICP	N	204					204			
6.4-0.8 um	Iron	ICP	Y	13,546					13,546			
6.4-0.8 um	Lead	ICP/MS	Y	46.6			43.5	6.9	45.1			
6.4-0.8 um	Magnesium	ICP	Y	1,952					1,952			
6.4-0.8 um	Manganese	ICP/MS	Y	269			392	37.1	331			
6.4-0.8 um	Manganese	ICP	N	337					337			
6.4-0.8 um	Mercury	ICP/MS	N	< 0.59			1.79	101.2	< 1.19			
6.4-0.8 um	Mercury	CVAA	Y	< 0.20					< 0.20			
6.4-0.8 um	Molybdenum	ICP/MS	Y	42.7			54.1	23.5	48.4			
6.4-0.8 um	Molybdenum	ICP	N	31.9					31.9			
6.4-0.8 um	Nickel	ICP/MS	Y	2,900			4,088	34.0	3,494			
6.4-0.8 um	Nickel	ICP	N	3,904					3,904			
6.4-0.8 um	Phosphorus	ICP	Y	861					861			
6.4-0.8 um	Potassium	ICP	Y	725 J					725 J			
6.4-0.8 um	Selenium	ICP/MS	N	174			267	41.9	220			
6.4-0.8 um	Selenium	GFAA	Y	316					316			
6.4-0.8 um	Sodium	ICP	N	509,960					509,960			
6.4-0.8 um	Titanium	ICP	Y	478					478			
6.4-0.8 um	Vanadium	ICP/MS	Y	334			343	2.6	338			

Table C-12. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
6.4-0.8 um	Vanadium	ICP	N	398					398			
6.4-0.8 um	Zinc	ICP	Y	346					346			
< 0.8 um	Aluminum	ICP	Y	21,693					21,693			
< 0.8 um	Antimony	ICP/MS	Y	21.3	22.7	25.7	27.6	7.3	23.2	2.3	9.7	5.6
< 0.8 um	Antimony	ICP	N	50.4 J					50.4 J			
< 0.8 um	Arsenic	ICP/MS	Y	599	576	690	476	36.7	621	60	9.7	150
< 0.8 um	Arsenic	GFAA	N	608	561	614			594	29	4.9	72
< 0.8 um	Barium	ICP/MS	Y	706	516	872	874	0.3	698	178	25.5	442
< 0.8 um	Barium	ICP	N	795					795			
< 0.8 um	Beryllium	ICP/MS	Y	21.0	18.8	20.3	28.8	34.3	20.0	1.1	5.6	2.8
< 0.8 um	Beryllium	ICP	N	20.9					20.9			
< 0.8 um	Cadmium	ICP/MS	Y	115	93	97	113	15.4	102	12	11.5	29
< 0.8 um	Calcium	ICP	N	26,929					26,929			
< 0.8 um	Chromium	ICP/MS	Y	1,013	947	1,078	919	16.0	1,013	66	6.5	163
< 0.8 um	Chromium	ICP	N	1,413					1,413			
< 0.8 um	Cobalt	ICP/MS	Y	214	35	37	52	34.6	95	103	107.9	255
< 0.8 um	Cobalt	ICP	N	279					279			
< 0.8 um	Copper	ICP/MS	Y	417	379	336	387	14.0	378	41	10.8	101
< 0.8 um	Copper	ICP	N	348					348			
< 0.8 um	Iron	ICP	Y	10,709					10,709			
< 0.8 um	Lead	ICP/MS	Y	12.4	11.5	12.2	9.6	24.0	12.0	0.5	4.1	1.2
< 0.8 um	Magnesium	ICP	Y	2,213					2,213			
< 0.8 um	Manganese	ICP/MS	Y	191	184	203	266	26.9	193	10	5.0	24
< 0.8 um	Manganese	ICP	N	243					243			
< 0.8 um	Mercury	ICP/MS	N	118	26	17	2	158.5	53	56	104.5	139
< 0.8 um	Mercury	CVAA	Y	< 0.20	< 0.20	< 0.19			< 0.20	NA	NA	NA
< 0.8 um	Molybdenum	ICP/MS	Y	187	174	216	213	1.6	192	21	11.1	53
< 0.8 um	Molybdenum	ICP	N	163					163			
< 0.8 um	Nickel	ICP/MS	Y	1,125	1,014	1,108	1,503	30.3	1,083	60	5.5	149
< 0.8 um	Nickel	ICP	N	1,575					1,575			
< 0.8 um	Phosphorus	ICP	Y	1,000					1,000			
< 0.8 um	Potassium	ICP	Y	3,520					3,520			
< 0.8 um	Selenium	ICP/MS	N	374	366	433	489	12.0	391	37	9.4	91
< 0.8 um	Selenium	GFAA	Y	555	508	548			537	25	4.7	63
< 0.8 um	Sodium	ICP	N	515,748					515,748			
< 0.8 um	Titanium	ICP	Y	421					421			

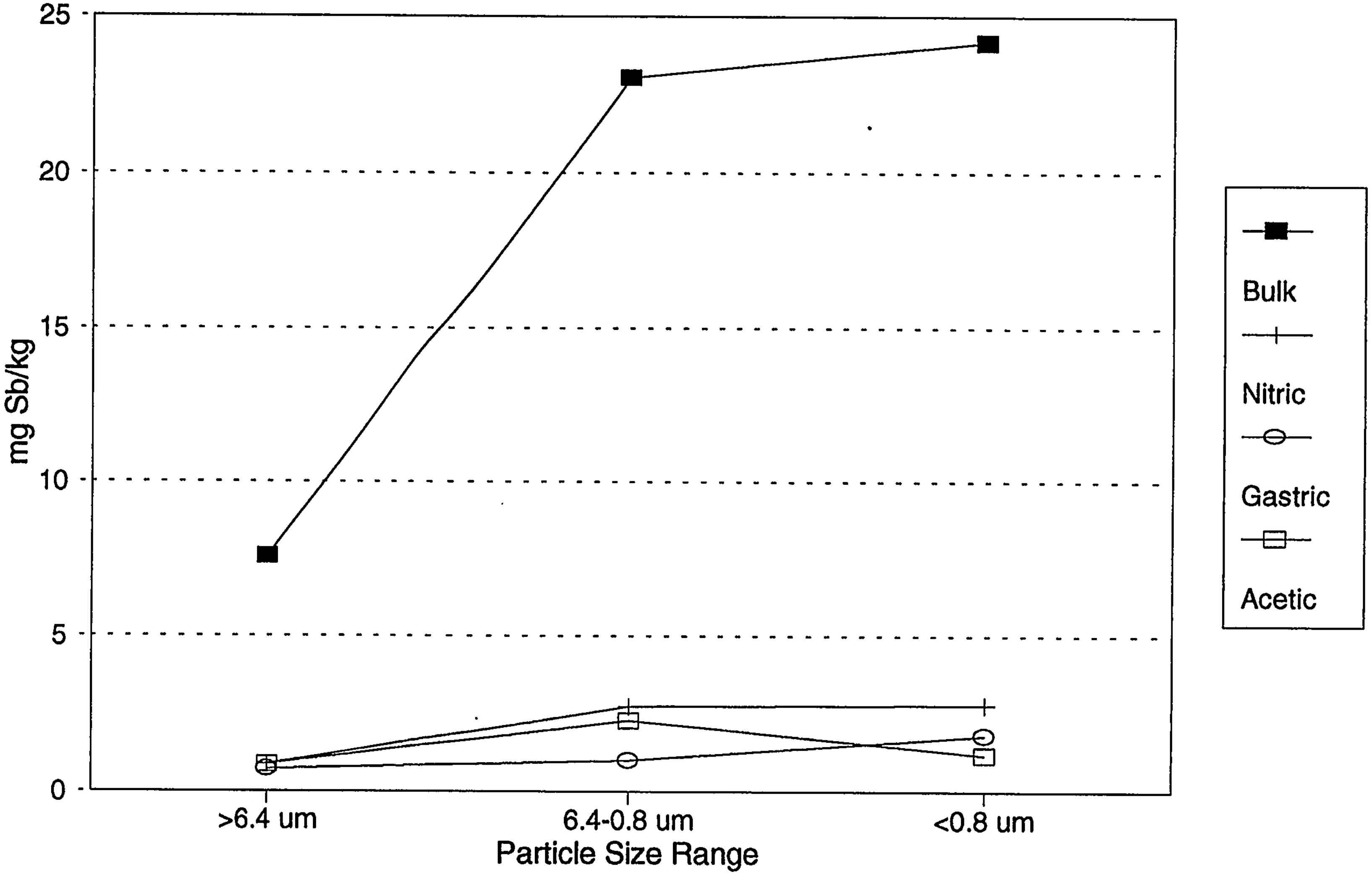
Table C-12. (Continued)

Size Range	Element	Analysis	Y/N	Run 1	Run 2	Run 3	Duplicate	RPD	Average	Std. Dev.	RSD	95% CI
< 0.8 um	Vanadium	ICP/MS	Y	494	489	550	494	10.7	511	34	6.7	85
< 0.8 um	Vanadium	ICP	N	591					591			
< 0.8 um	Zinc	ICP	Y	445					445			

APPENDIX D: PHASE II PLOTS; CONCENTRATION VS. PARTICLE SIZE

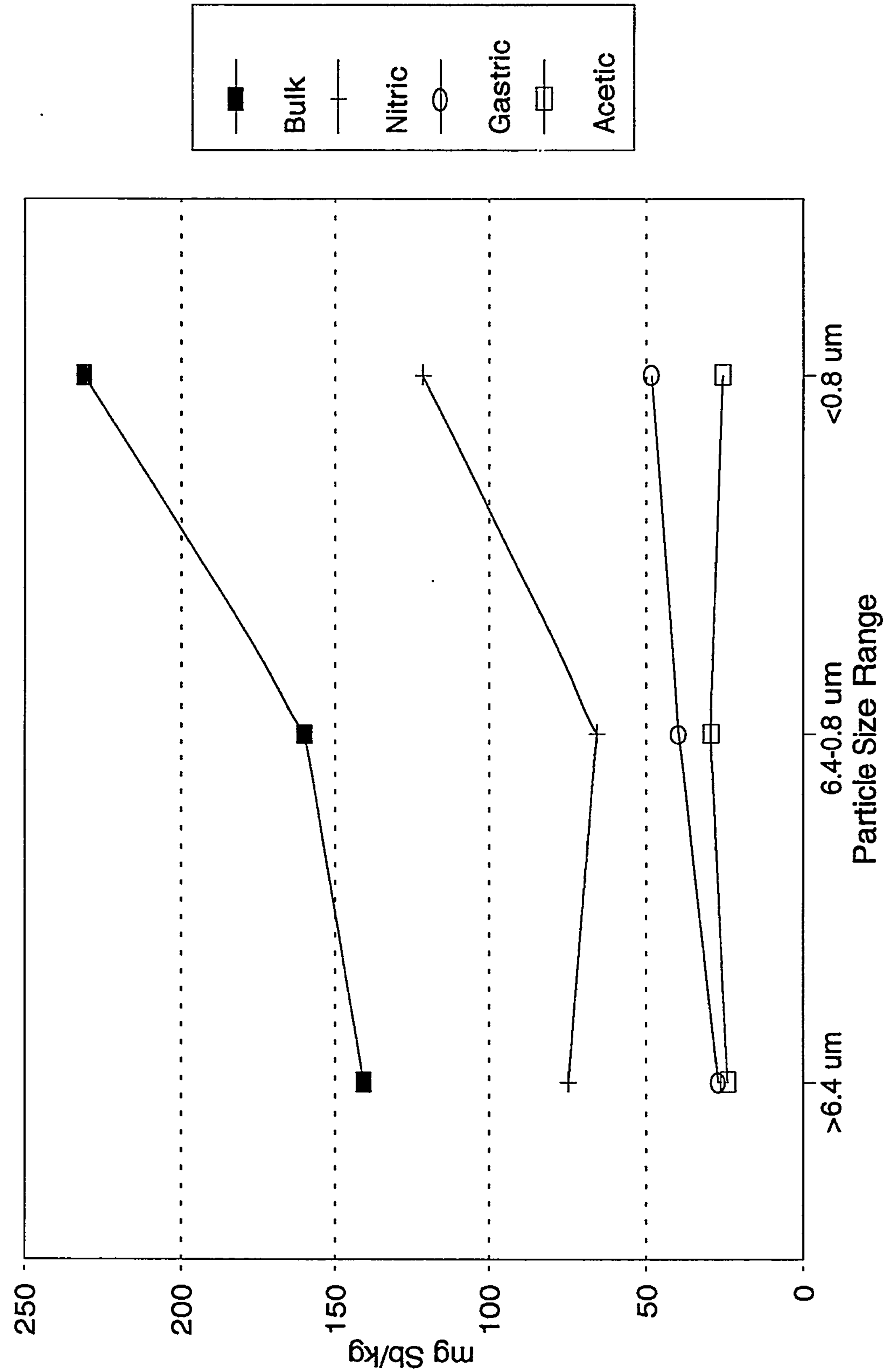
FGD Inlet

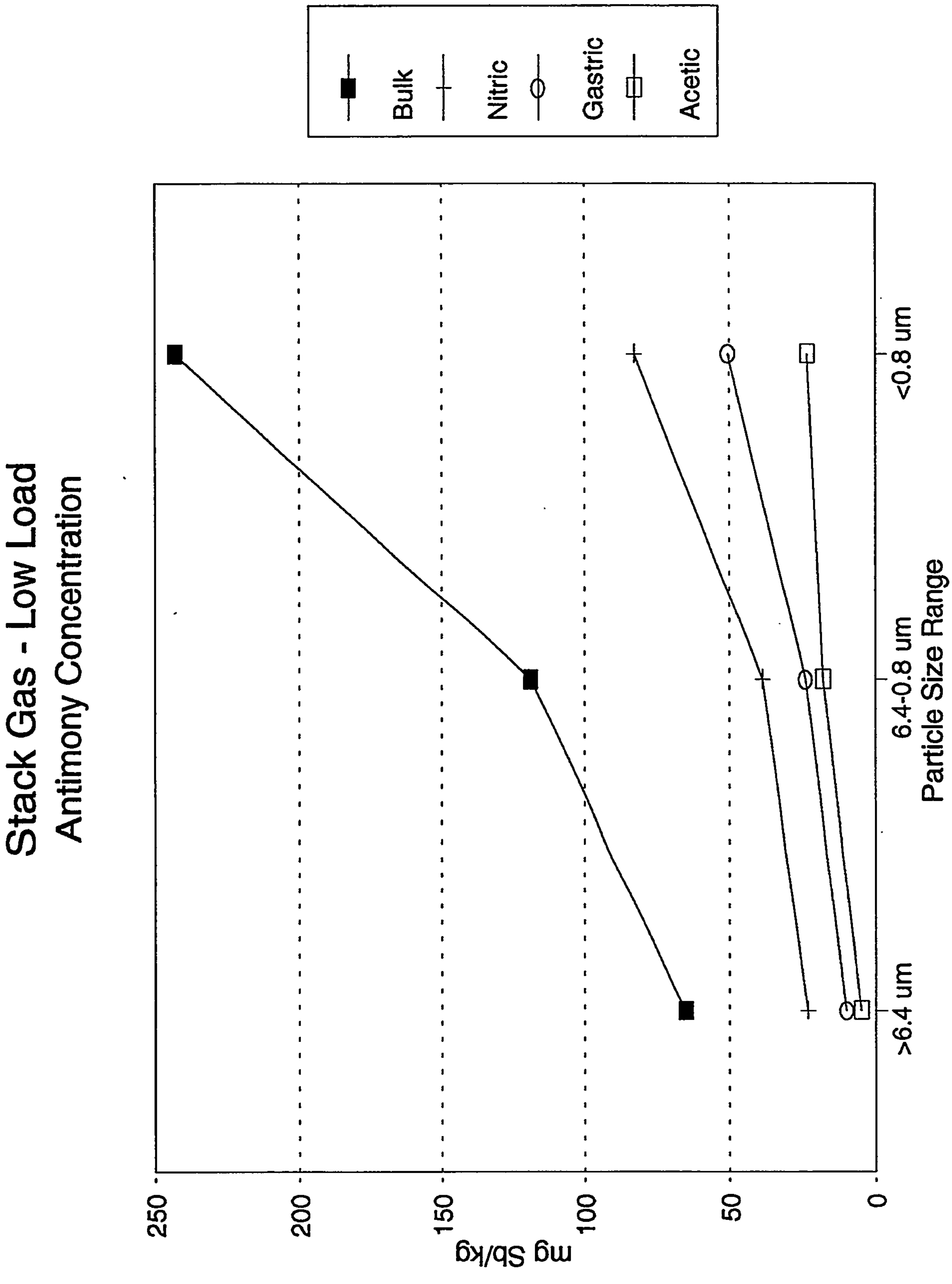
Antimony Concentration



Stack Gas - High Load

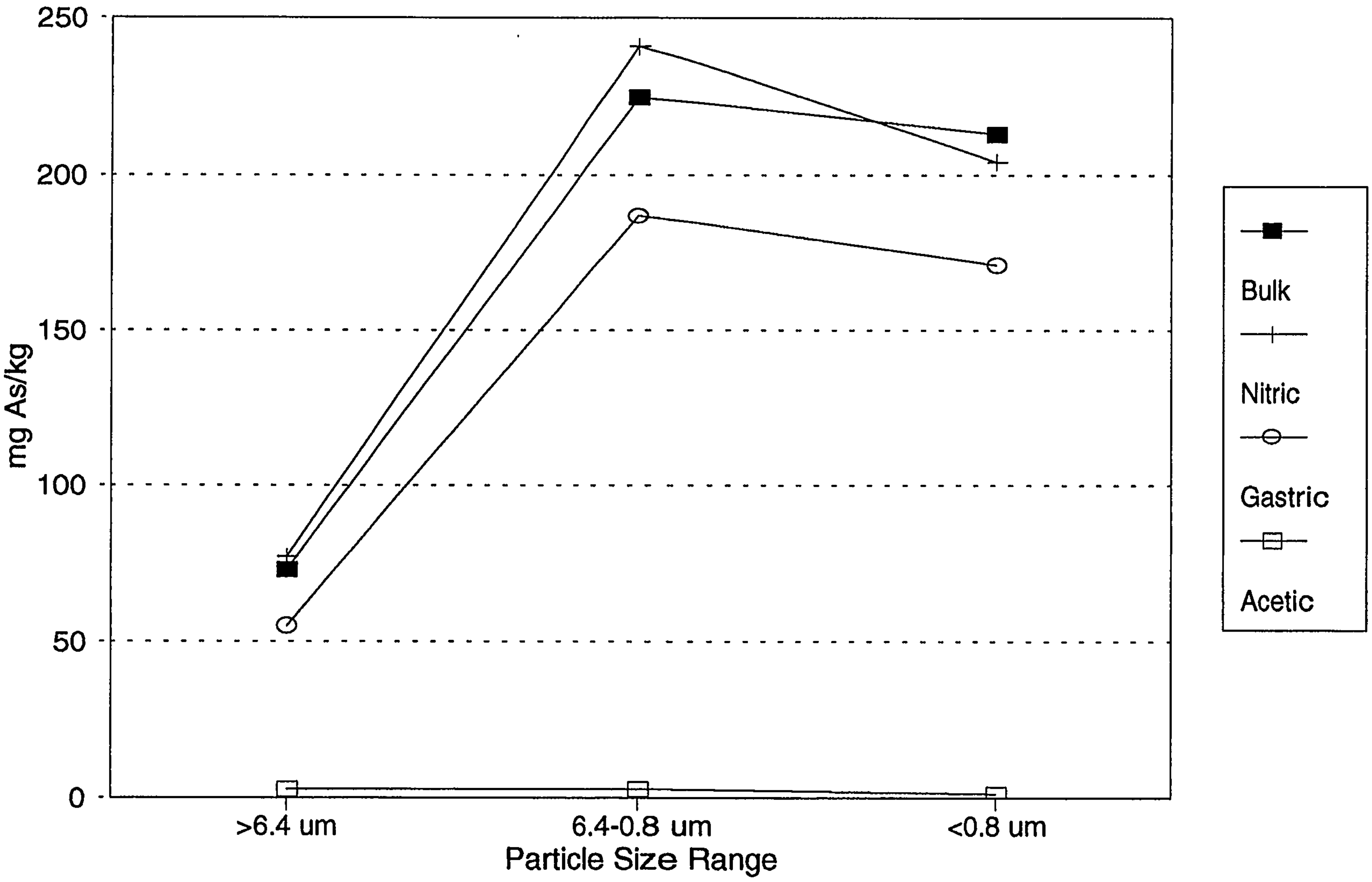
Antimony Concentration



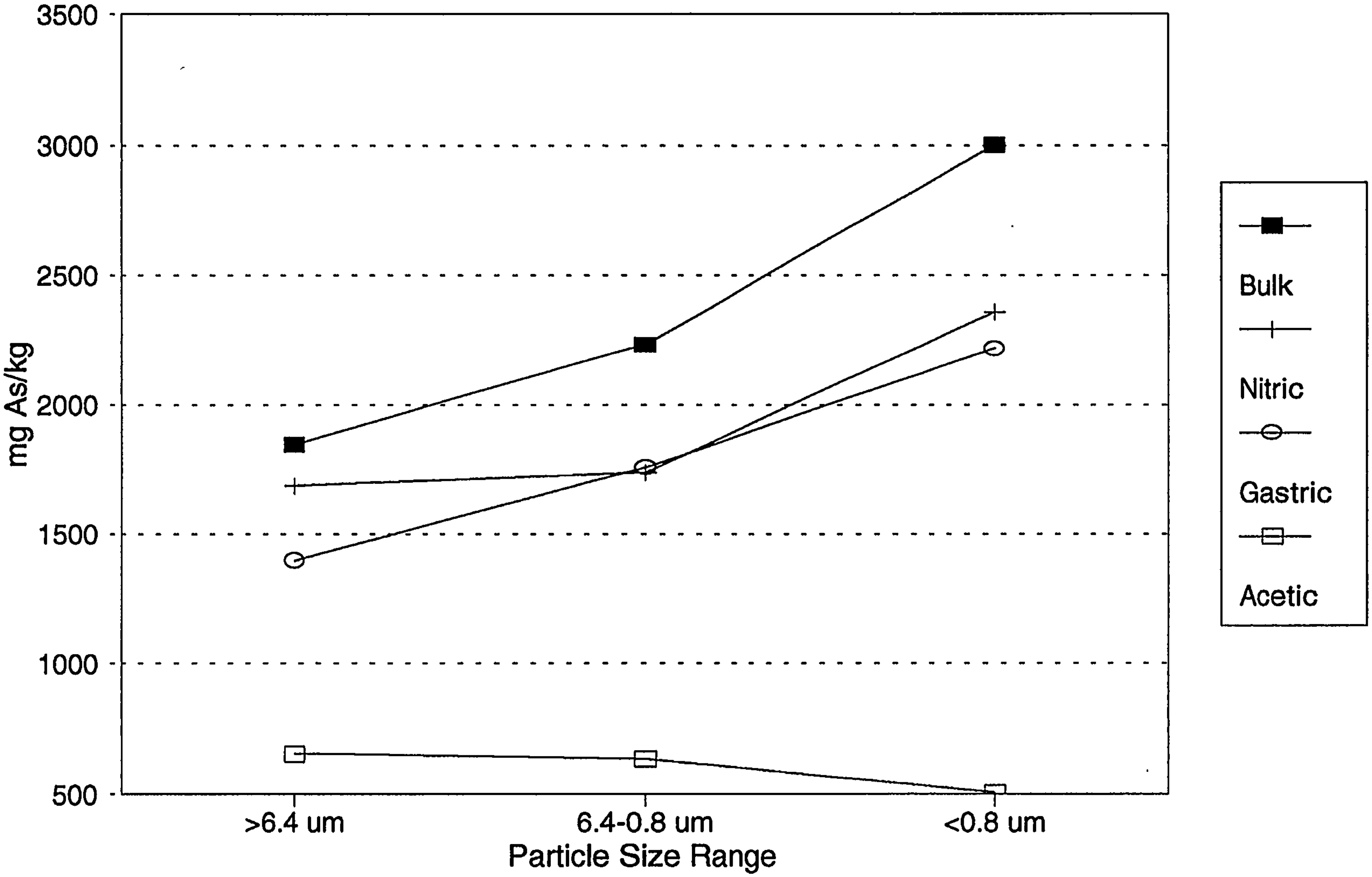

Stack Gas - Low Load
Antimony Concentration
mg Sb/kg
250
200
150
100
50
0
>6.4 um
6.4-0.8 um
<0.8 um
Particle Size Range
Bulk
Nitric
Gastric
Acetic

FGD Inlet

Arsenic Concentration

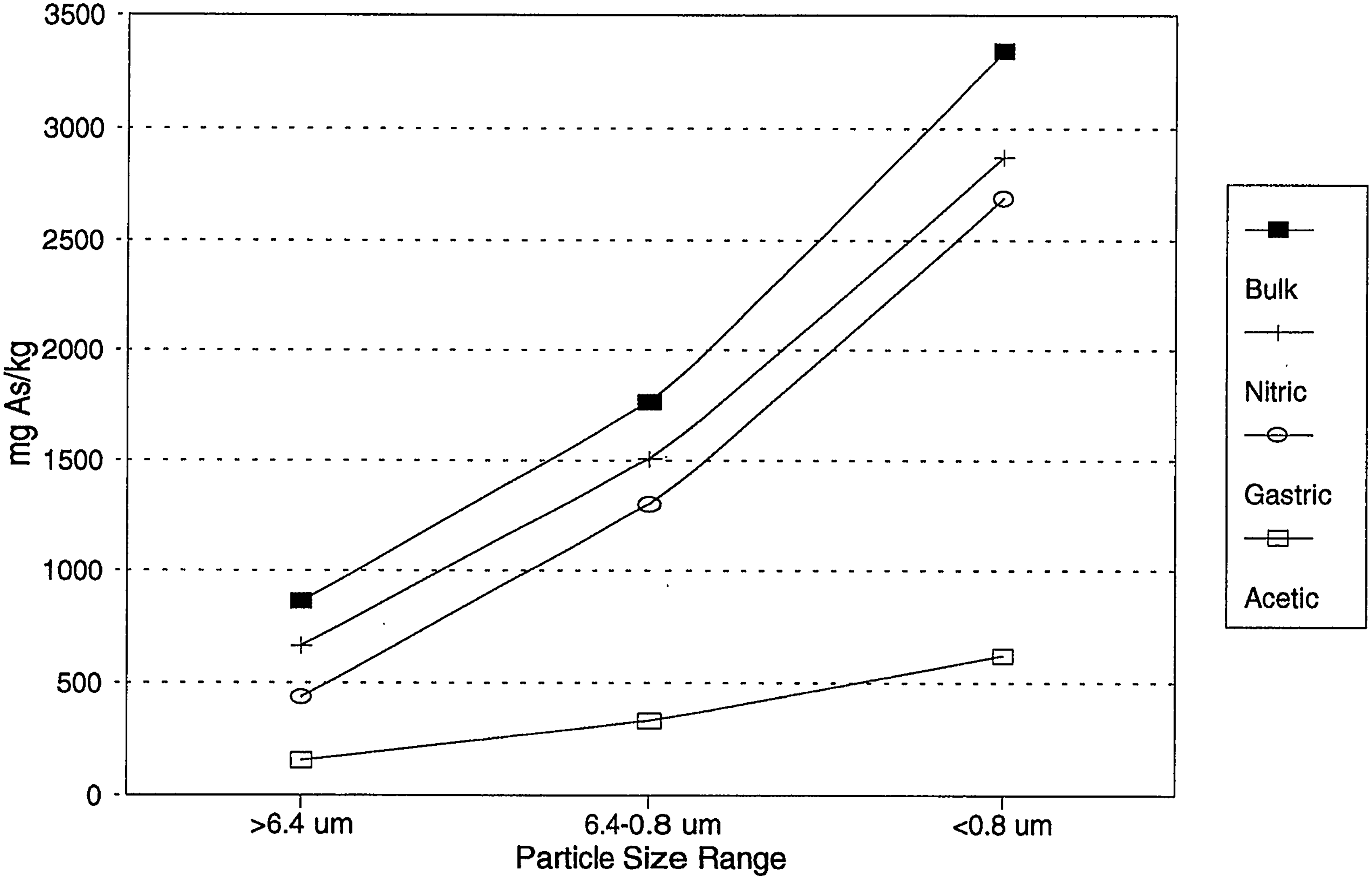


Stack Gas - High Load
Arsenic Concentration



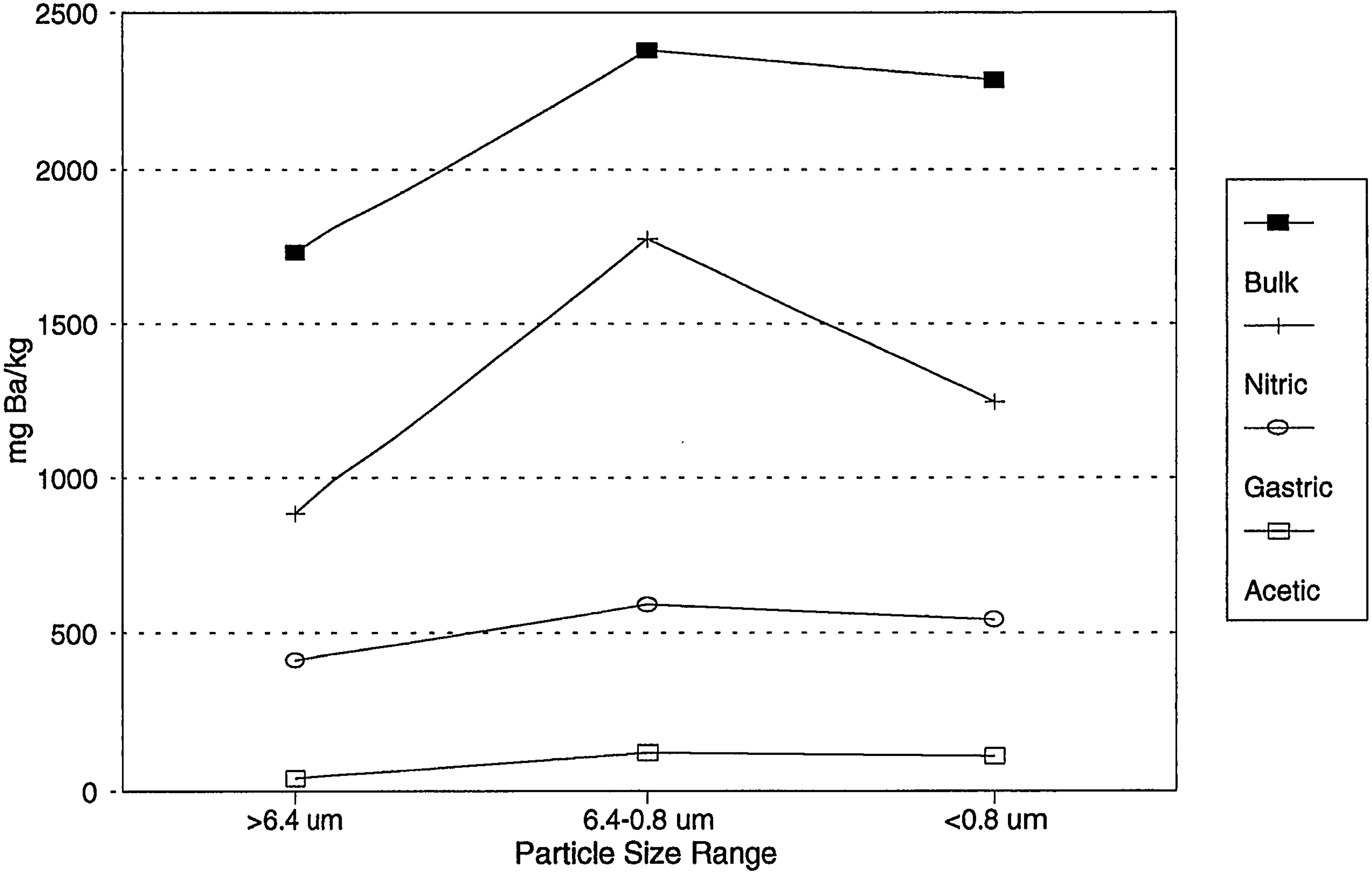
Stack Gas - Low Load

Arsenic Concentration

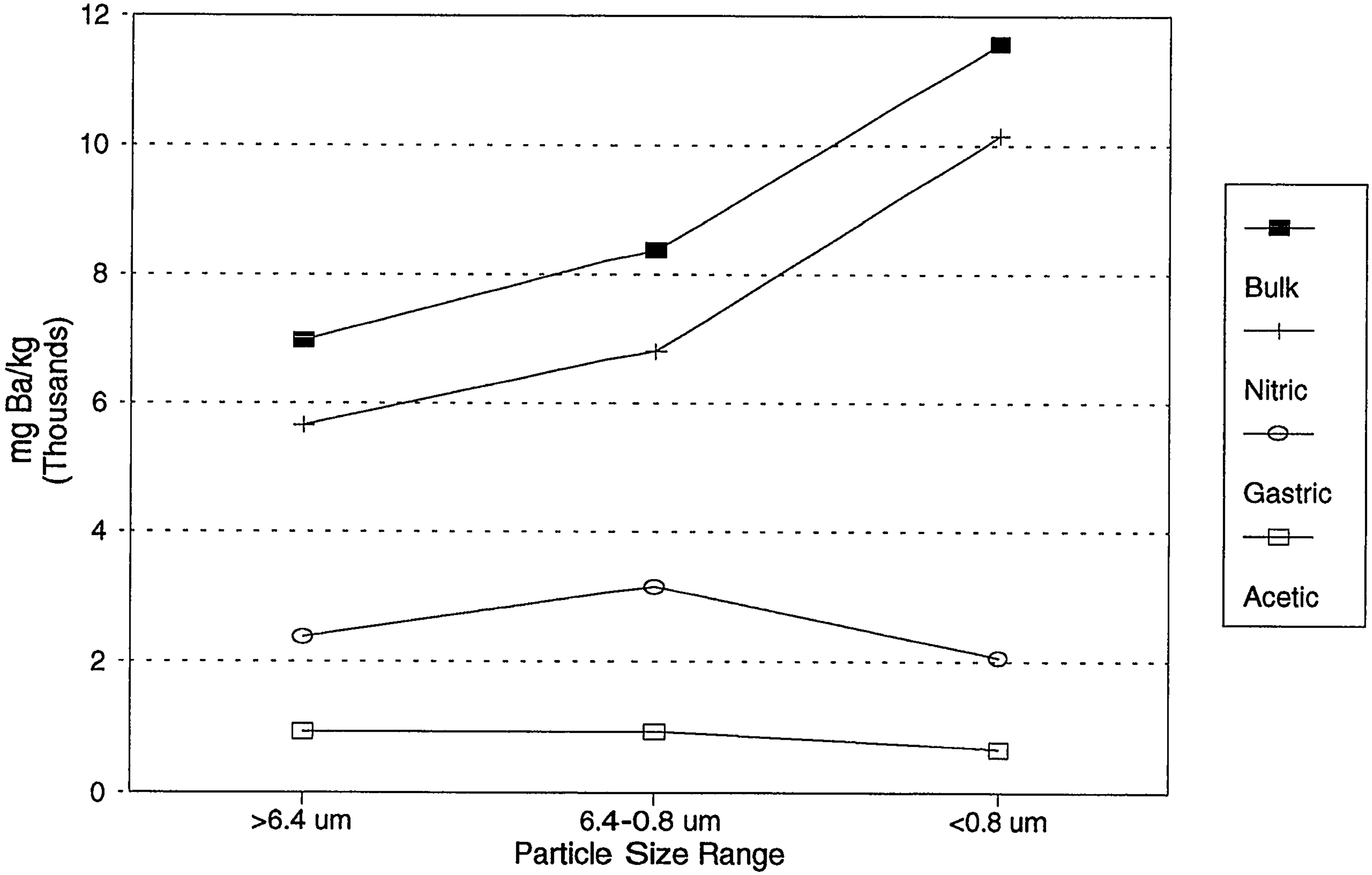


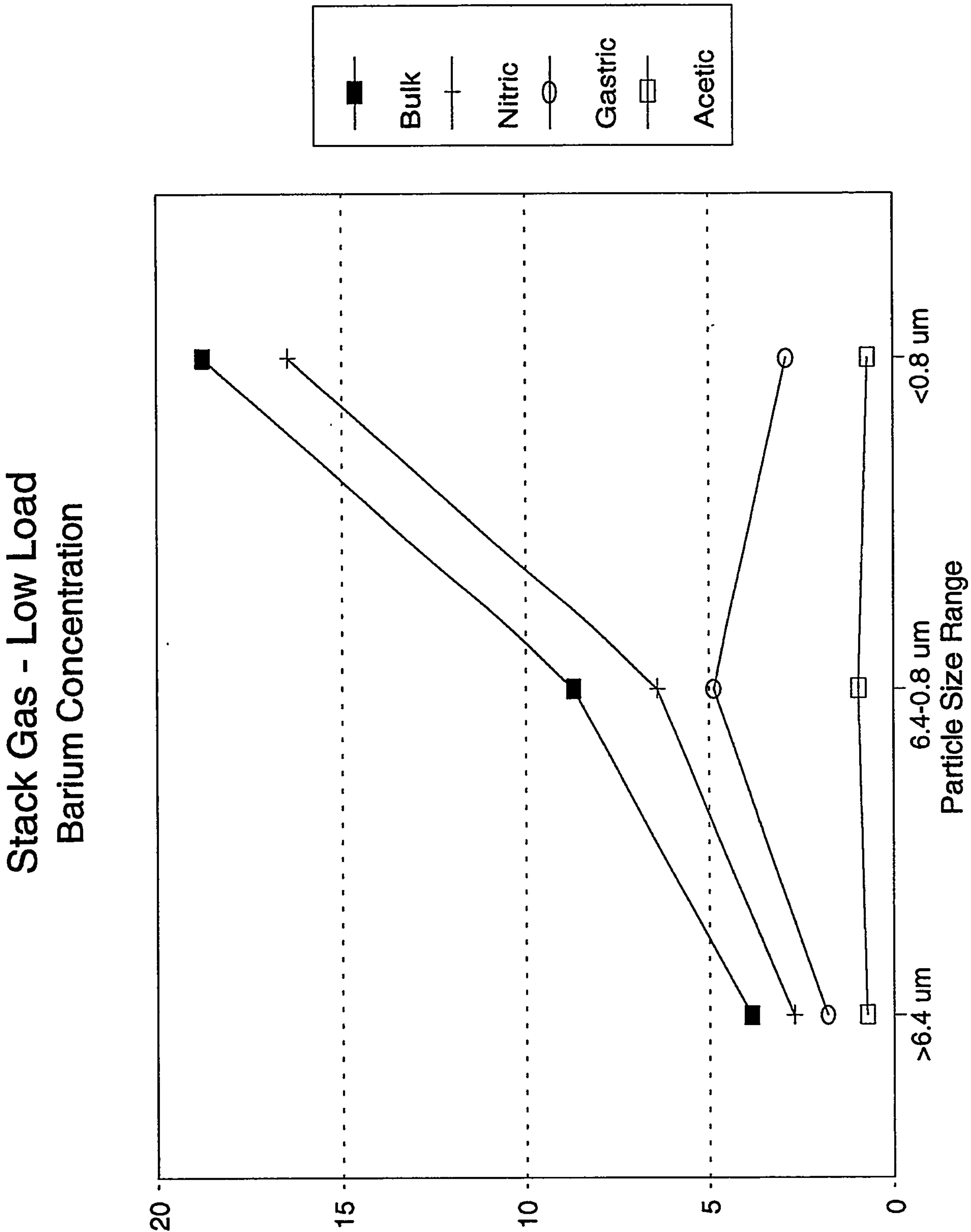
FGD Inlet

Barium Concentration



Stack Gas - High Load
Barium Concentration

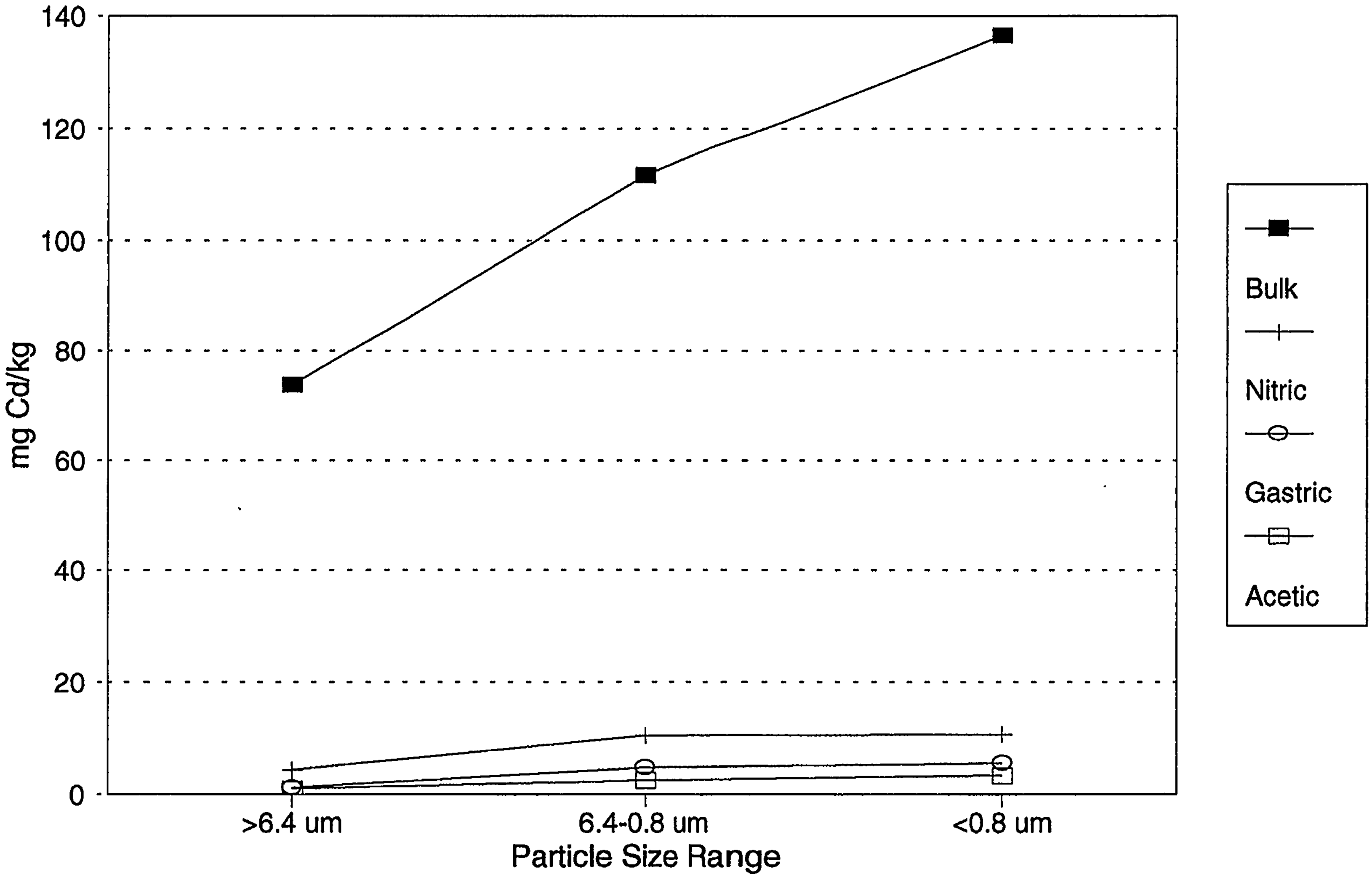


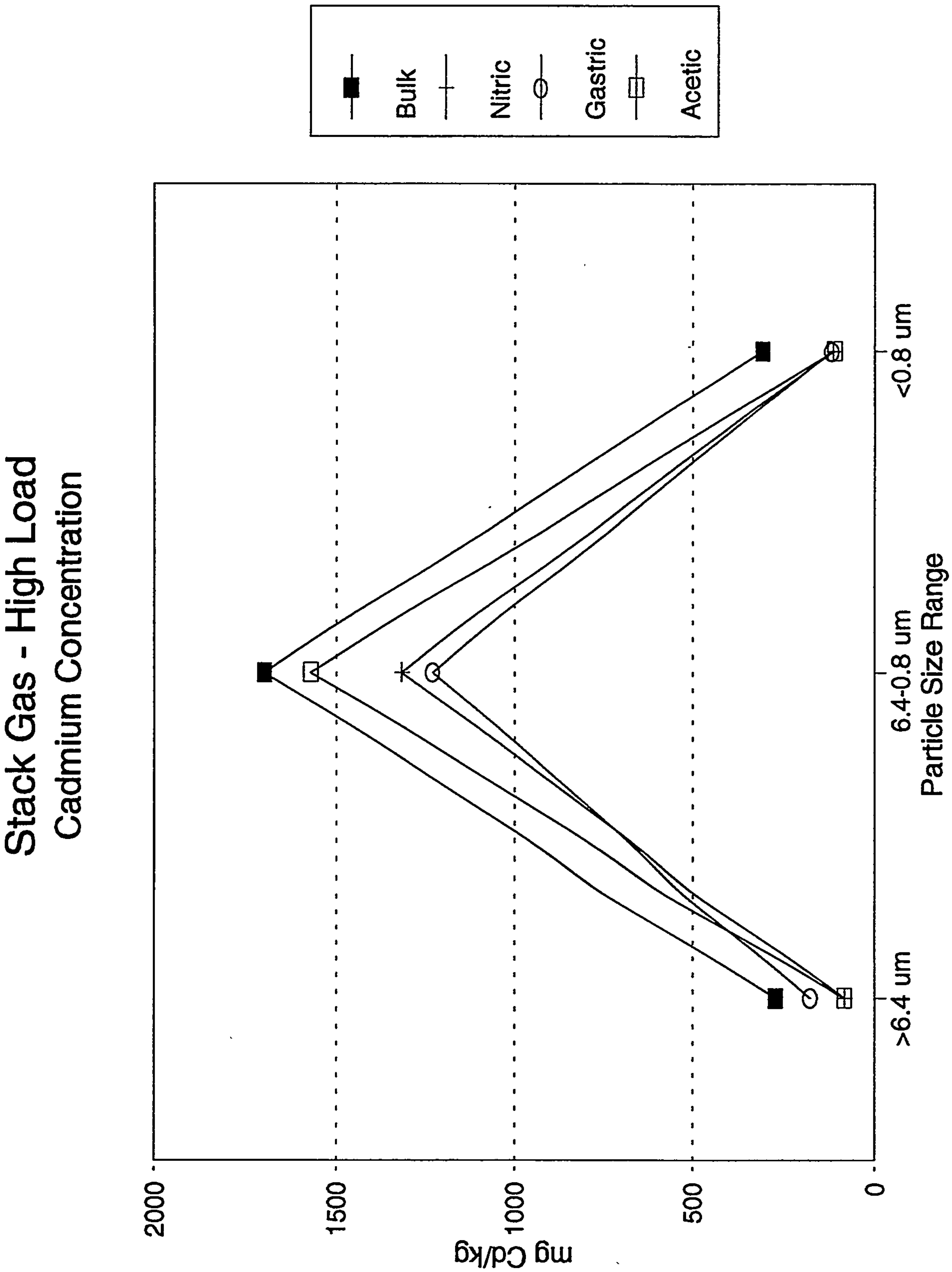


Stack Gas - Low Load

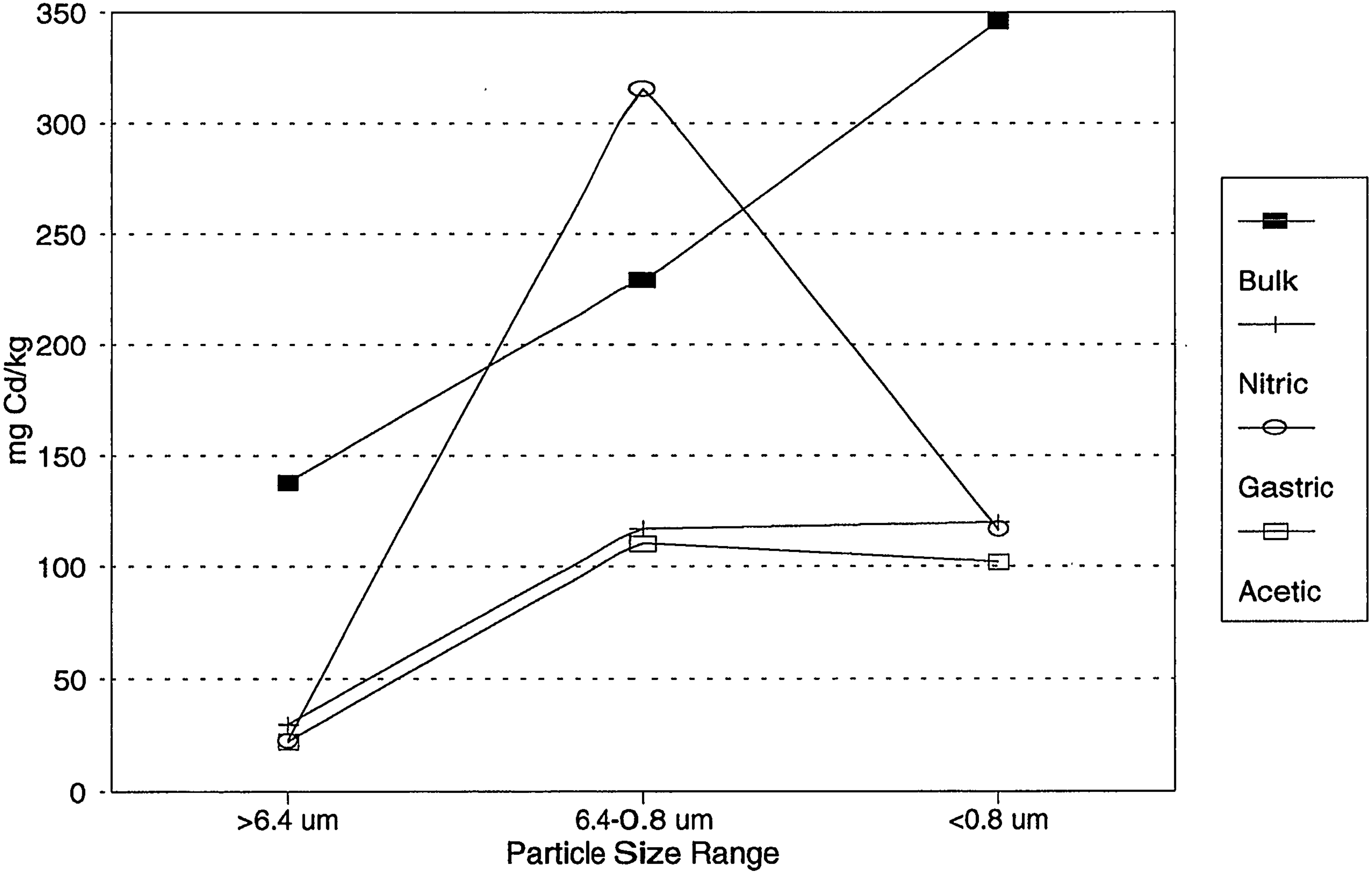
Barium Concentration

FGD Inlet
Cadmium Concentration



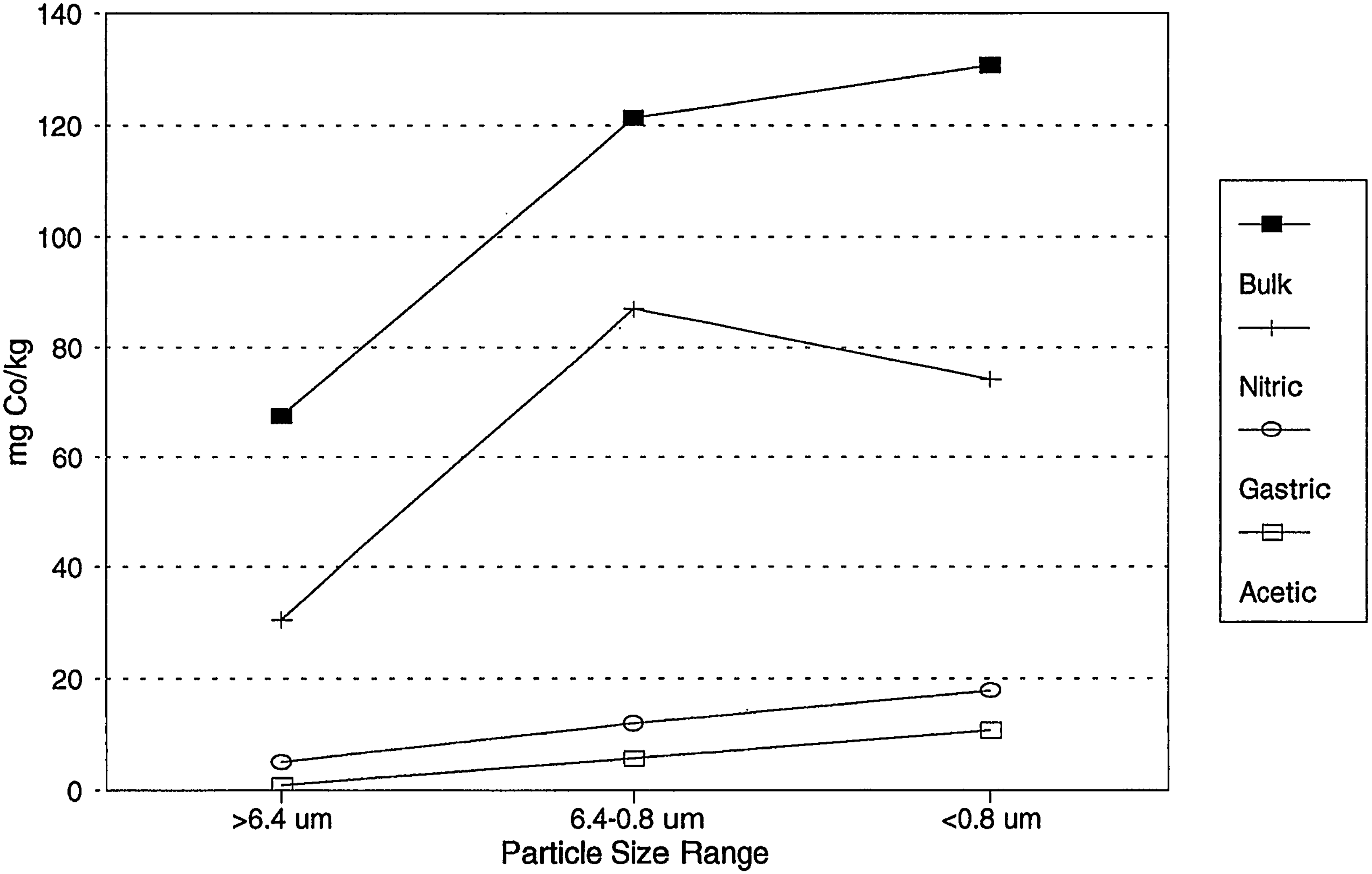

Stack Gas - High Load
Cadmium Concentration
mg Cd/kg
2000
1500
1000
500
0
>6.4 um
6.4-0.8 um
<0.8 um
Particle Size Range
Bulk
Nitric
Gastric
Acetic

Stack Gas - Low Load
Cadmium Concentration



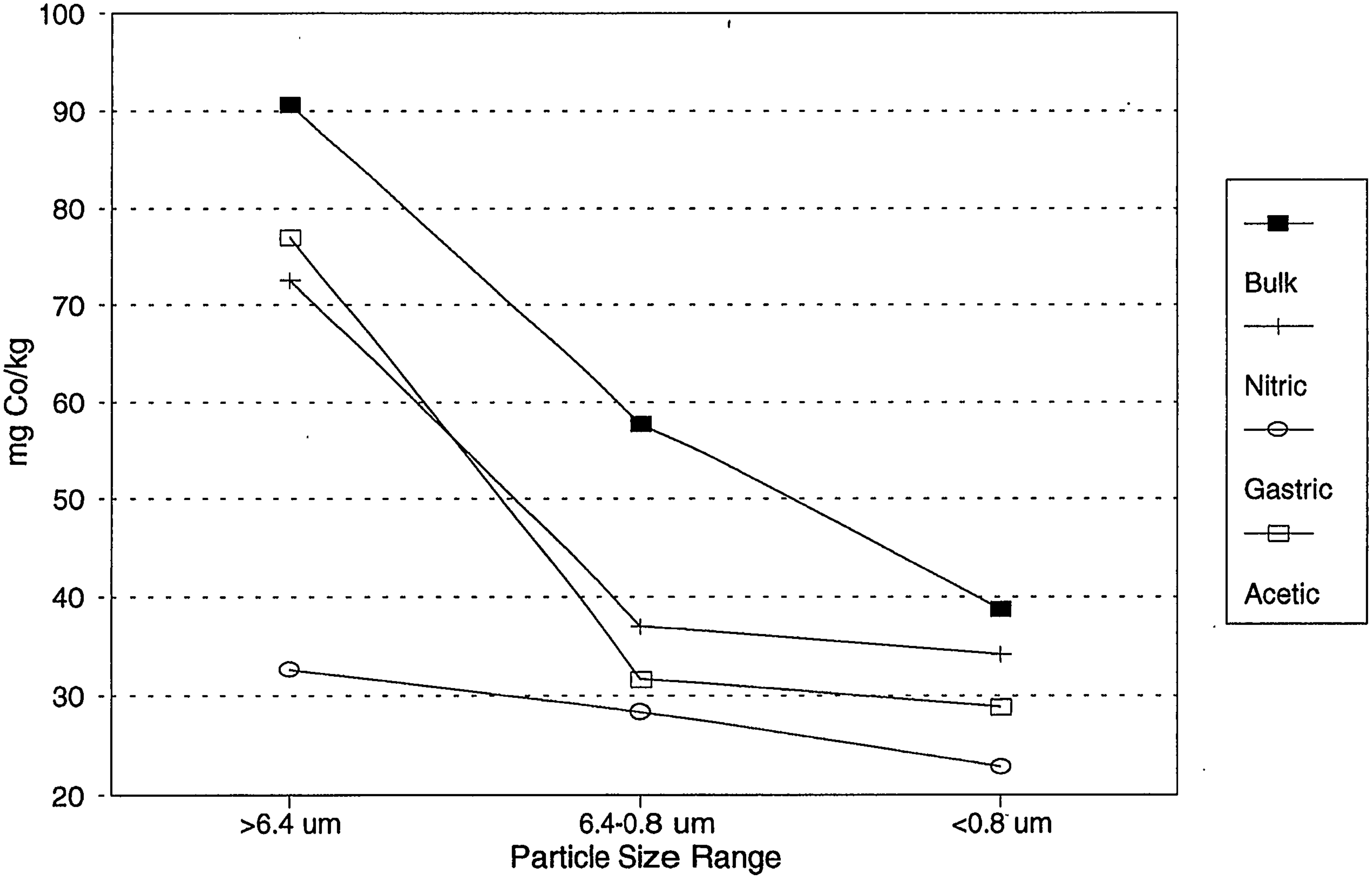
FGD Inlet

Cobalt Concentration

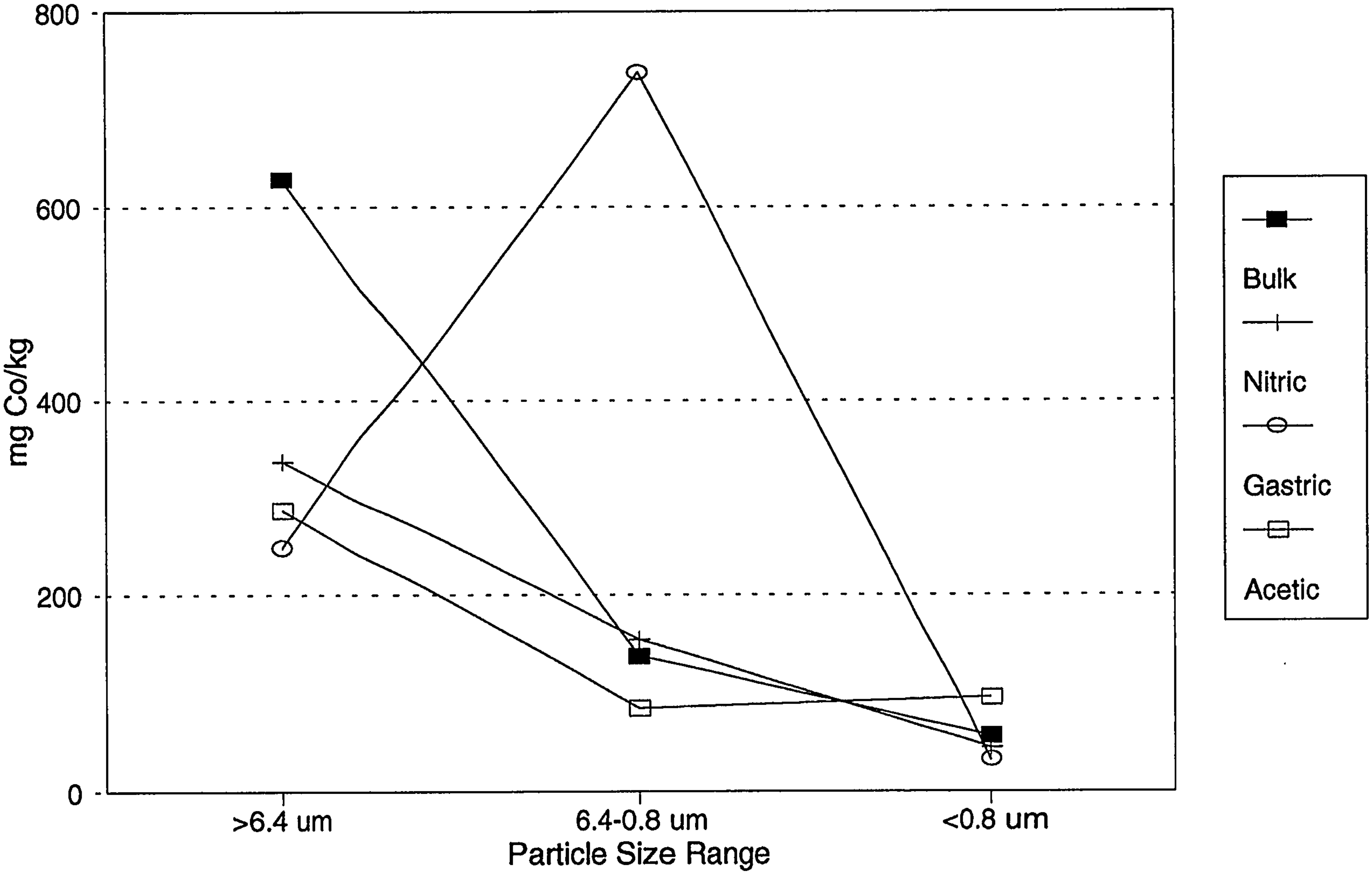


Stack Gas - High Load

Cobalt Concentration

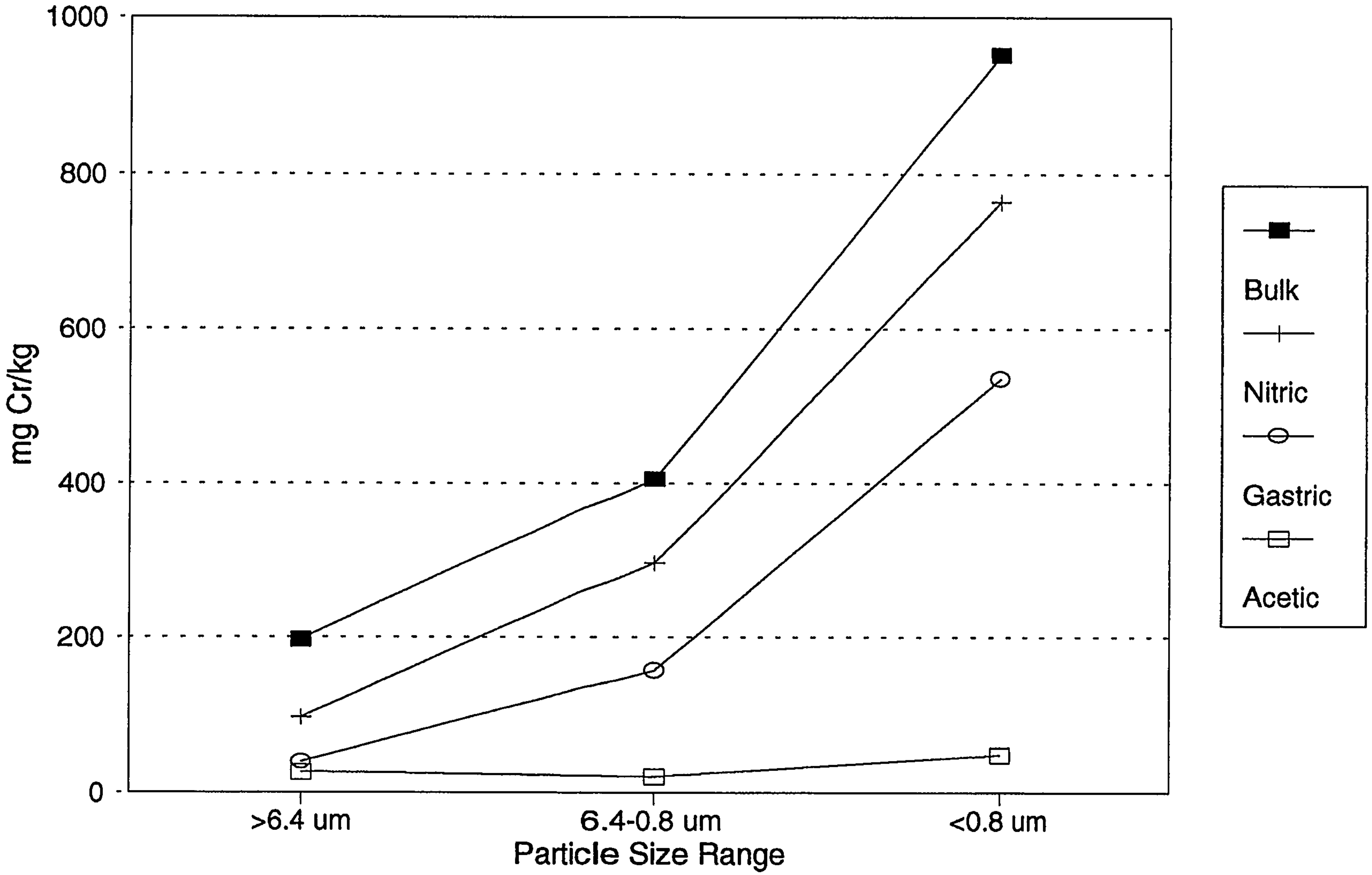


Stack Gas - Low Load
Cobalt Concentration



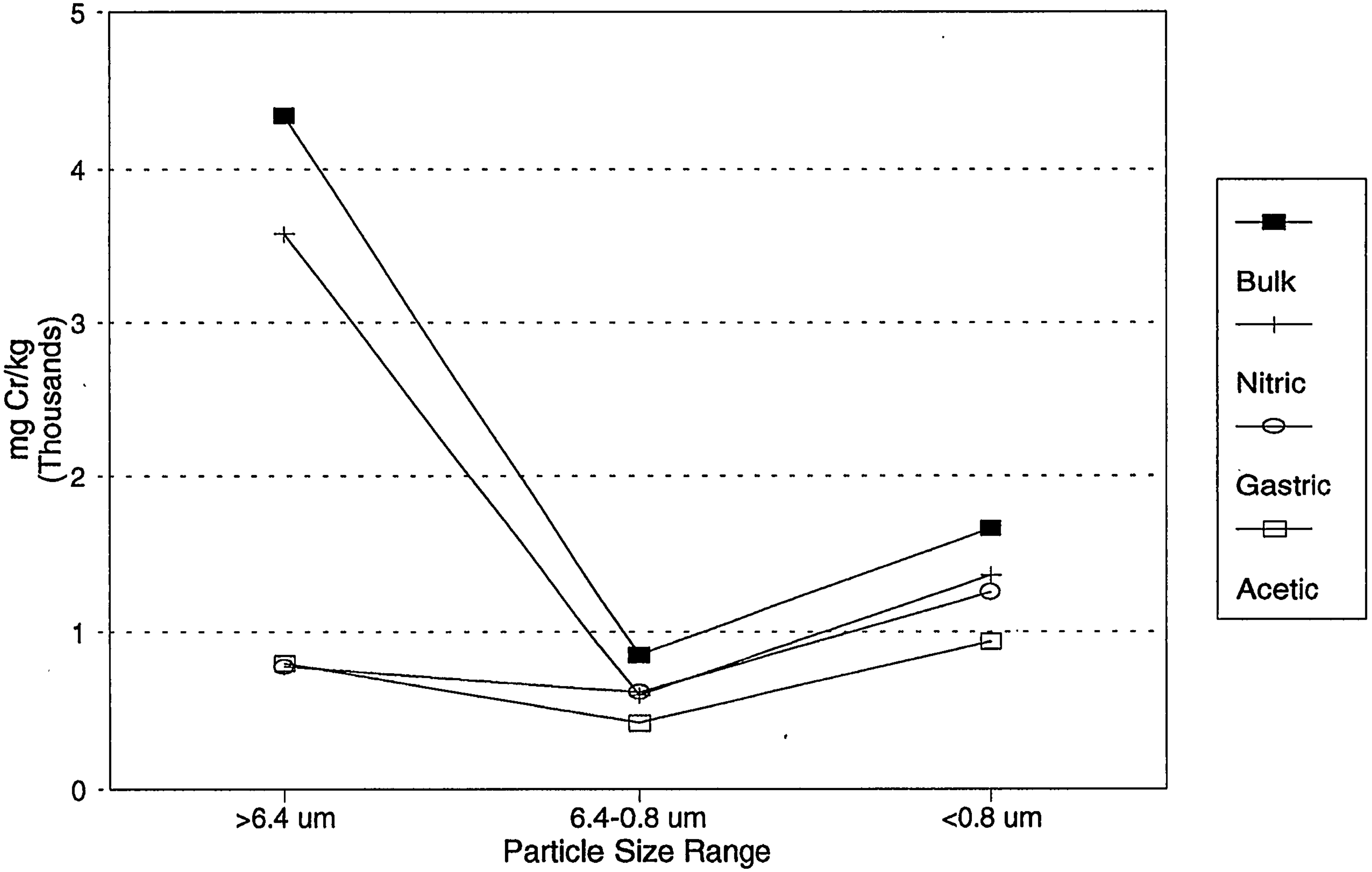
FGD Inlet

Chromium Concentration

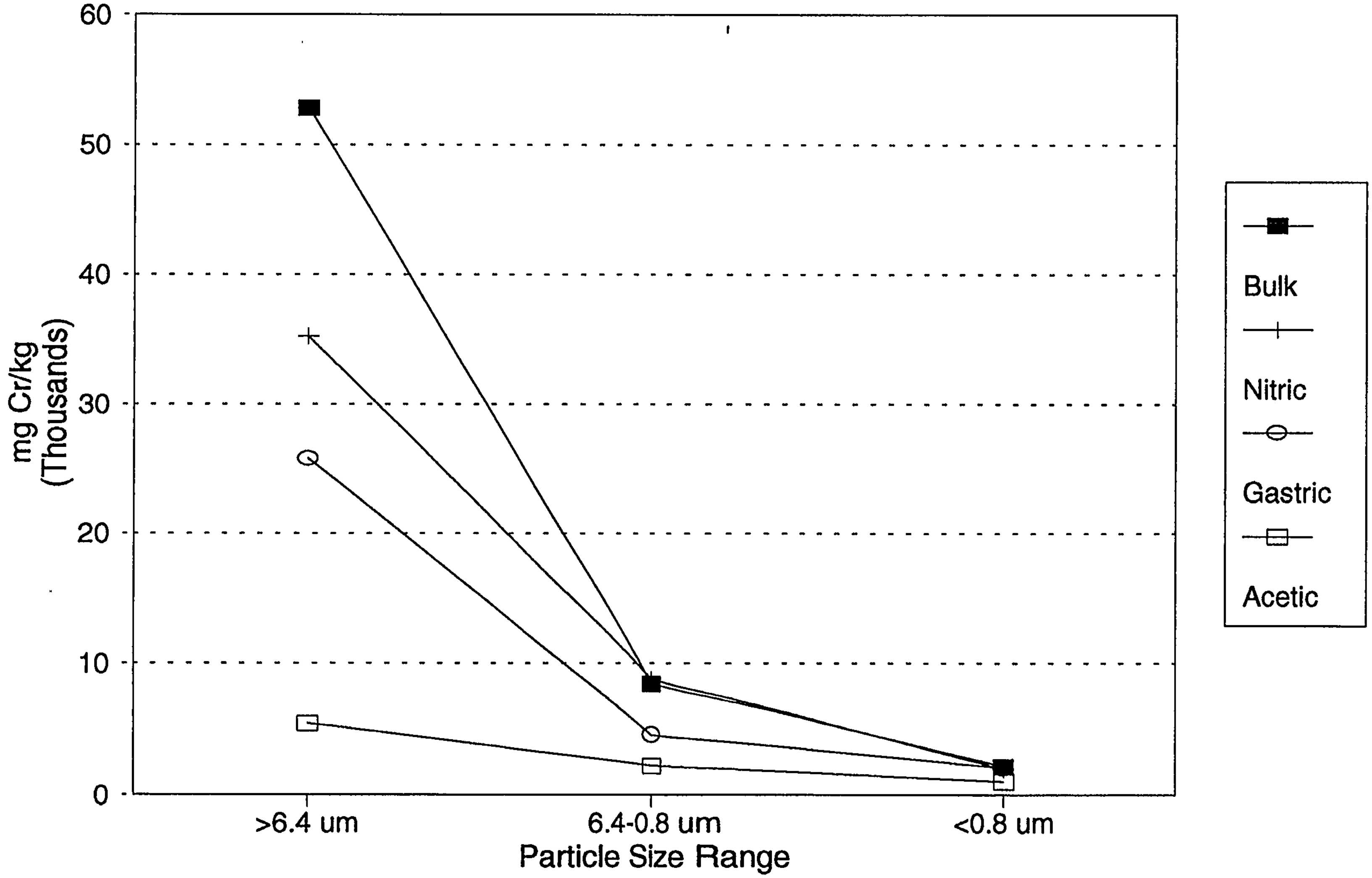


Stack Gas - High Load

Chromium Concentration

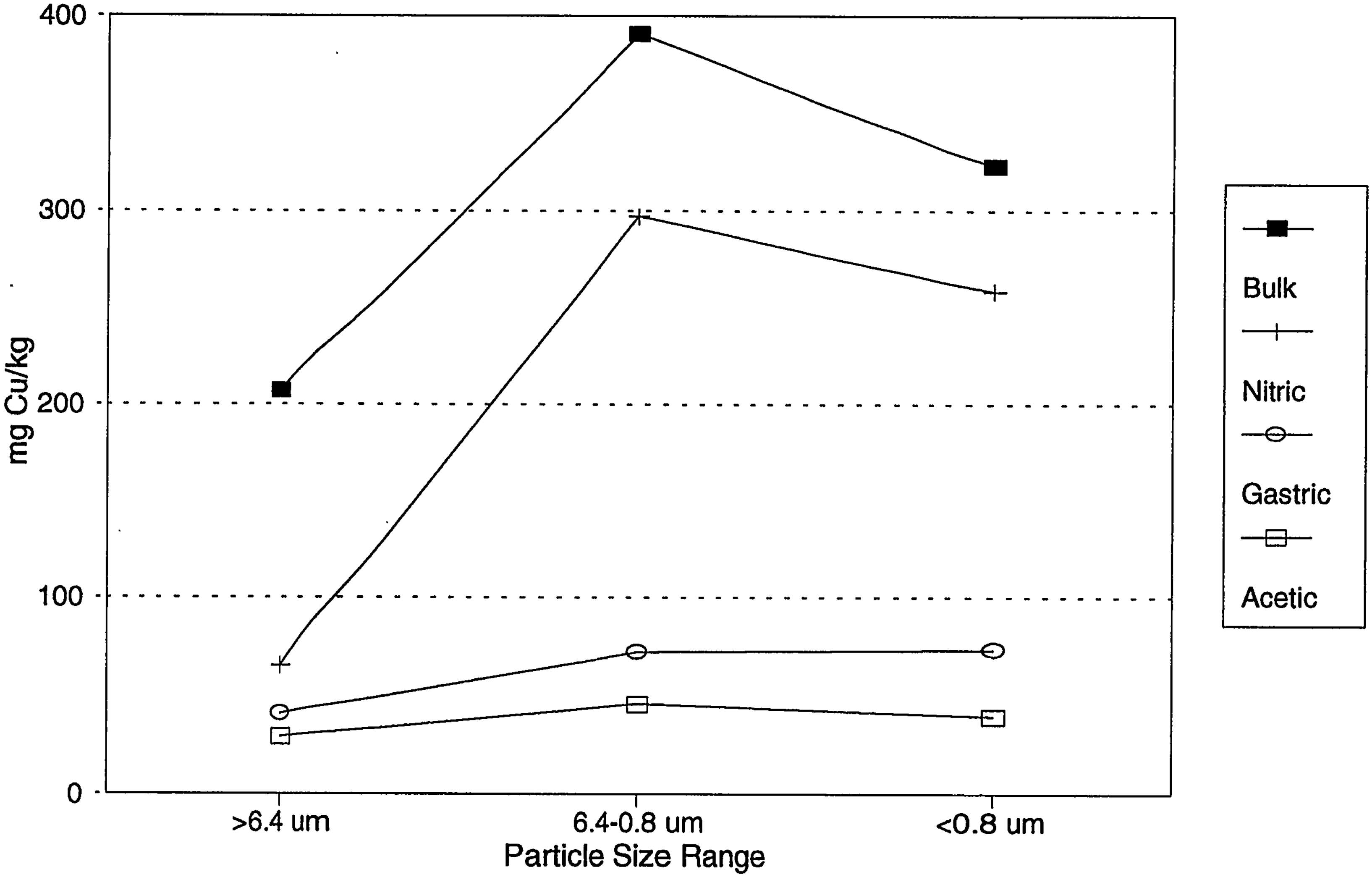


Stack Gas - Low Load
Chromium Concentration



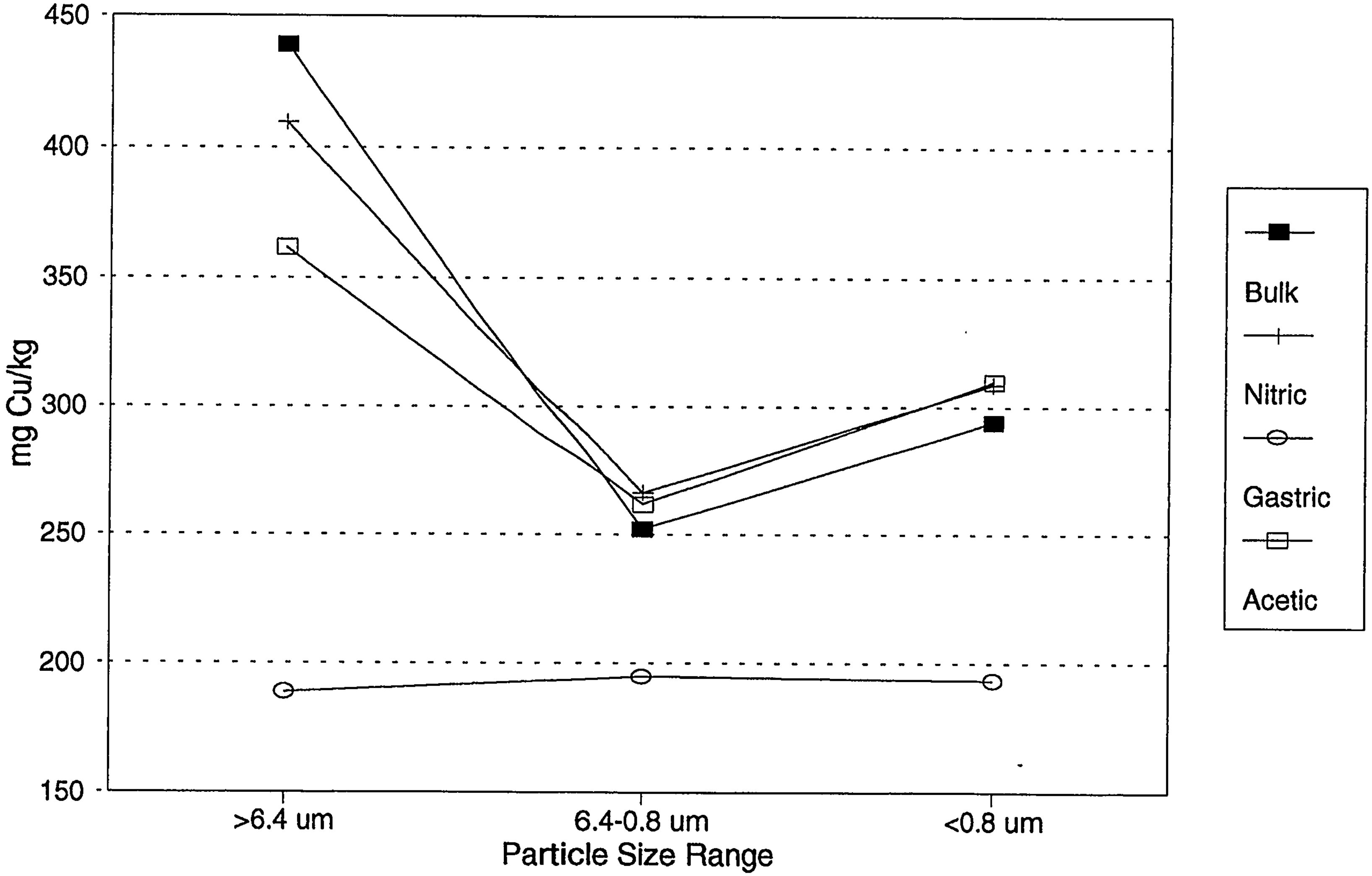
FGD Inlet

Copper Concentration



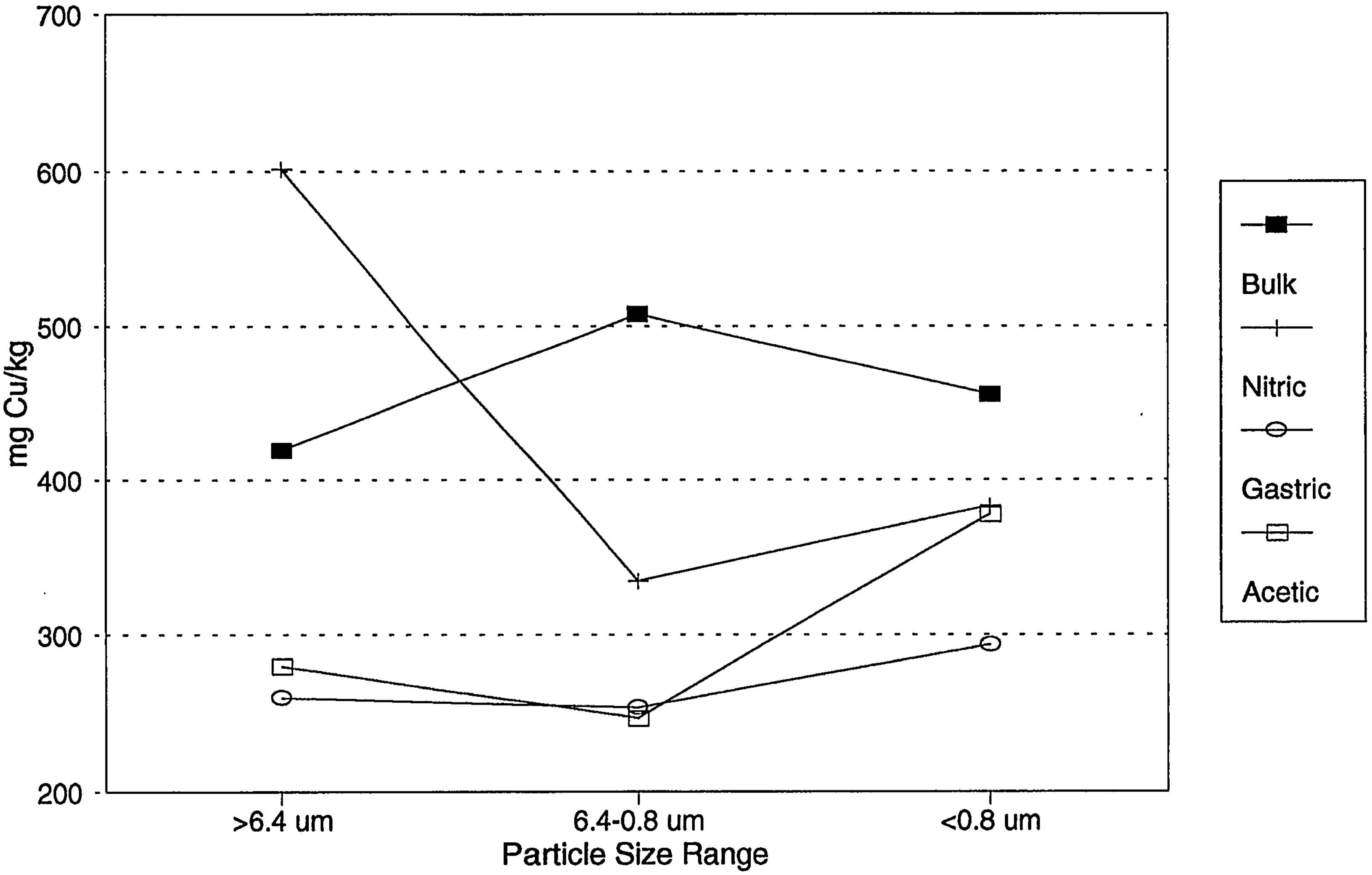
Stack Gas - High Load

Copper Concentration

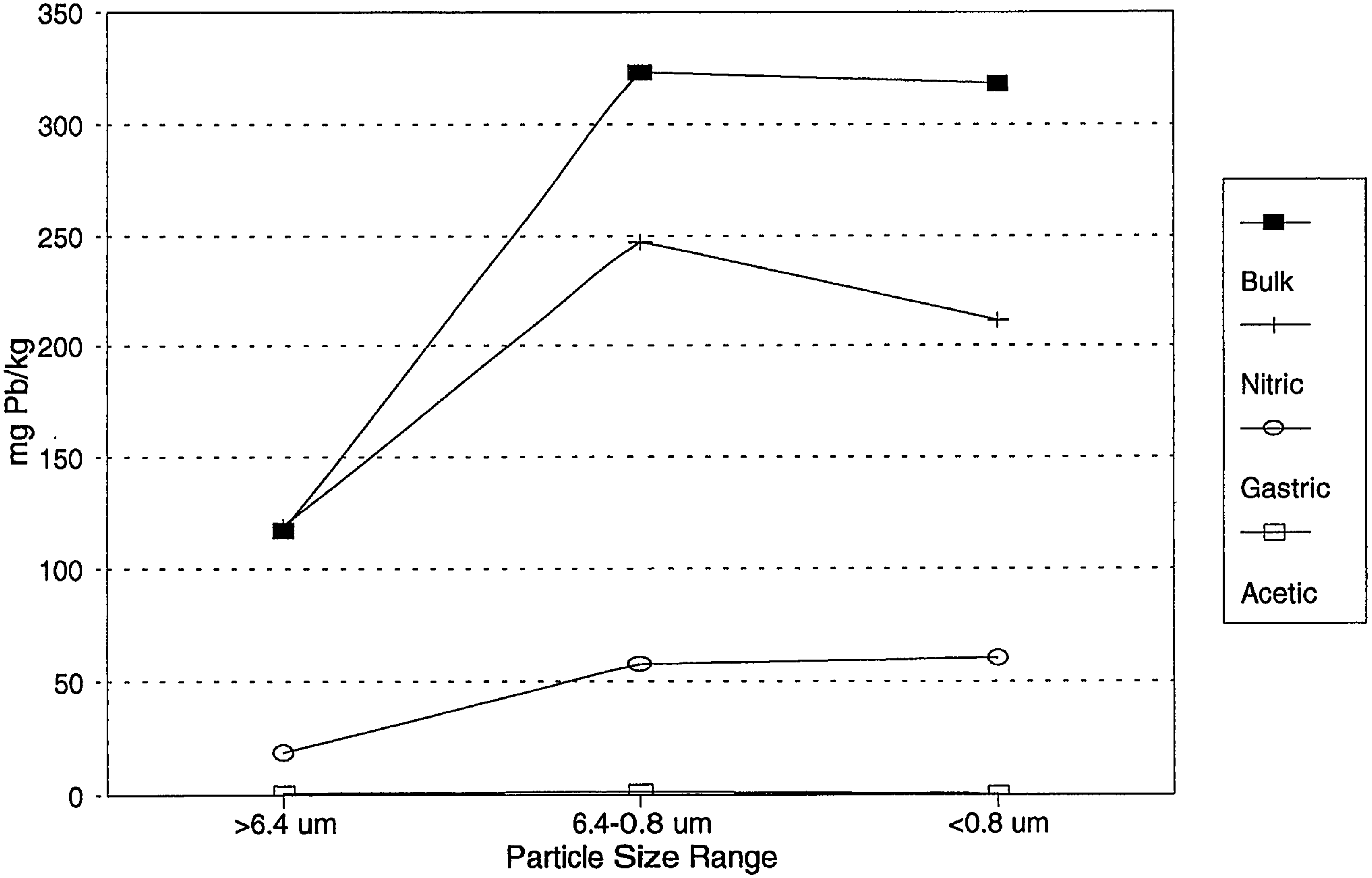


Stack Gas - Low Load

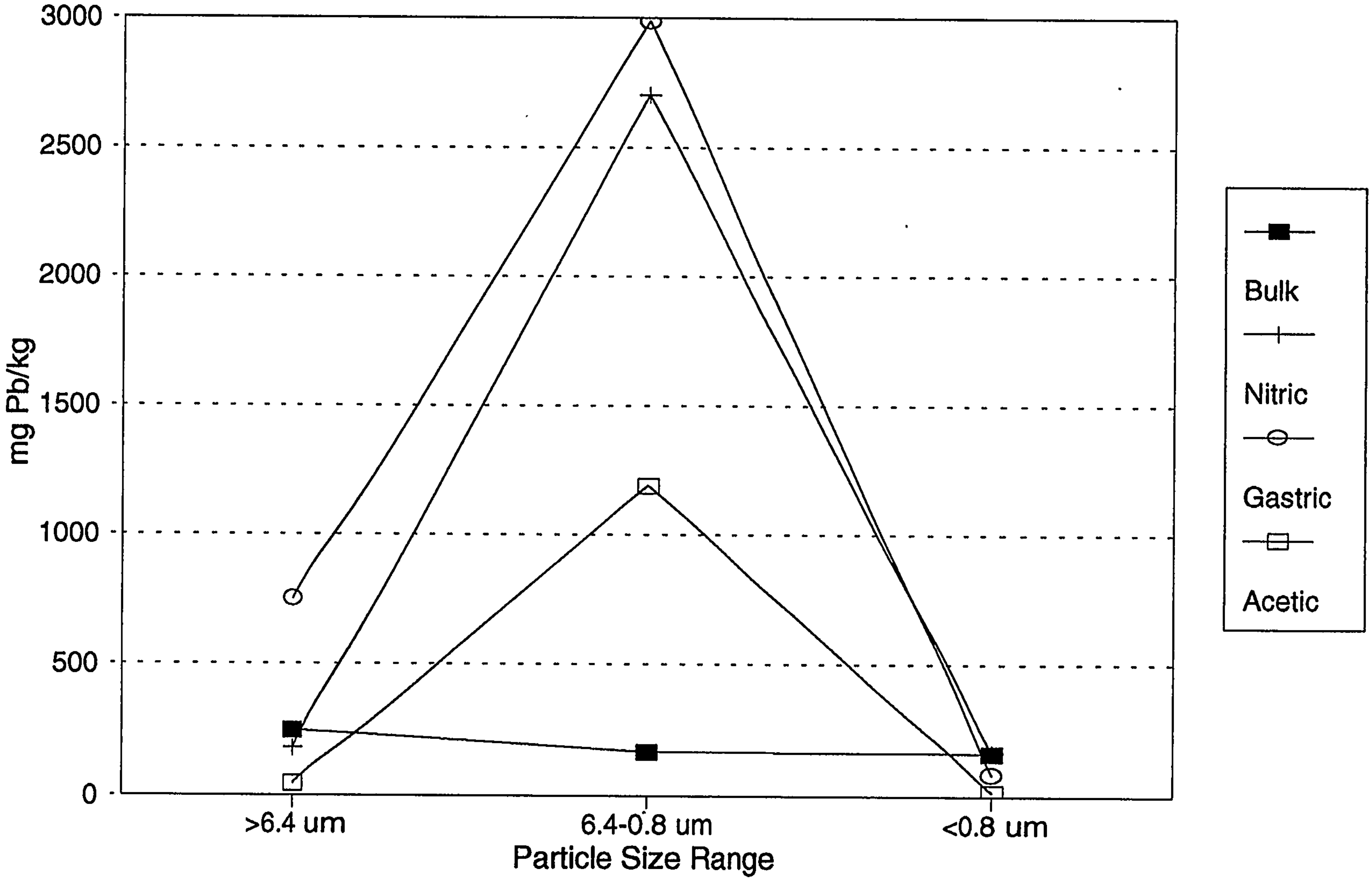
Copper Concentration

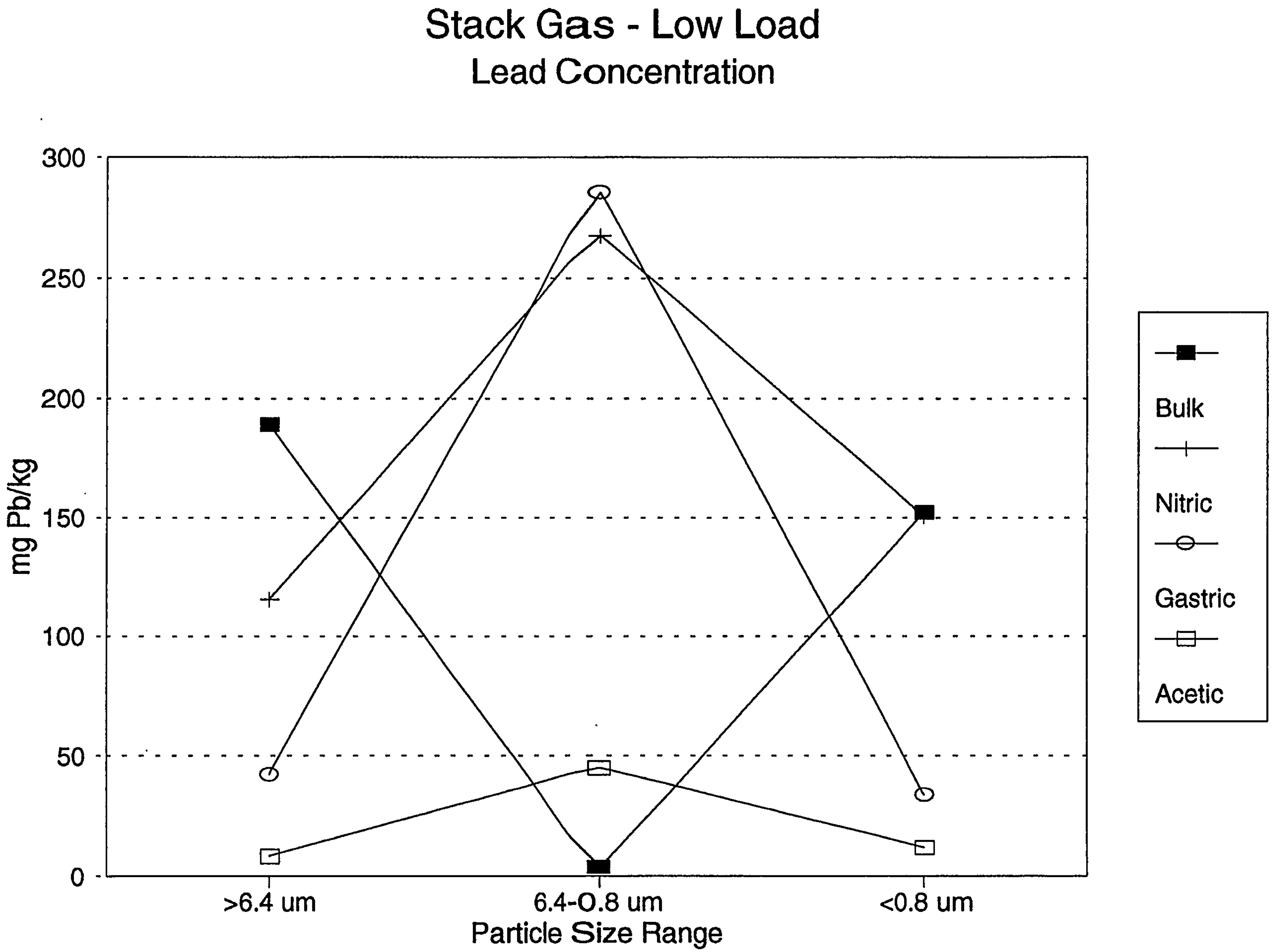


FGD Inlet
Lead Concentration

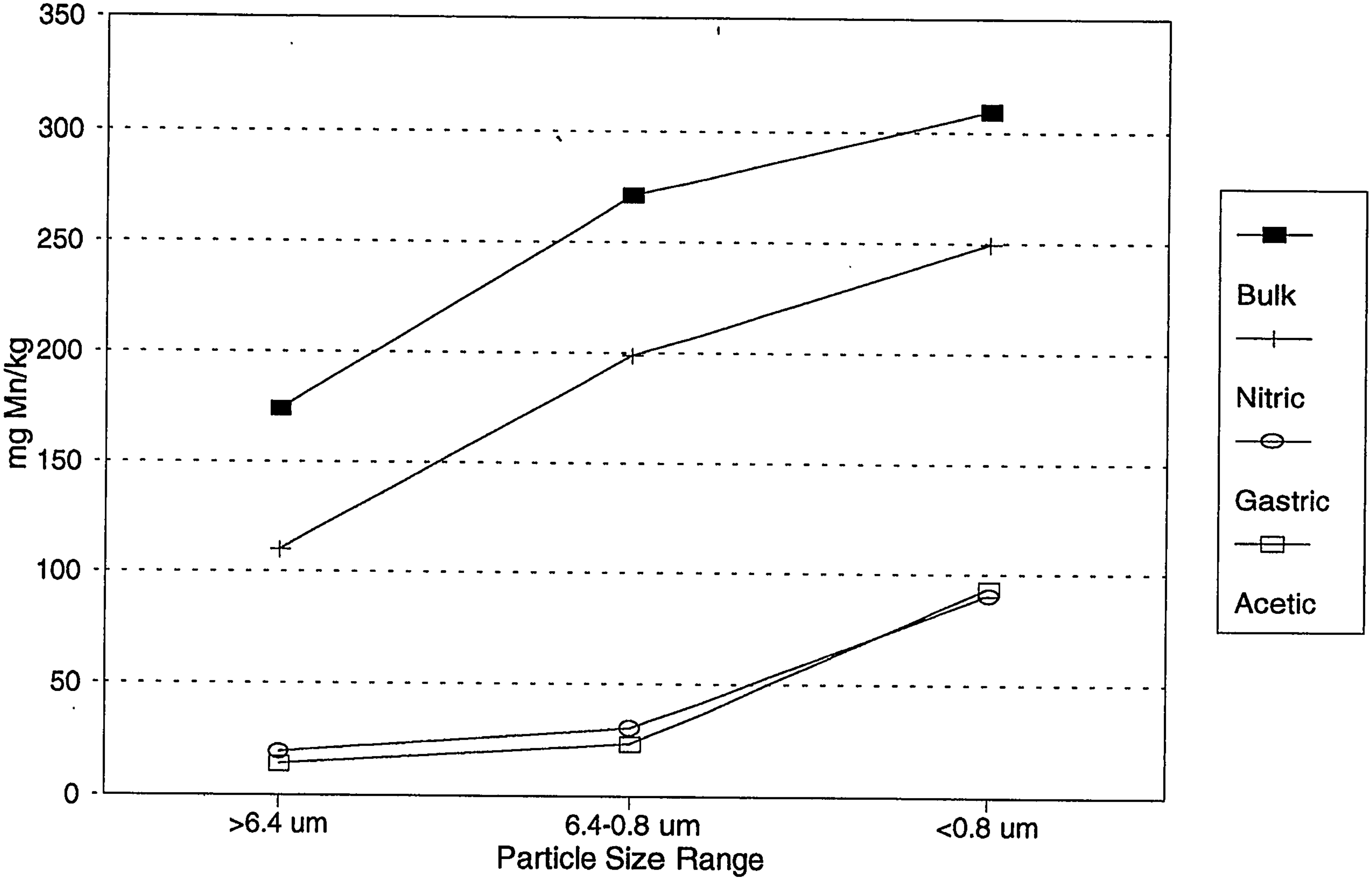


Stack Gas - High Load
Lead Concentration

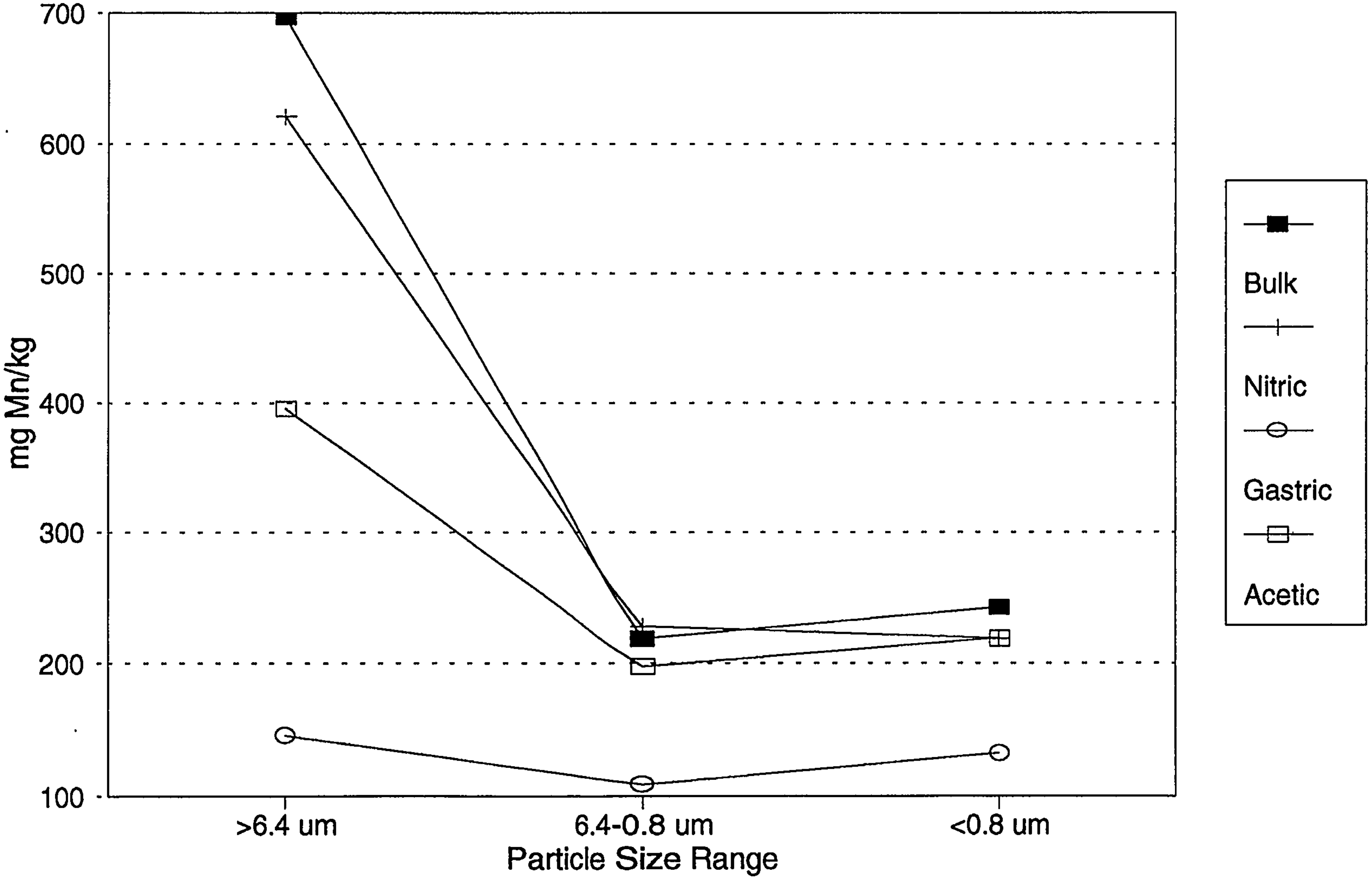



Stack Gas - Low Load
Lead Concentration
mg Pb/kg
300
250
200
150
100
50
0
>6.4 um
6.4-O.8 um
<0.8 um
Particle Size Range
Bulk
Nitric
Gastric
Acetic

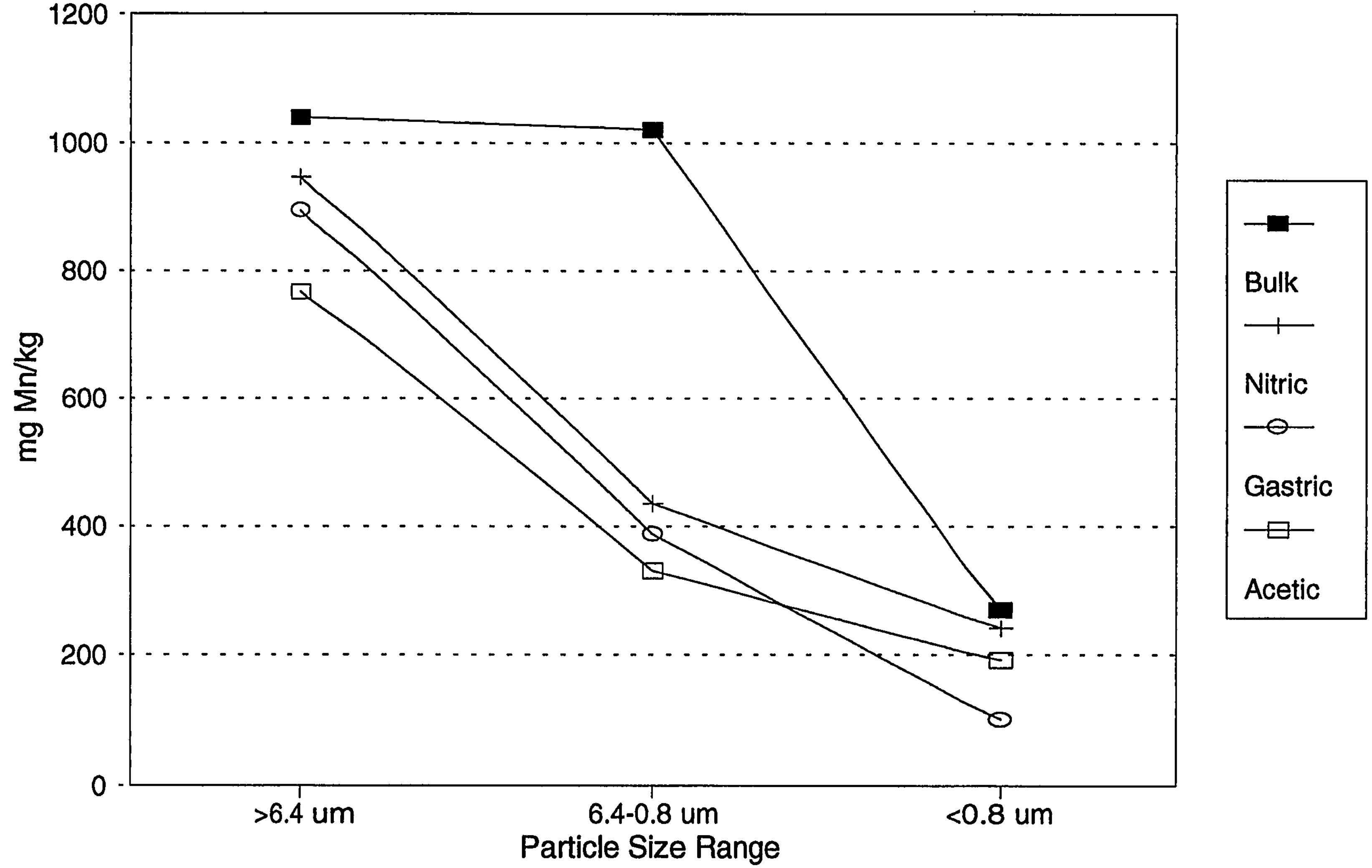
FGD Inlet
Manganese Concentration

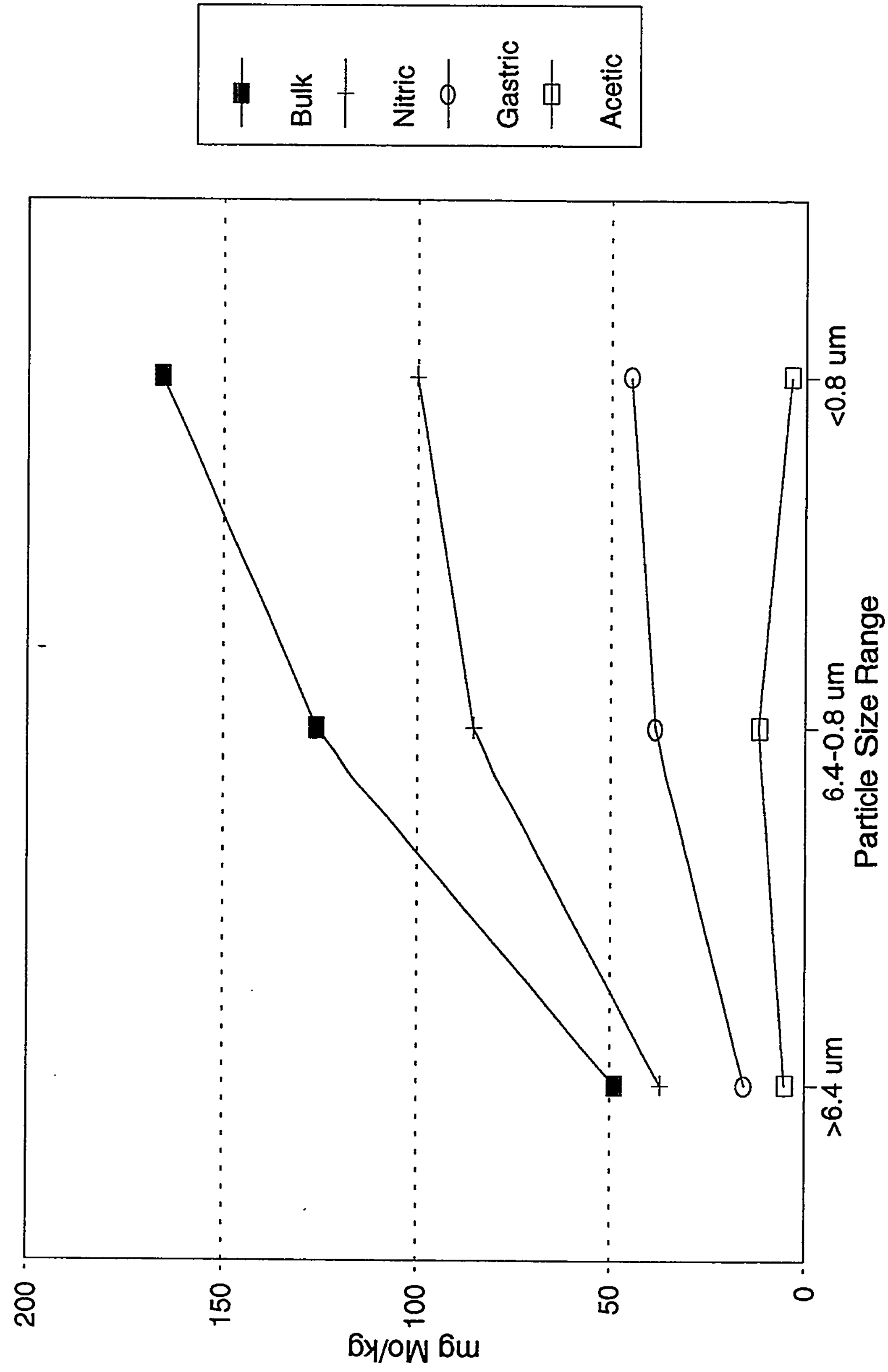


Stack Gas - High Load
Manganese Concentration

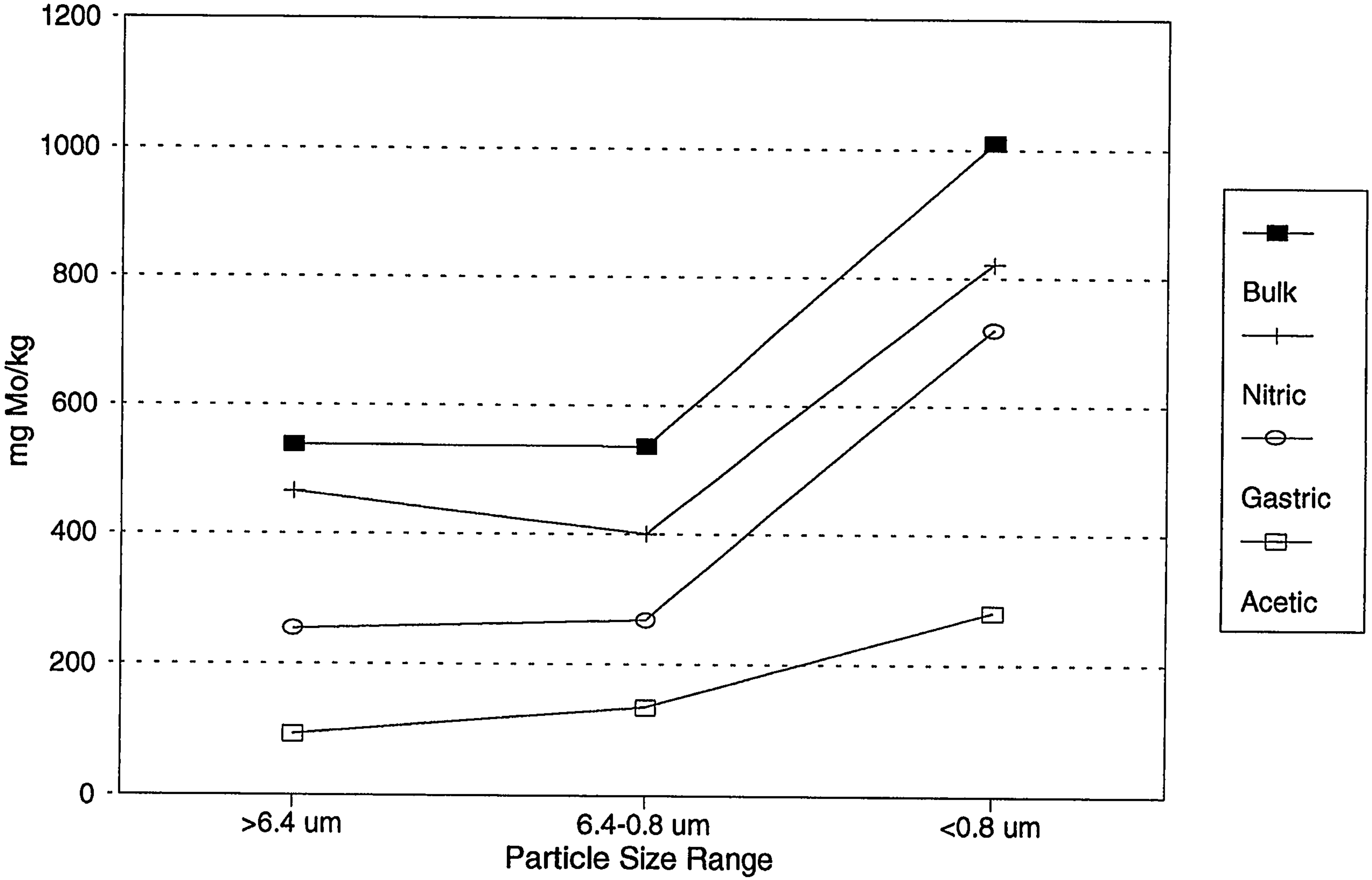


Stack Gas - Low Load
Manganese Concentration

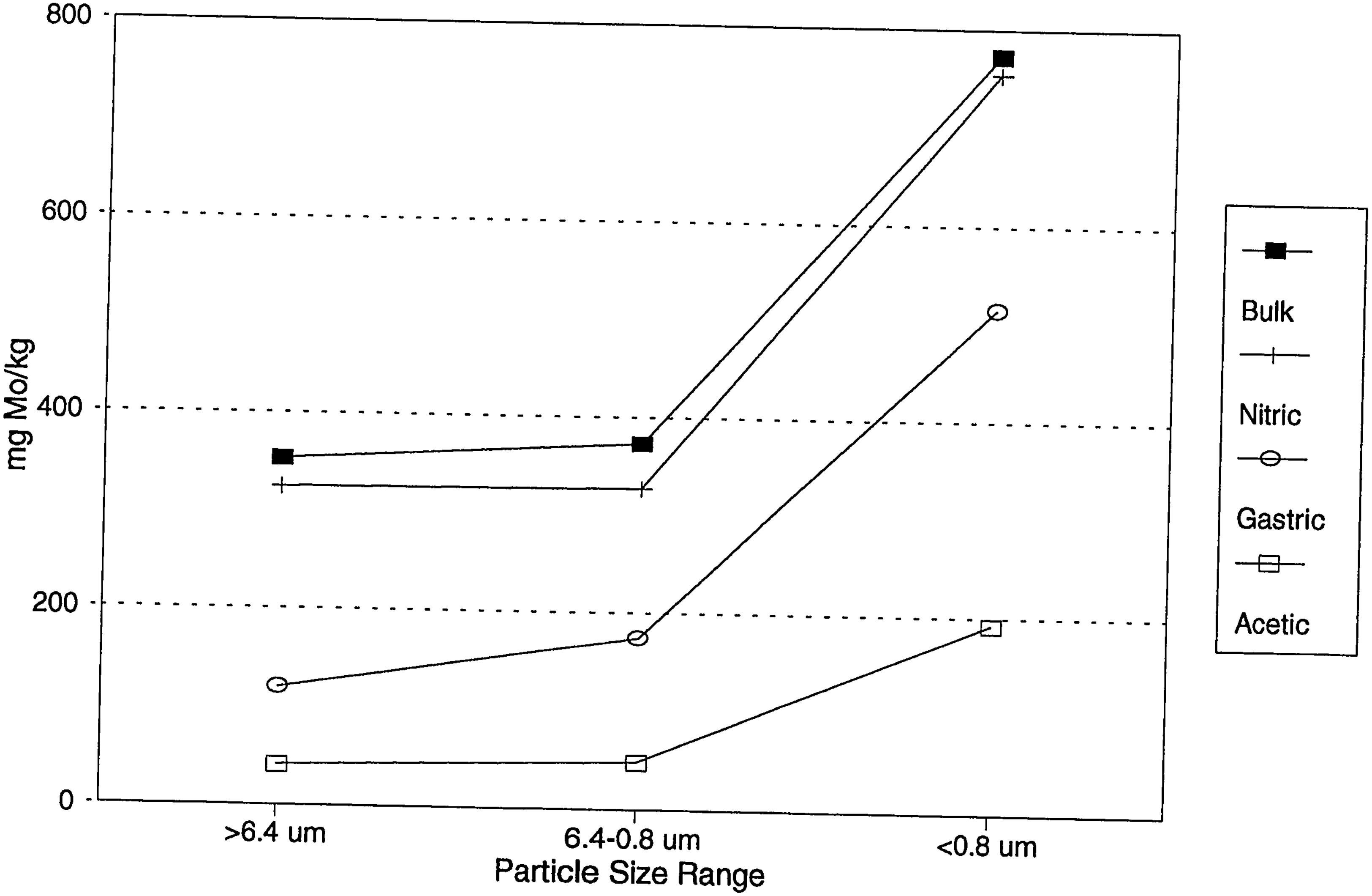



FGD Inlet
Molybdenum Concentration
mg Mo/kg
200
150
100
50
0
>6.4 um
6.4-0.8 um
<0.8 um
Particle Size Range
Bulk
Nitric
Gastric
Acetic

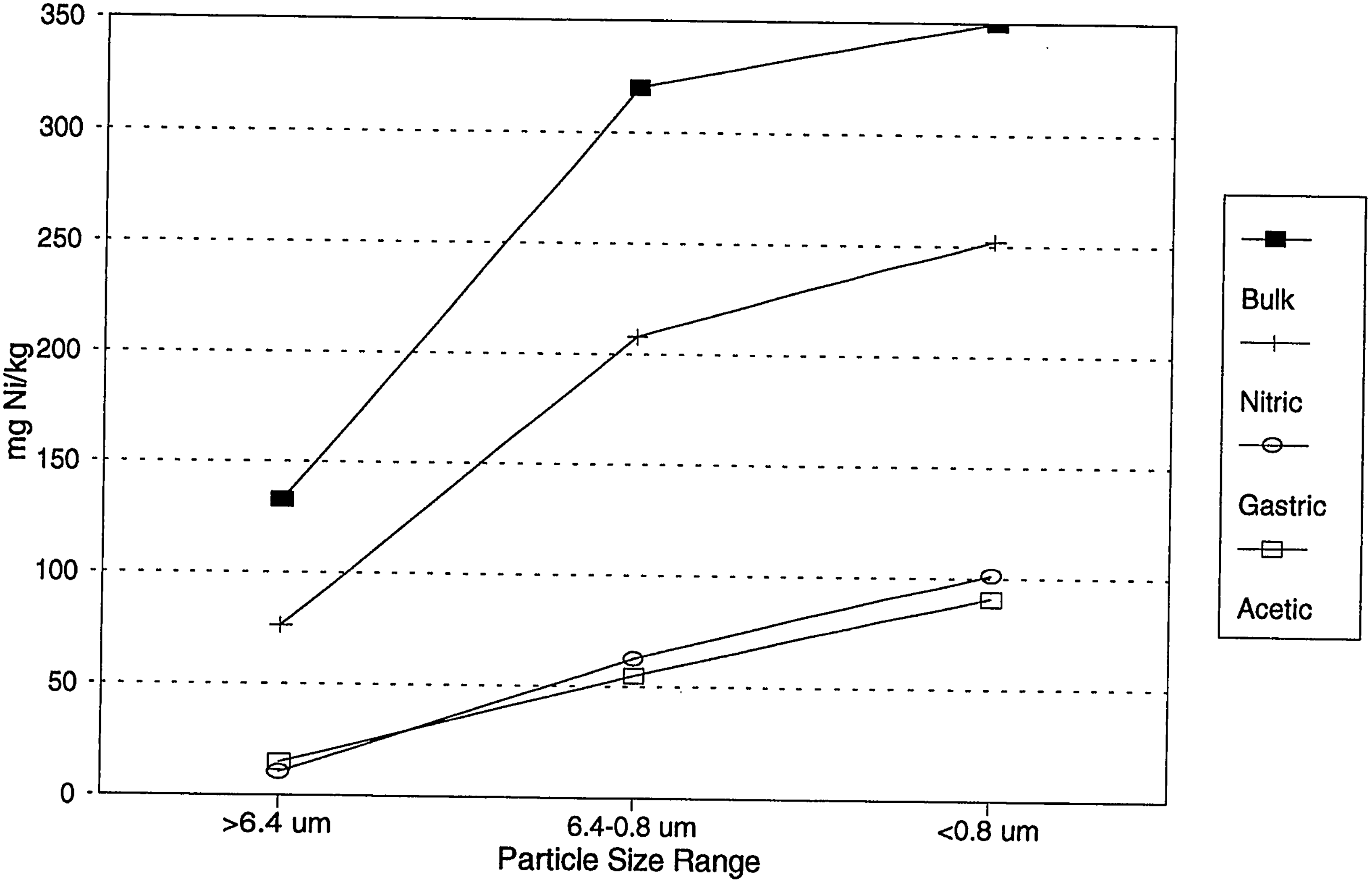
Stack Gas - High Load
Molybdenum Concentration



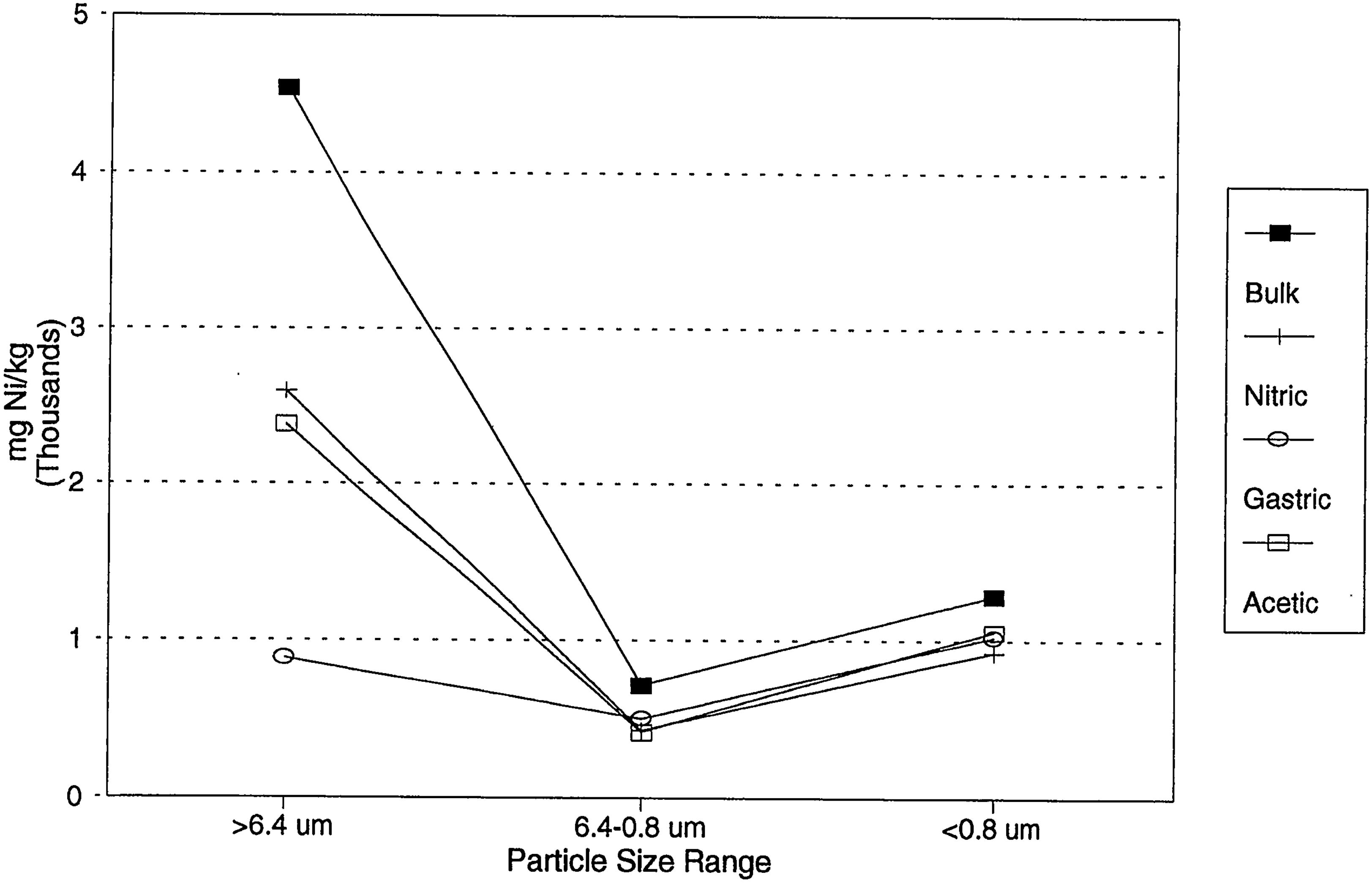
Stack Gas - Low Load
Molybdenum Concentration



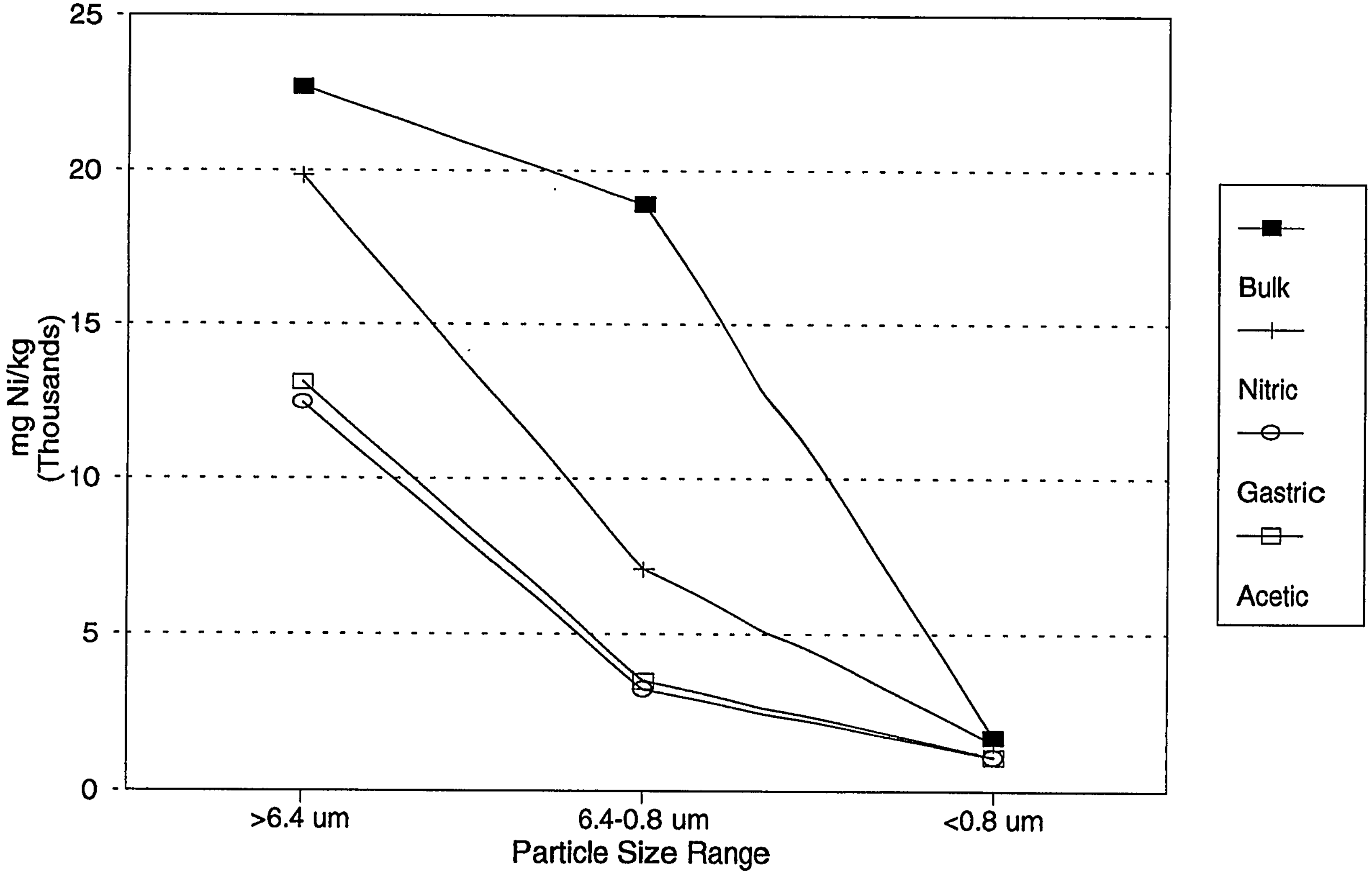
FGD Inlet
Nickel Concentration



Stack Gas - High Load
Nickel Concentration

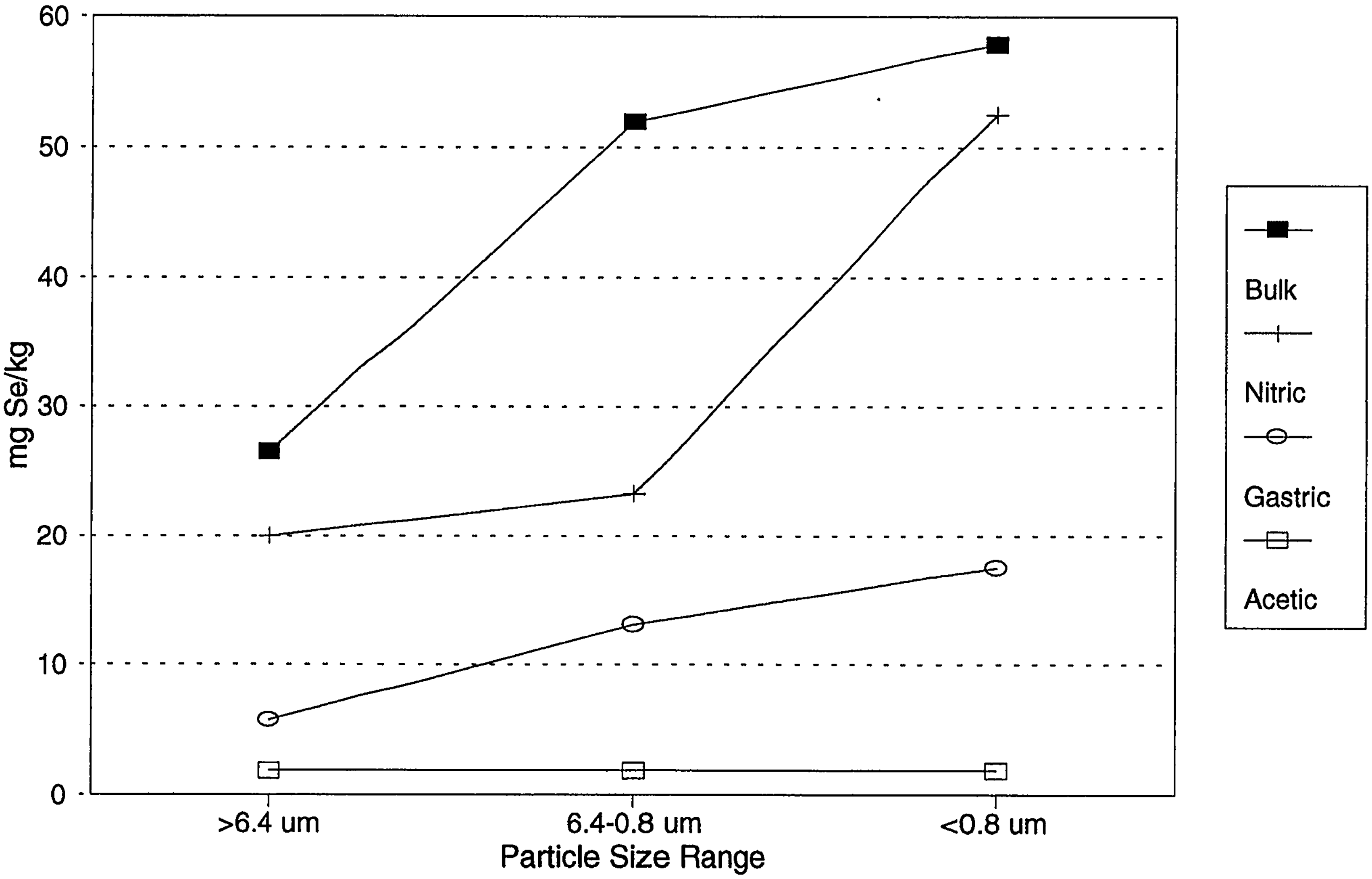


Stack Gas - Low Load
Nickel Concentration

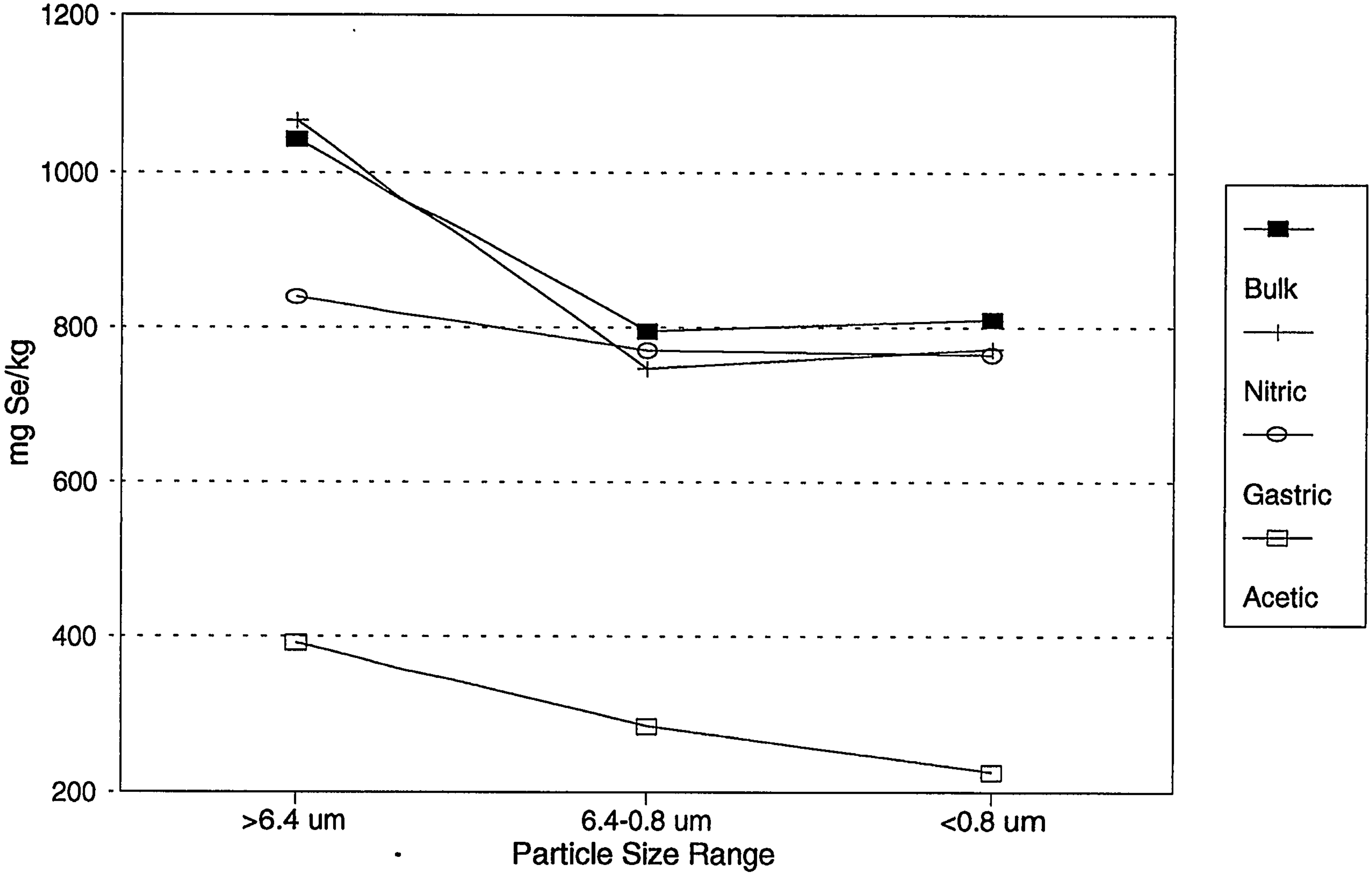


FGD Inlet

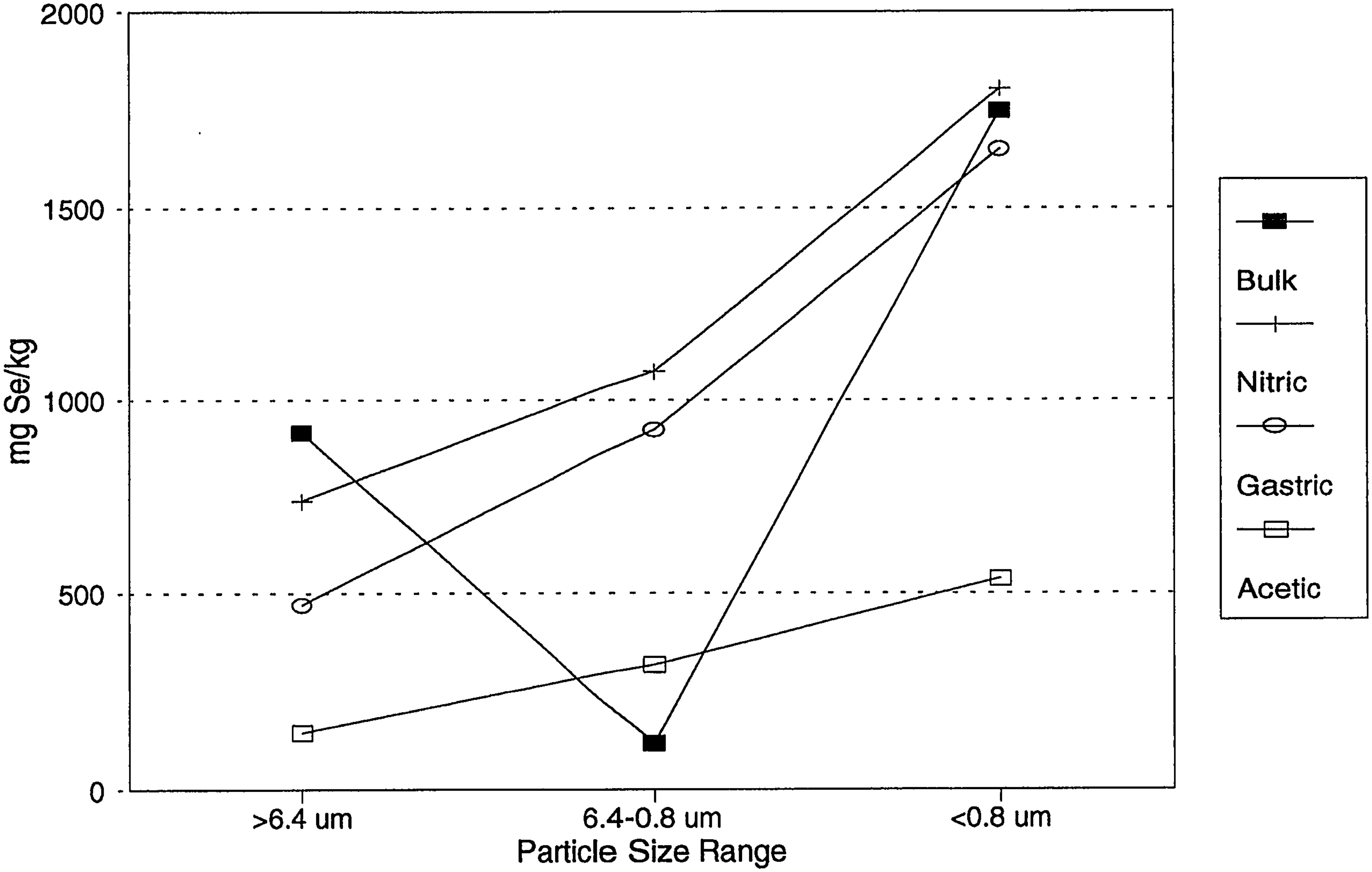
Selenium Concentration



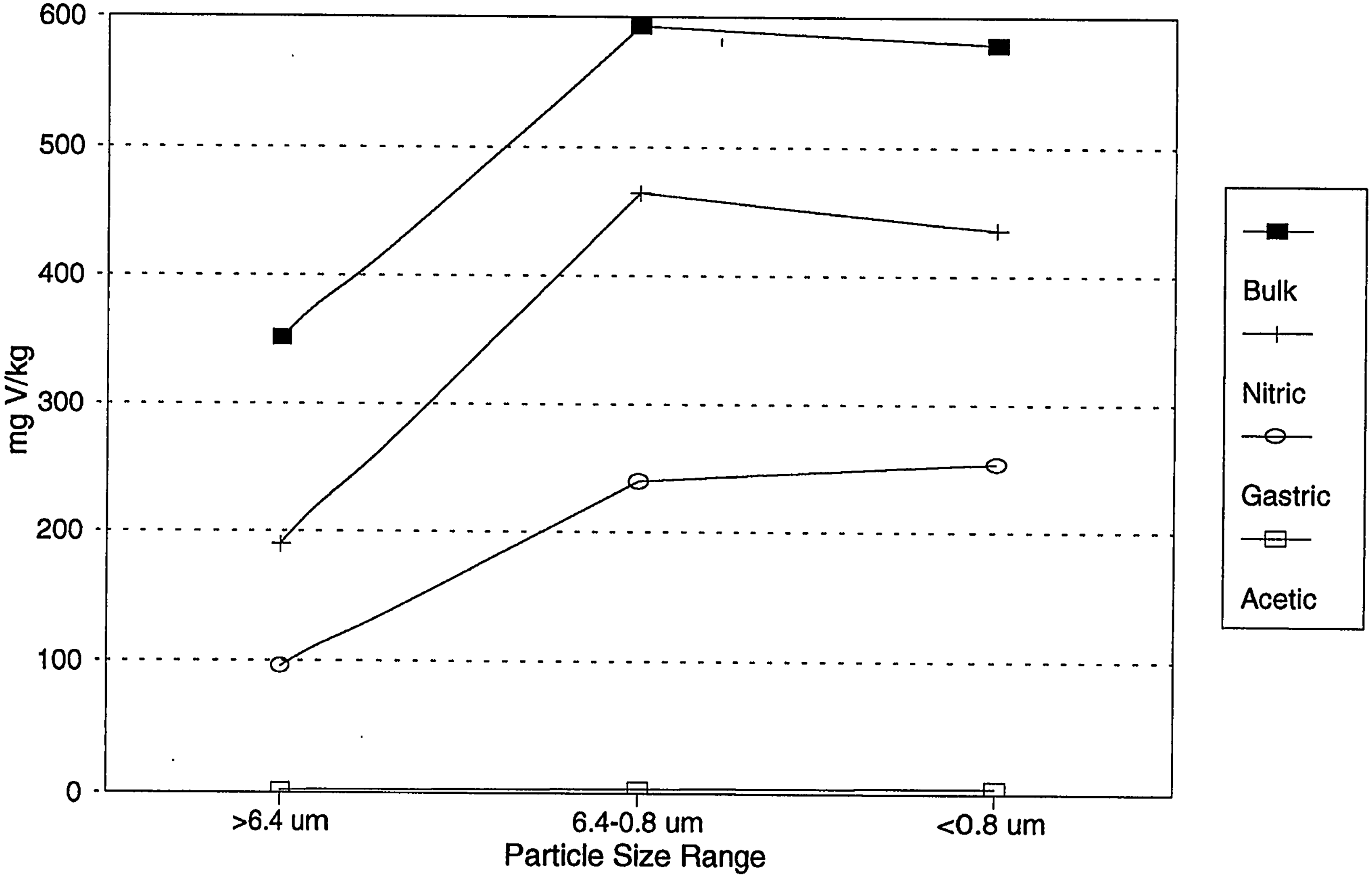
Stack Gas - High Load
Selenium Concentration

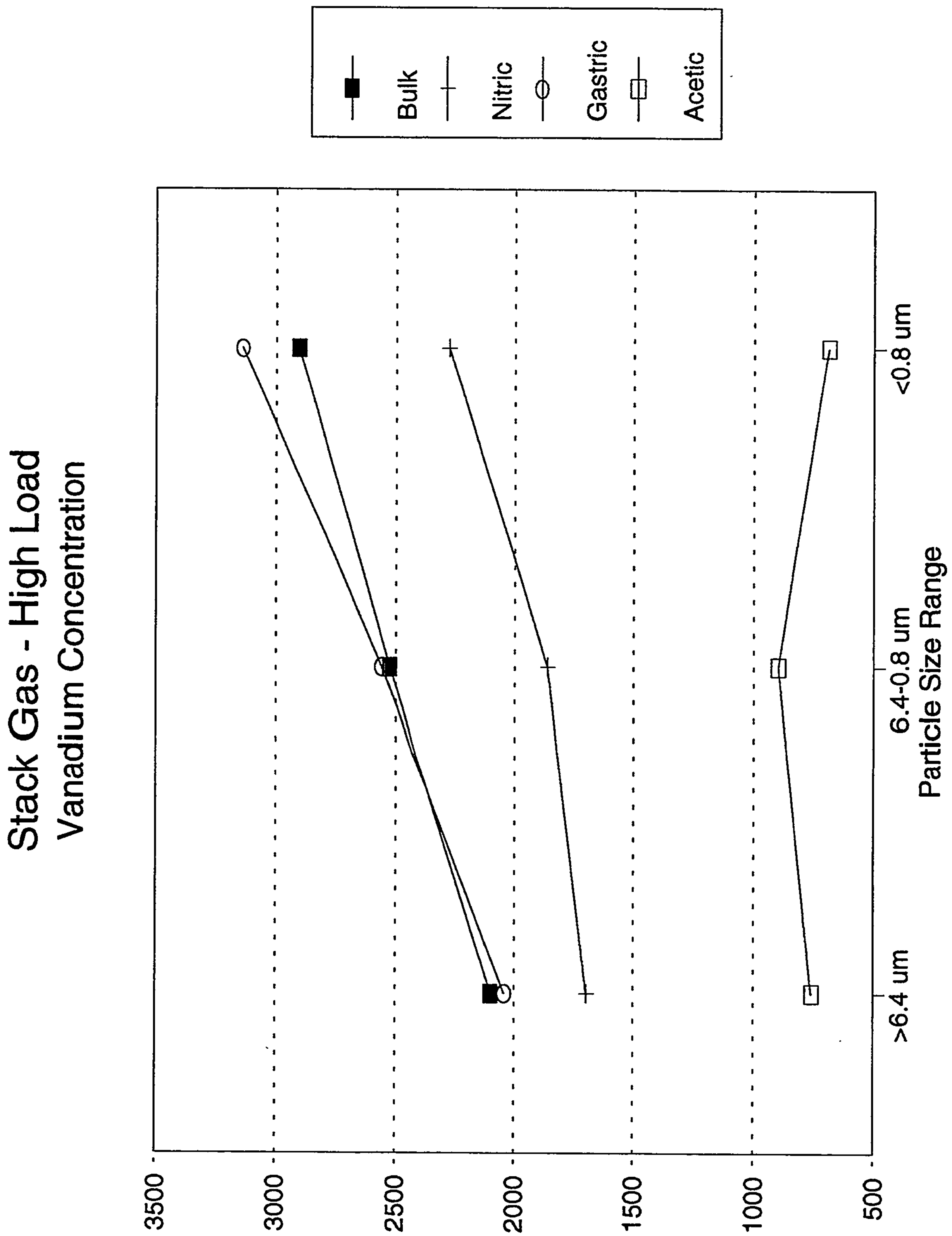


Stack Gas - Low Load
Selenium Concentration



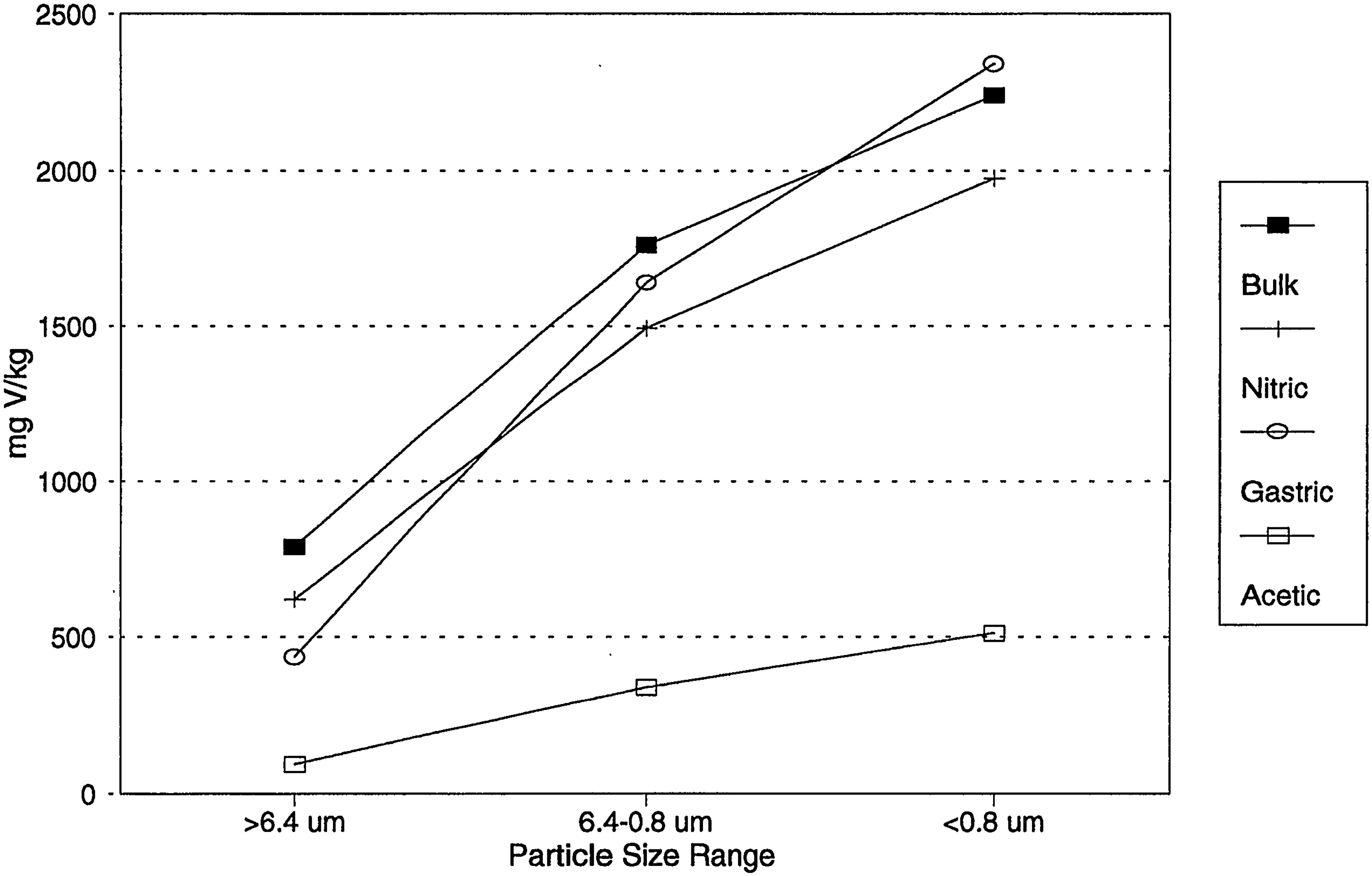
FGD Inlet
Vanadium Concentration



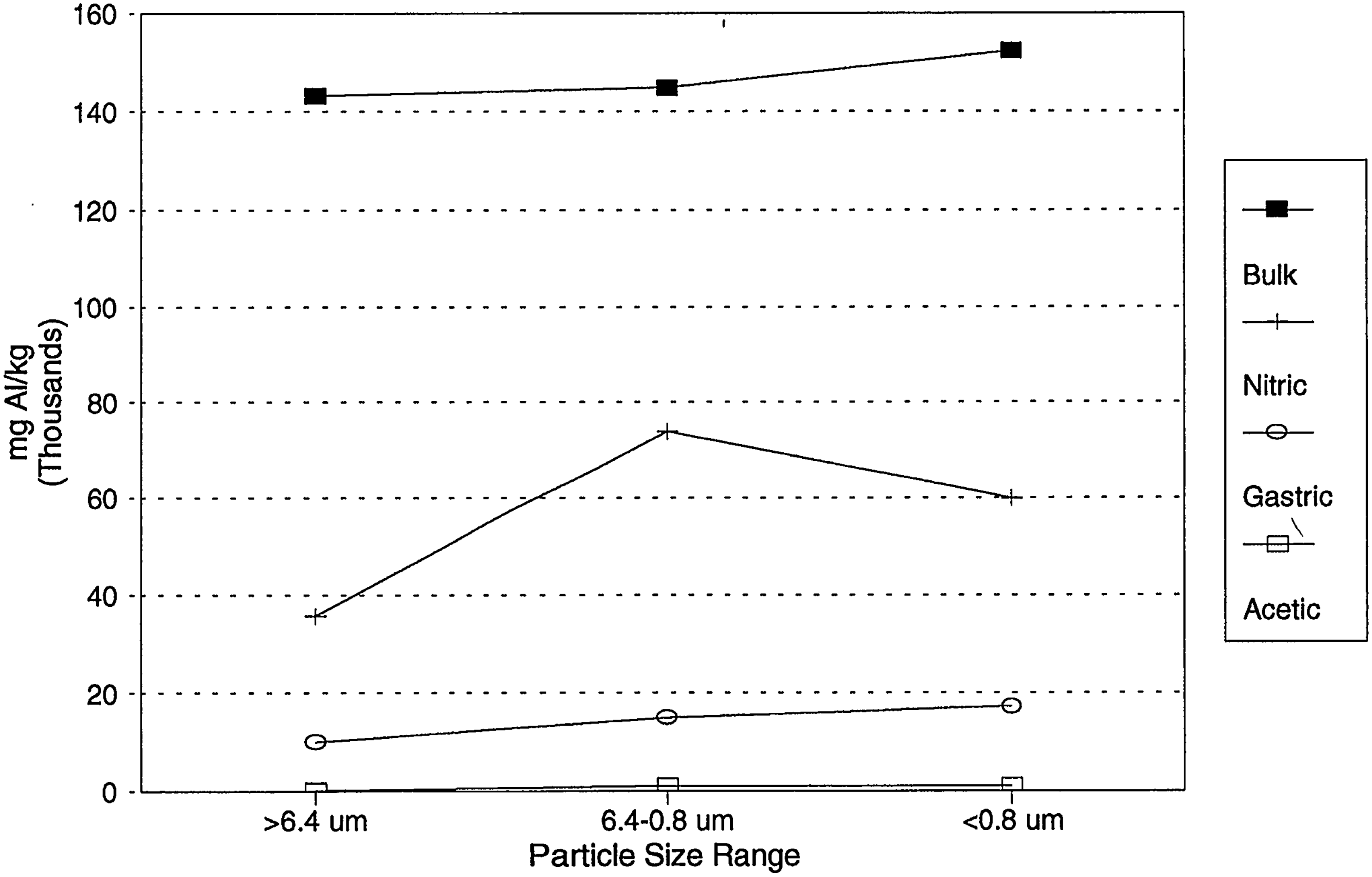

Stack Gas - High Load
Vanadium Concentration

Stack Gas - Low Load

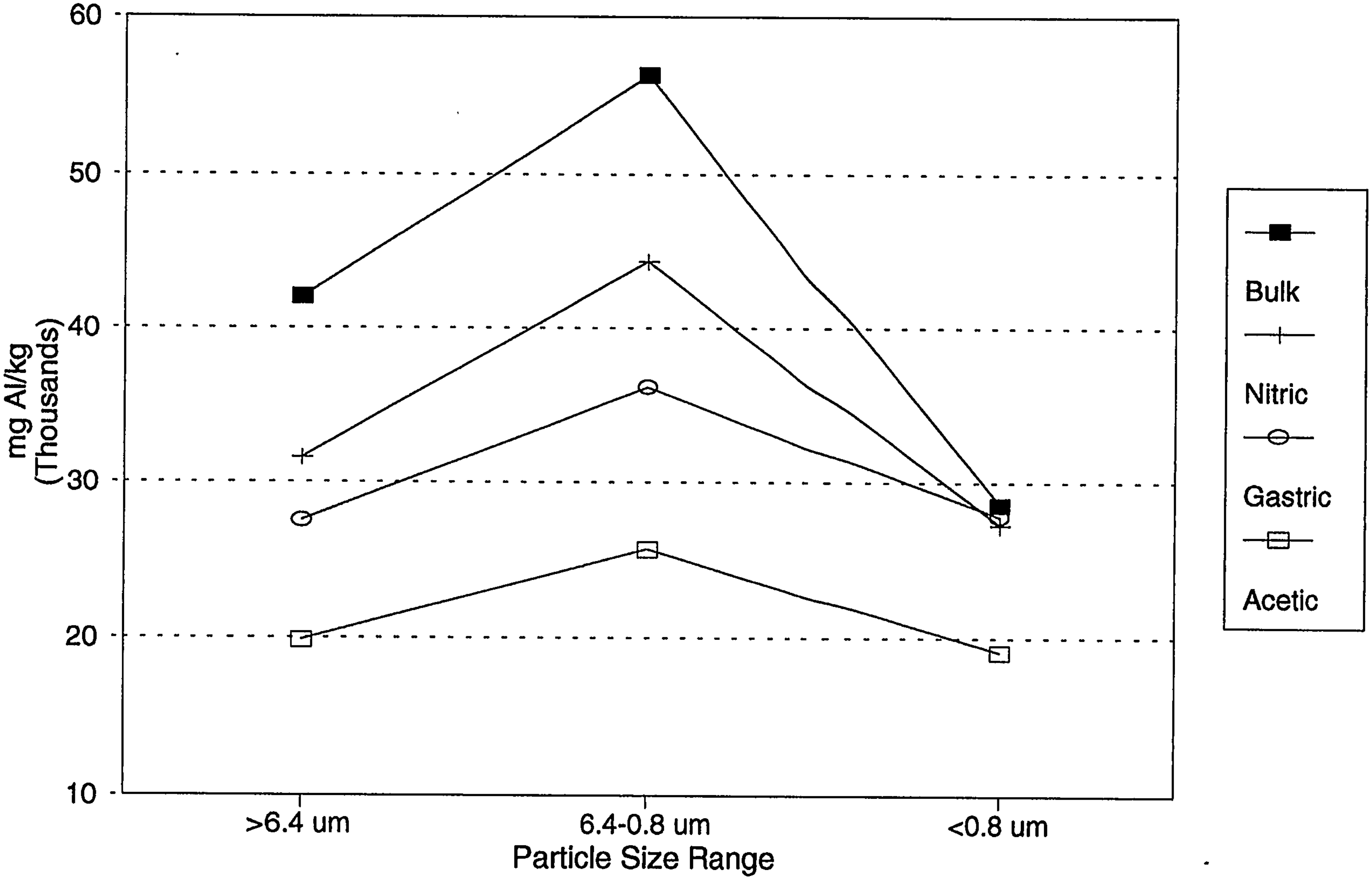
Vanadium Concentration



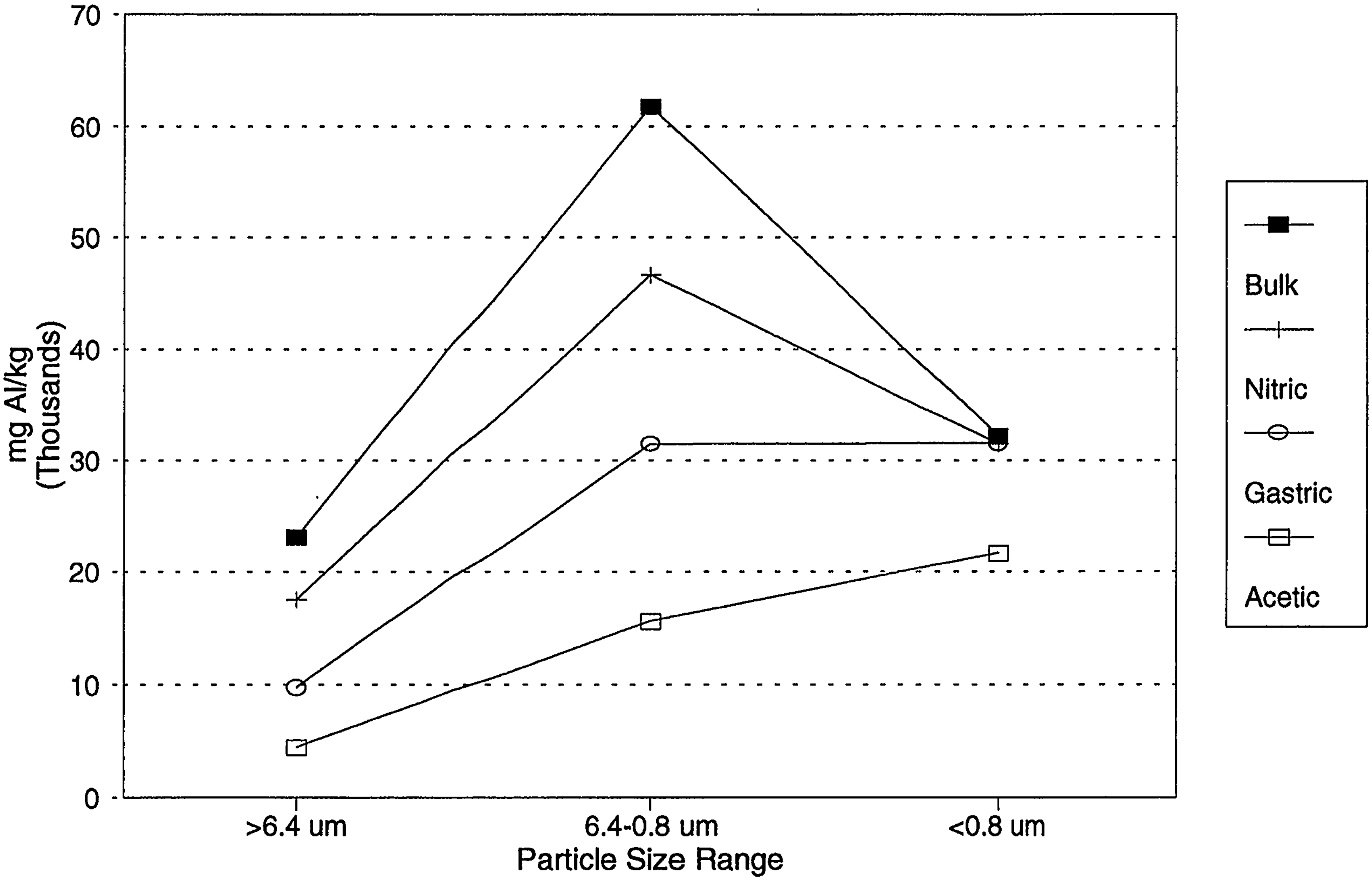
FGD Inlet
Aluminum Concentration



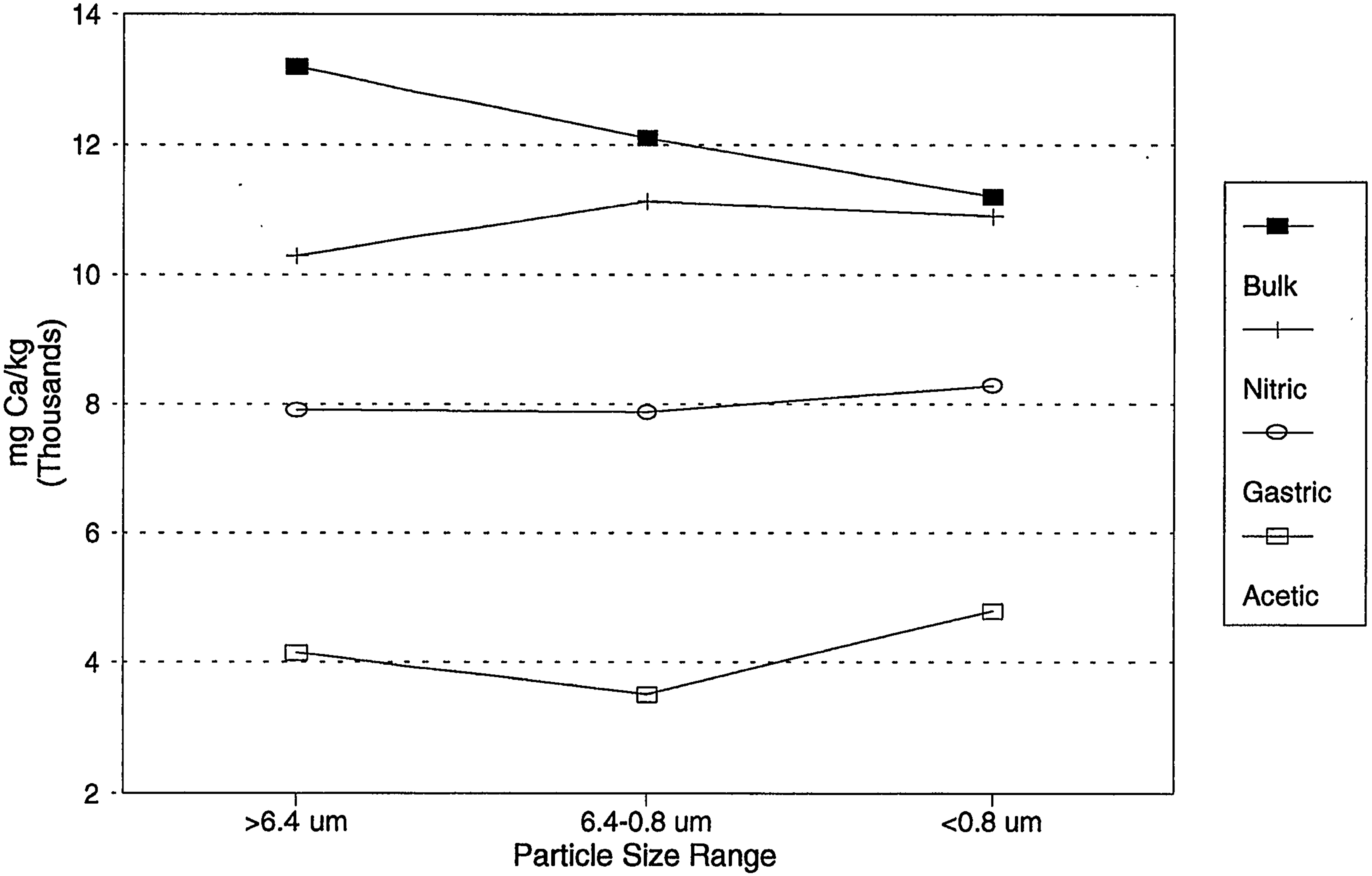
Stack Gas - High Load
Aluminum Concentration



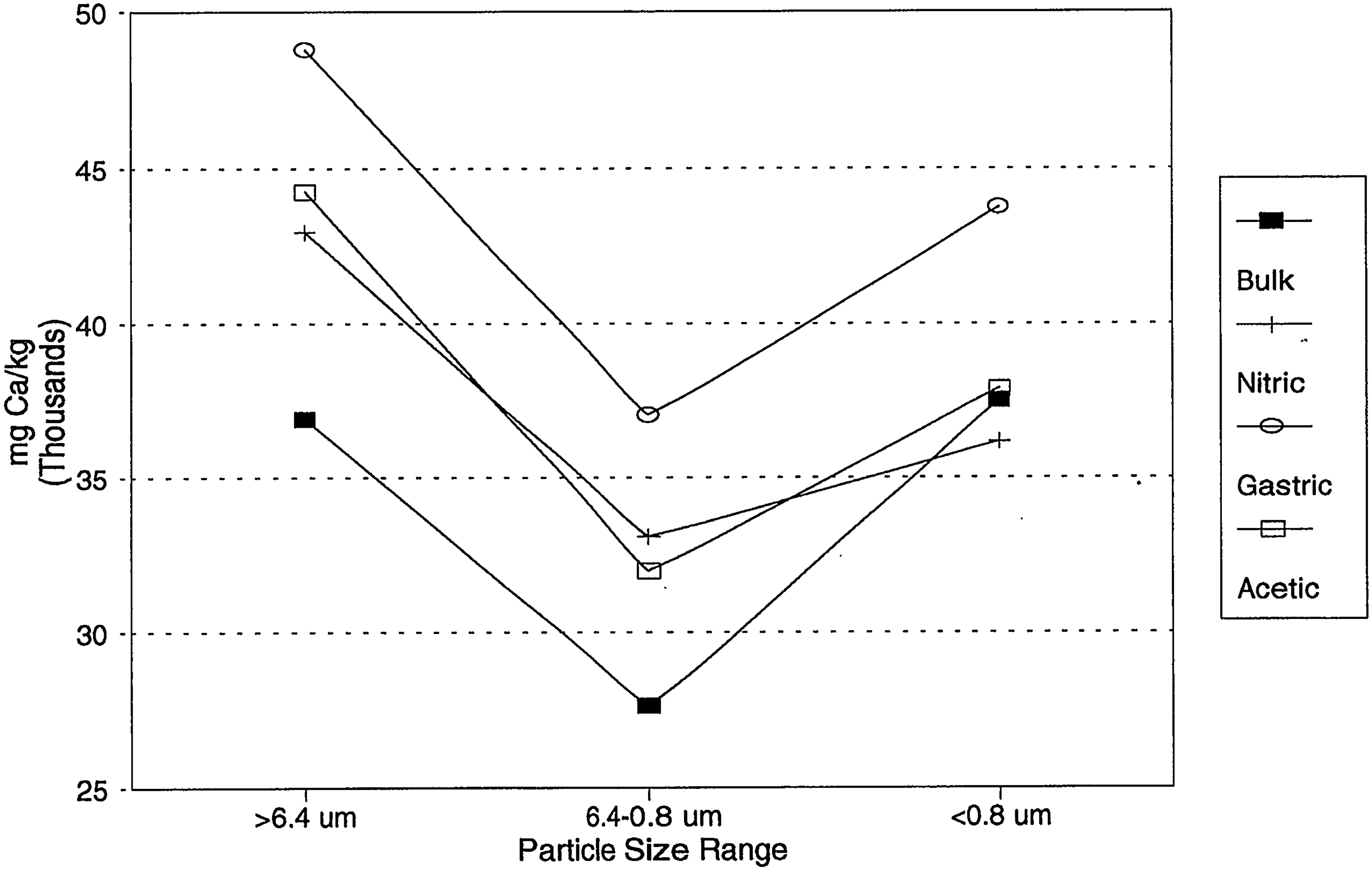
Stack Gas - Low Load
Aluminum Concentration



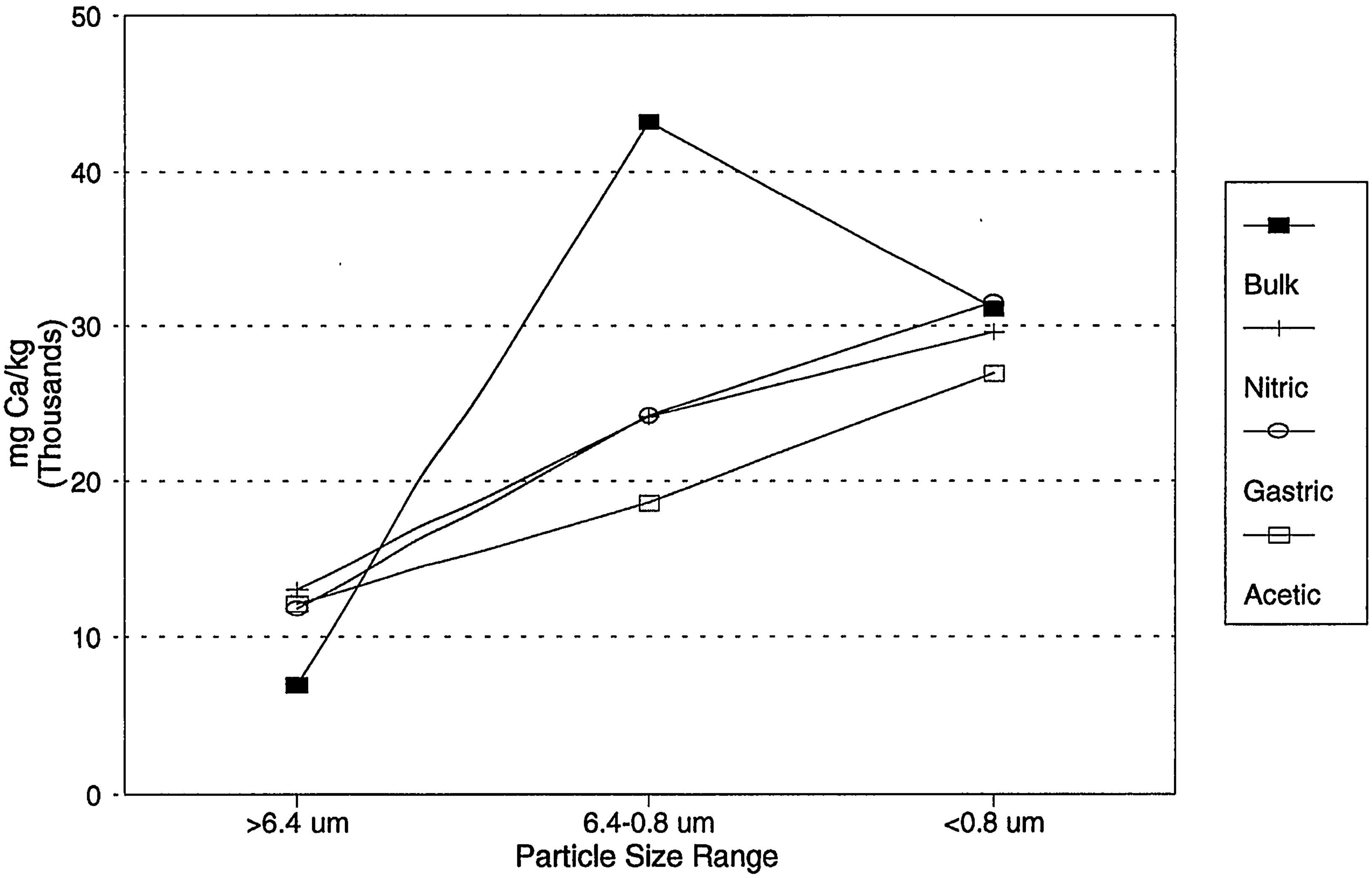
FGD Inlet
Calcium Concentration



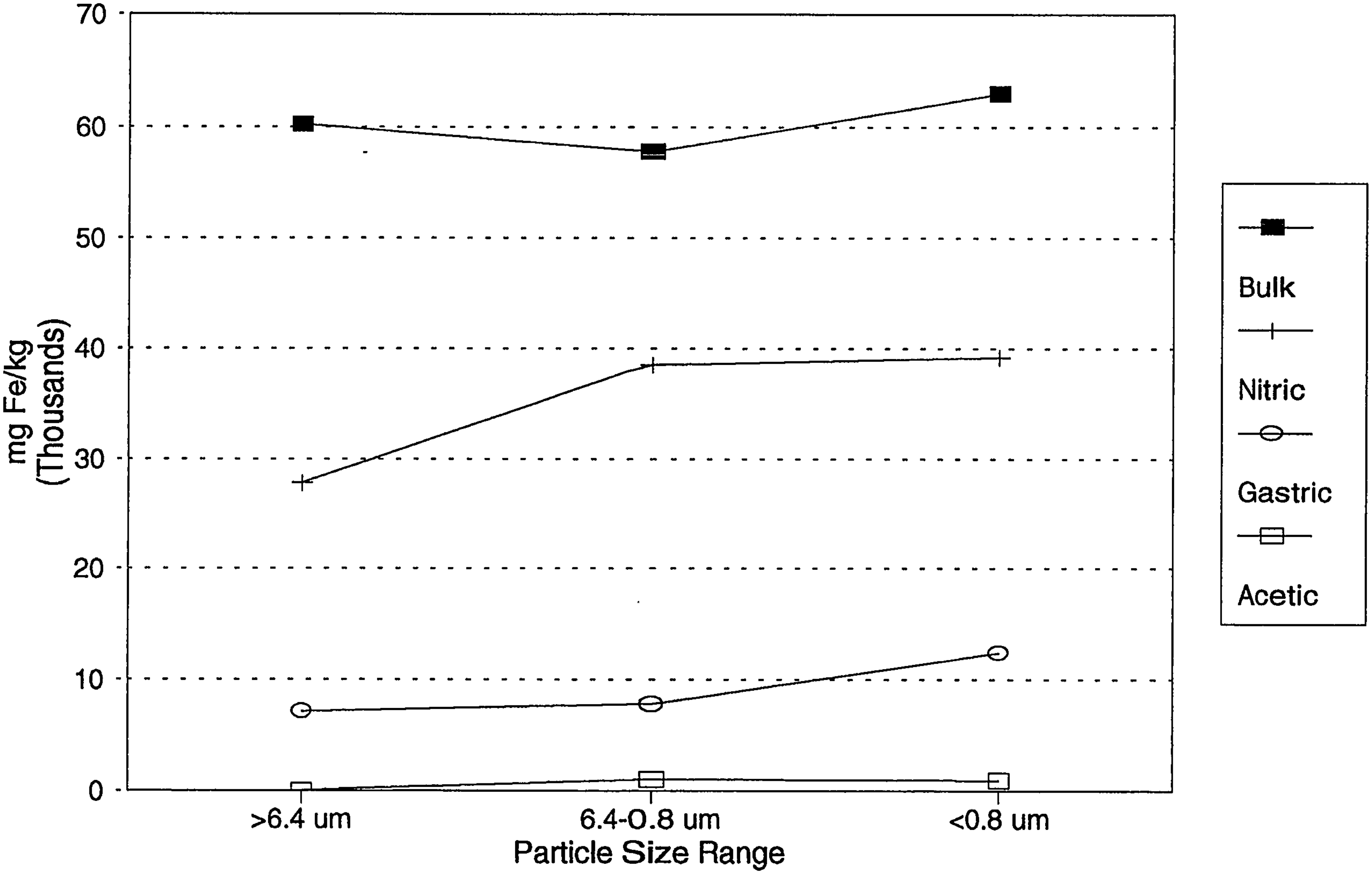
Stack Gas - High Load
Calcium Concentration



Stack Gas - Low Load
Calcium Concentration

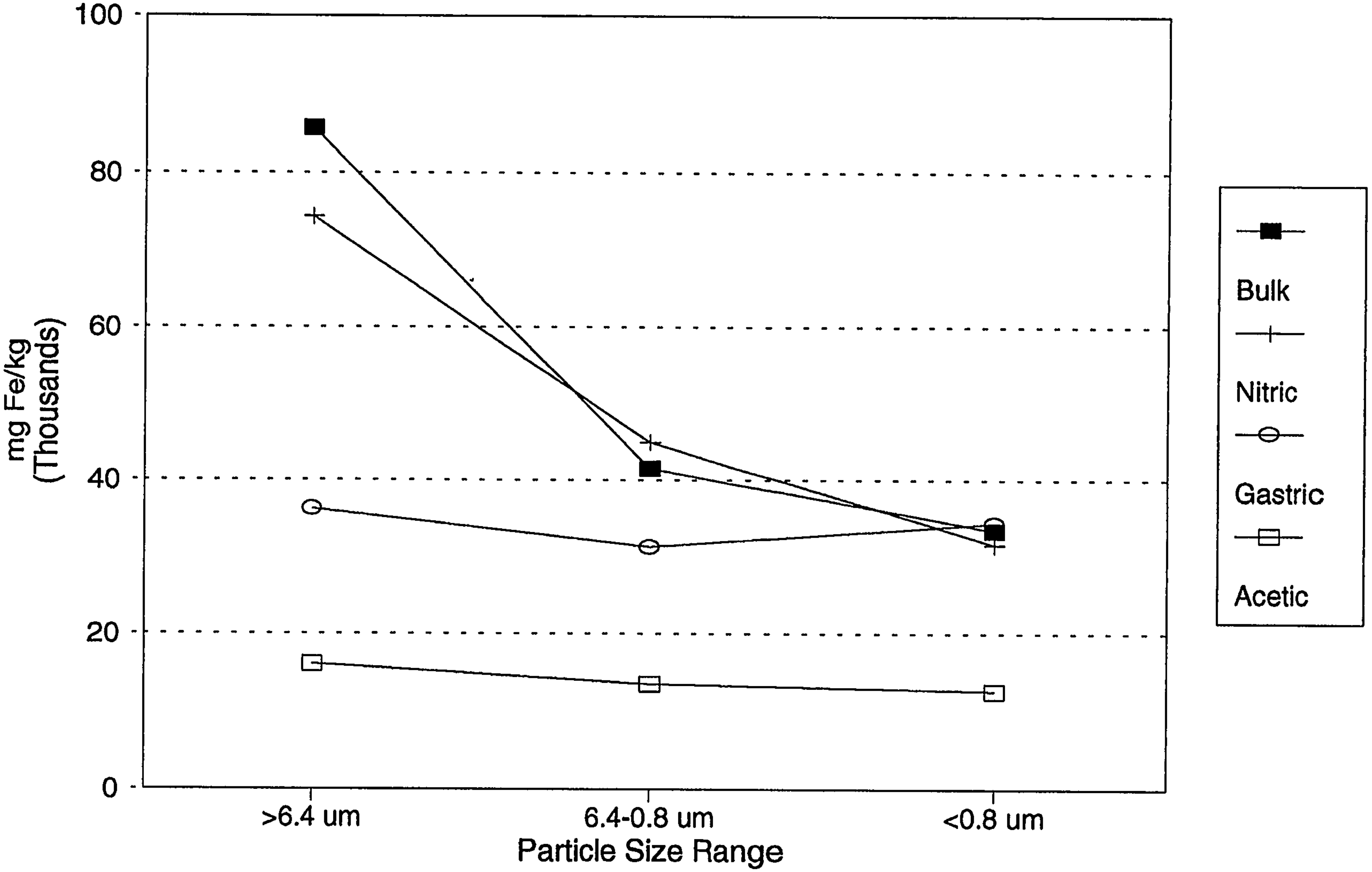


FGD Inlet
Iron Concentration

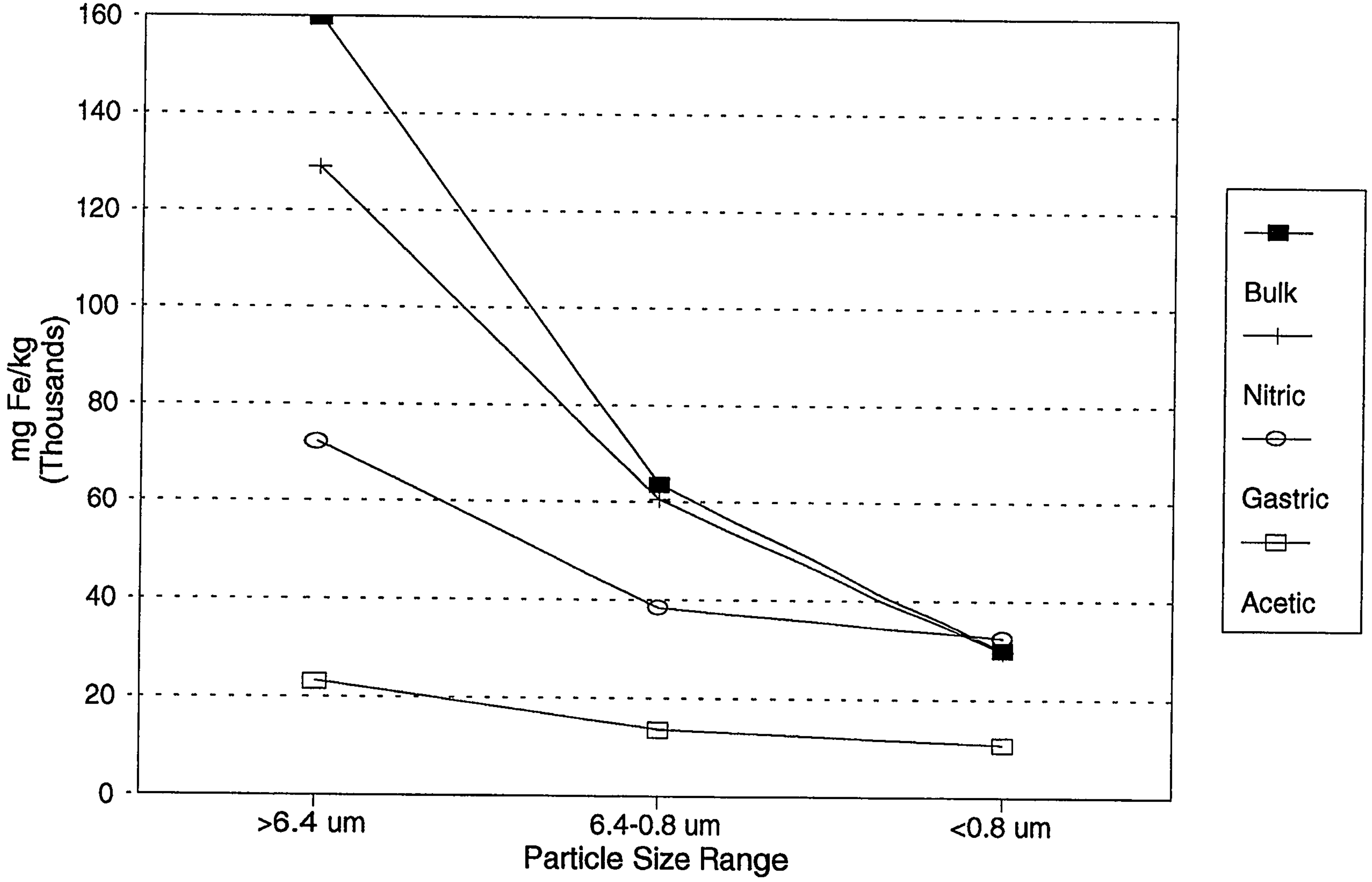


Stack Gas - High Load

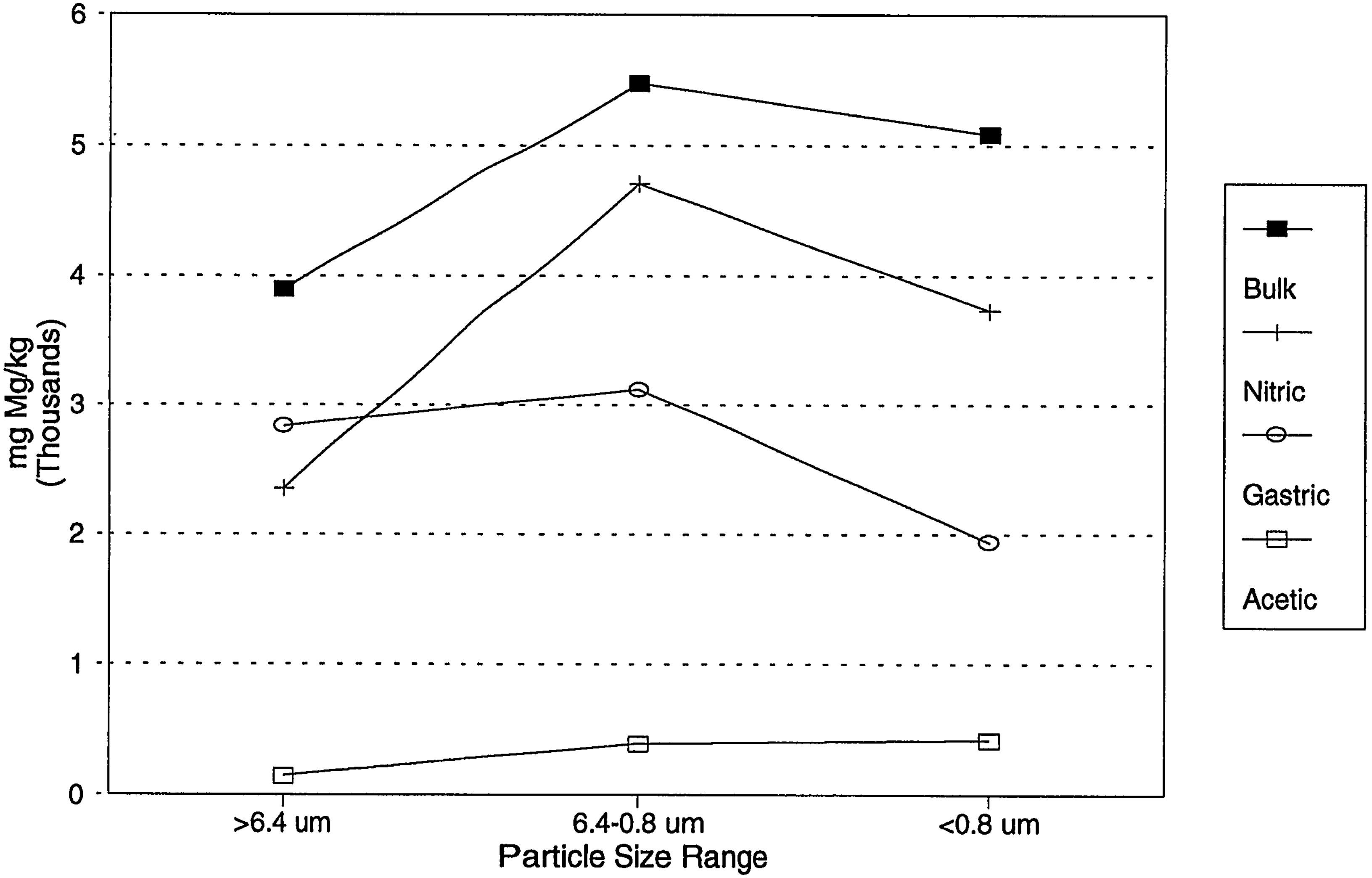
Iron Concentration



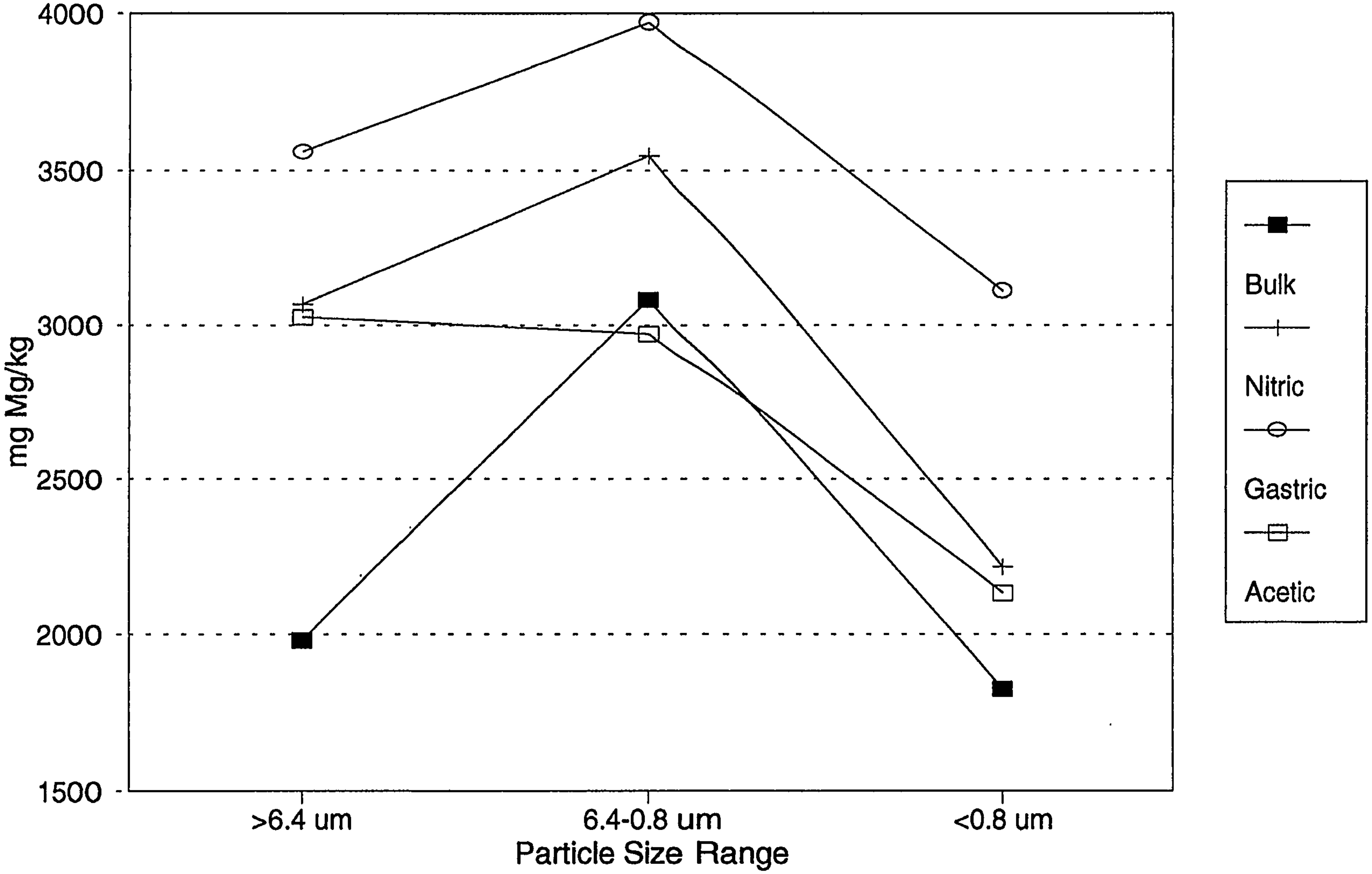
Stack Gas - Low Load
Iron Concentration



FGD Inlet
Magnesium Concentration

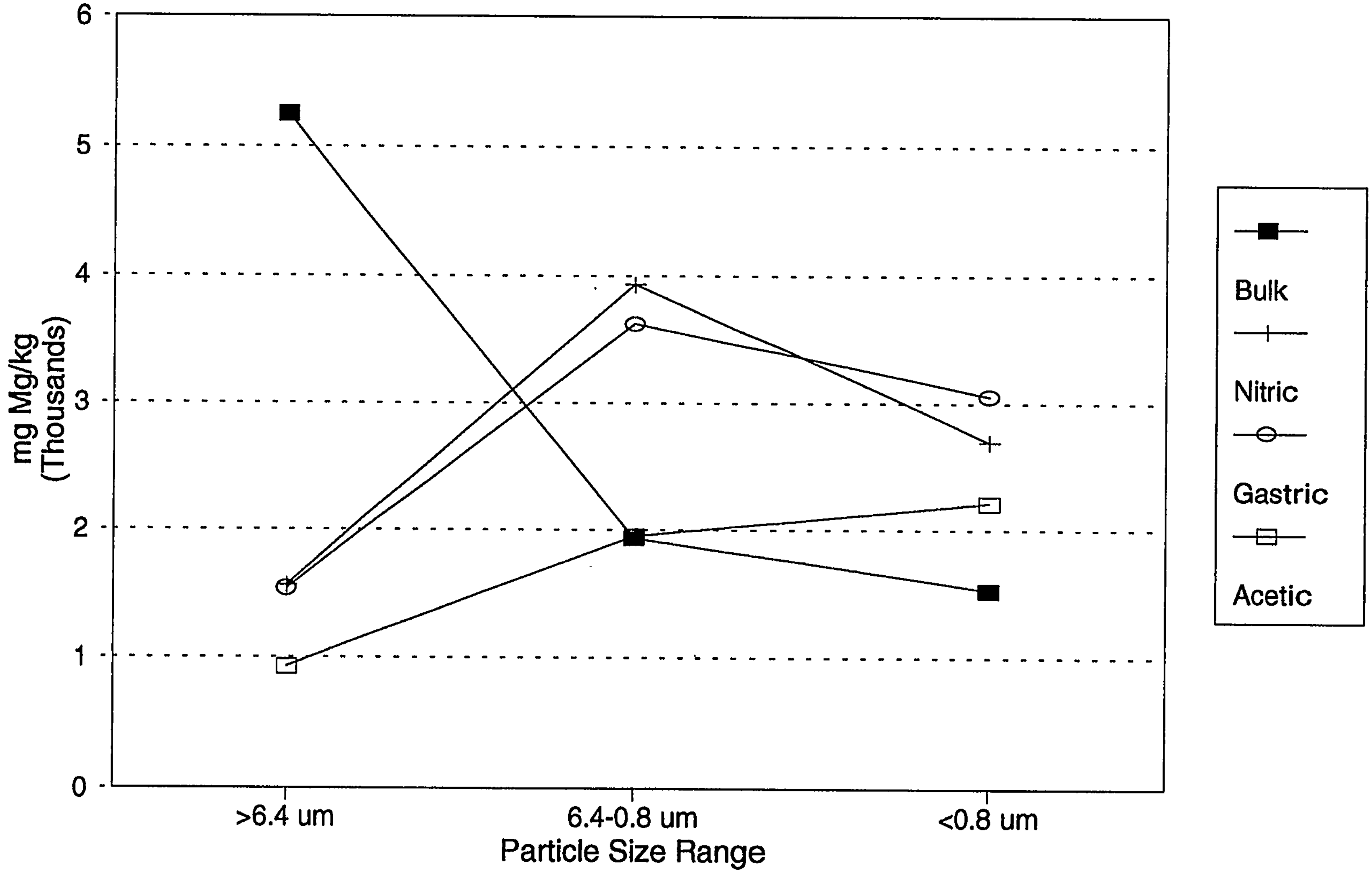


Stack Gas - High Load
Magnesium Concentration



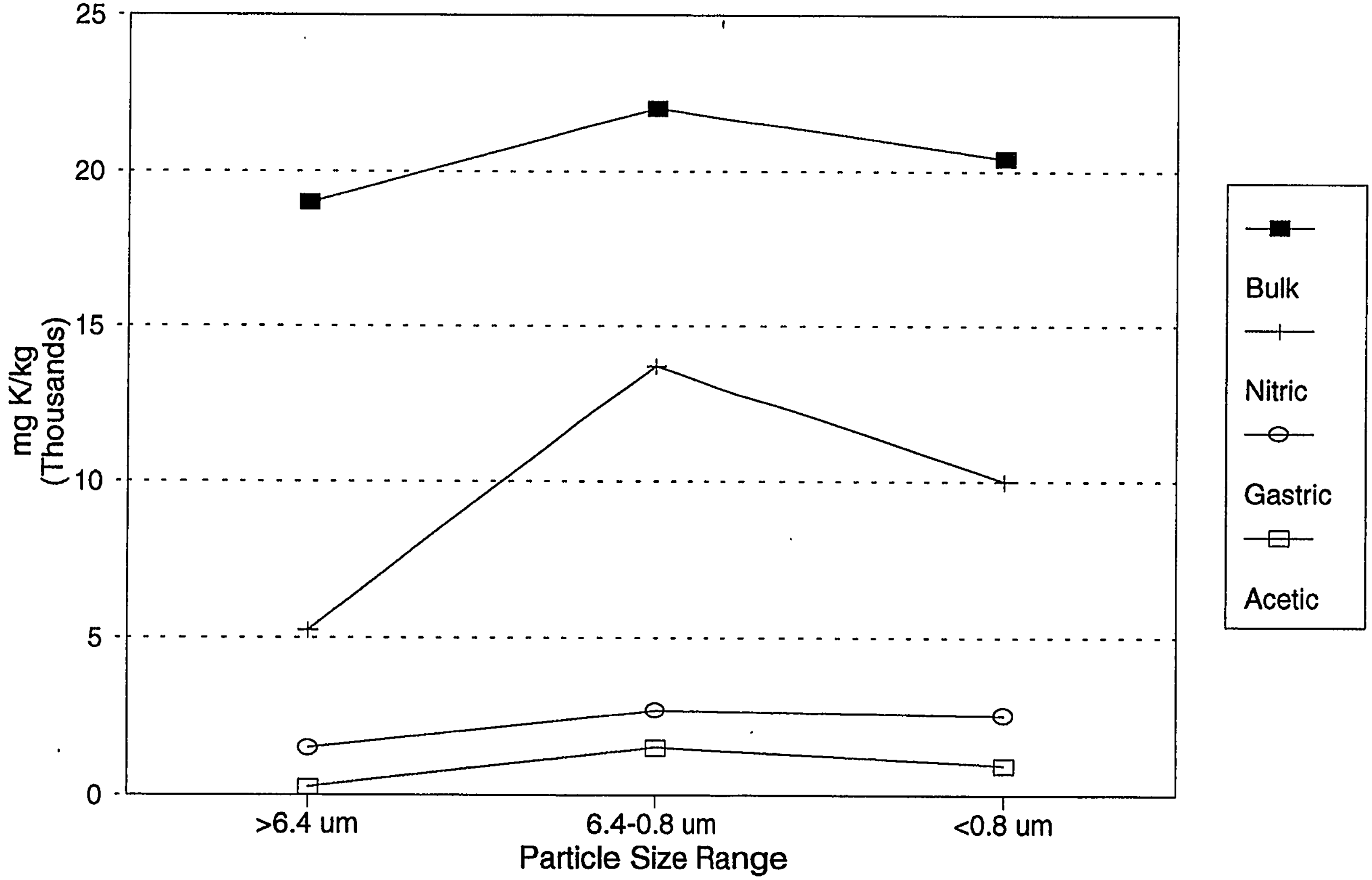
Stack Gas - Low Load

Magnesium Concentration



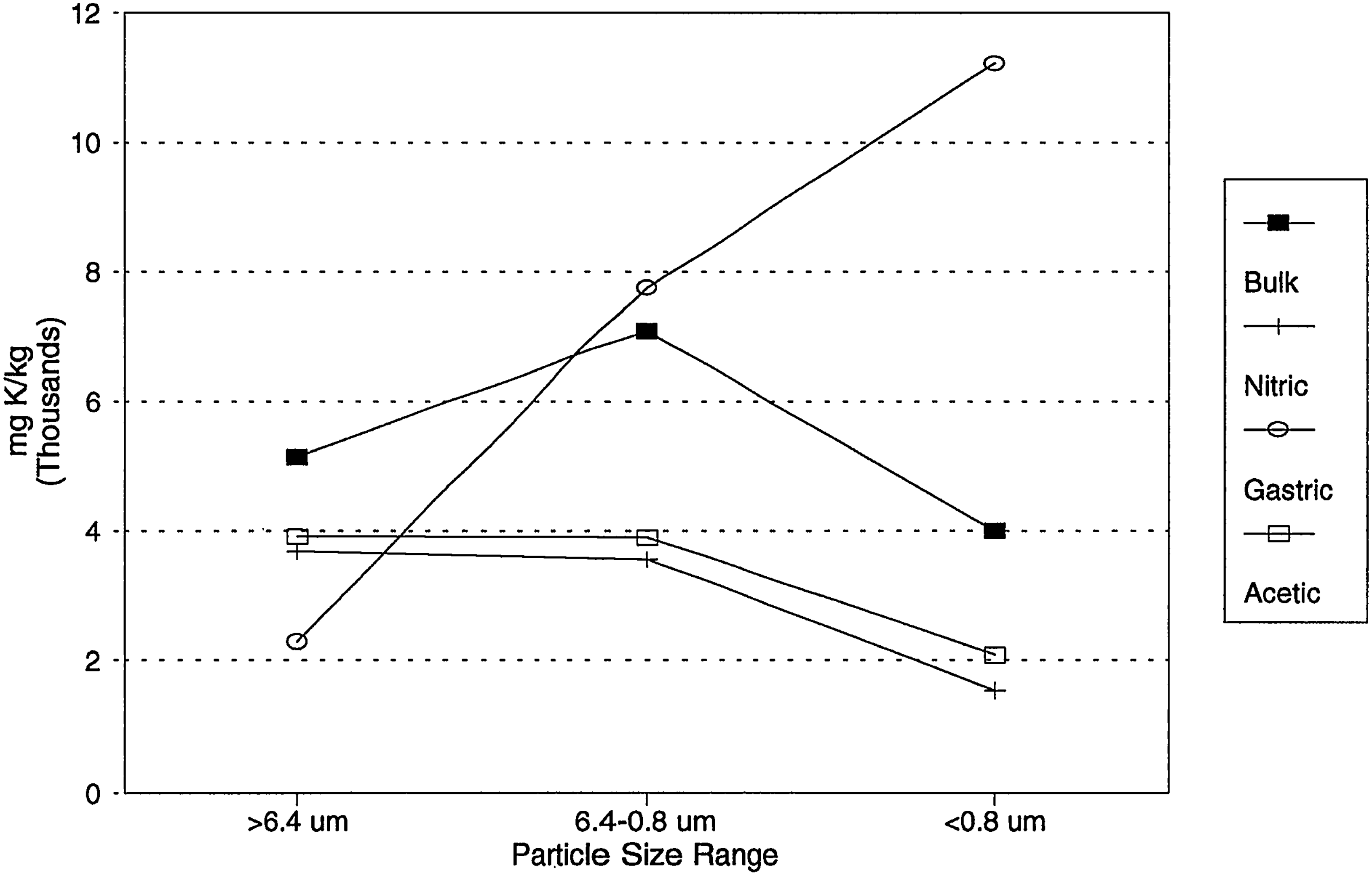
FGD Inlet

Potassium Concentration



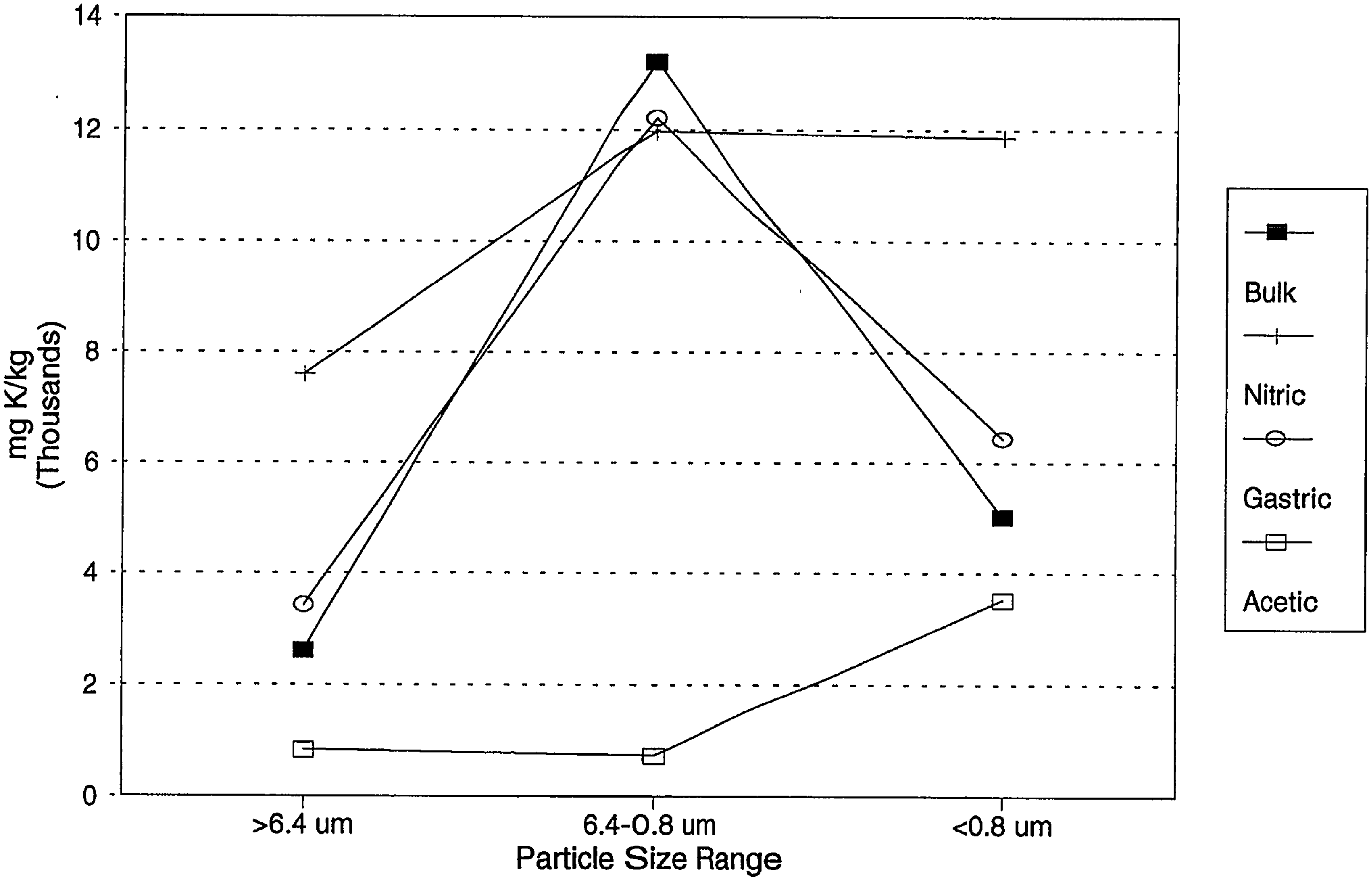
Stack Gas - High Load

Potassium Concentration



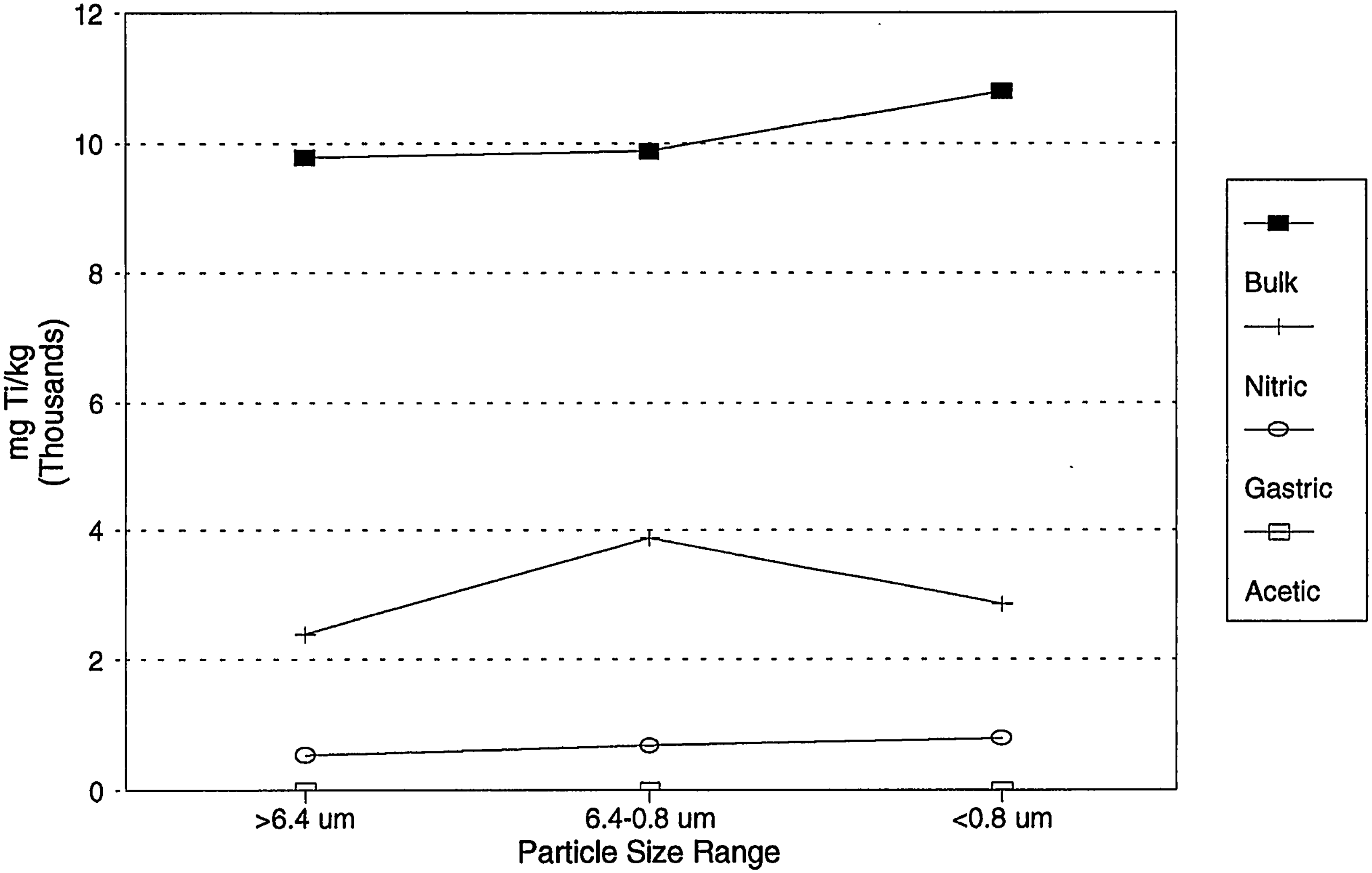
Stack Gas - Low Load

Potassium Concentration

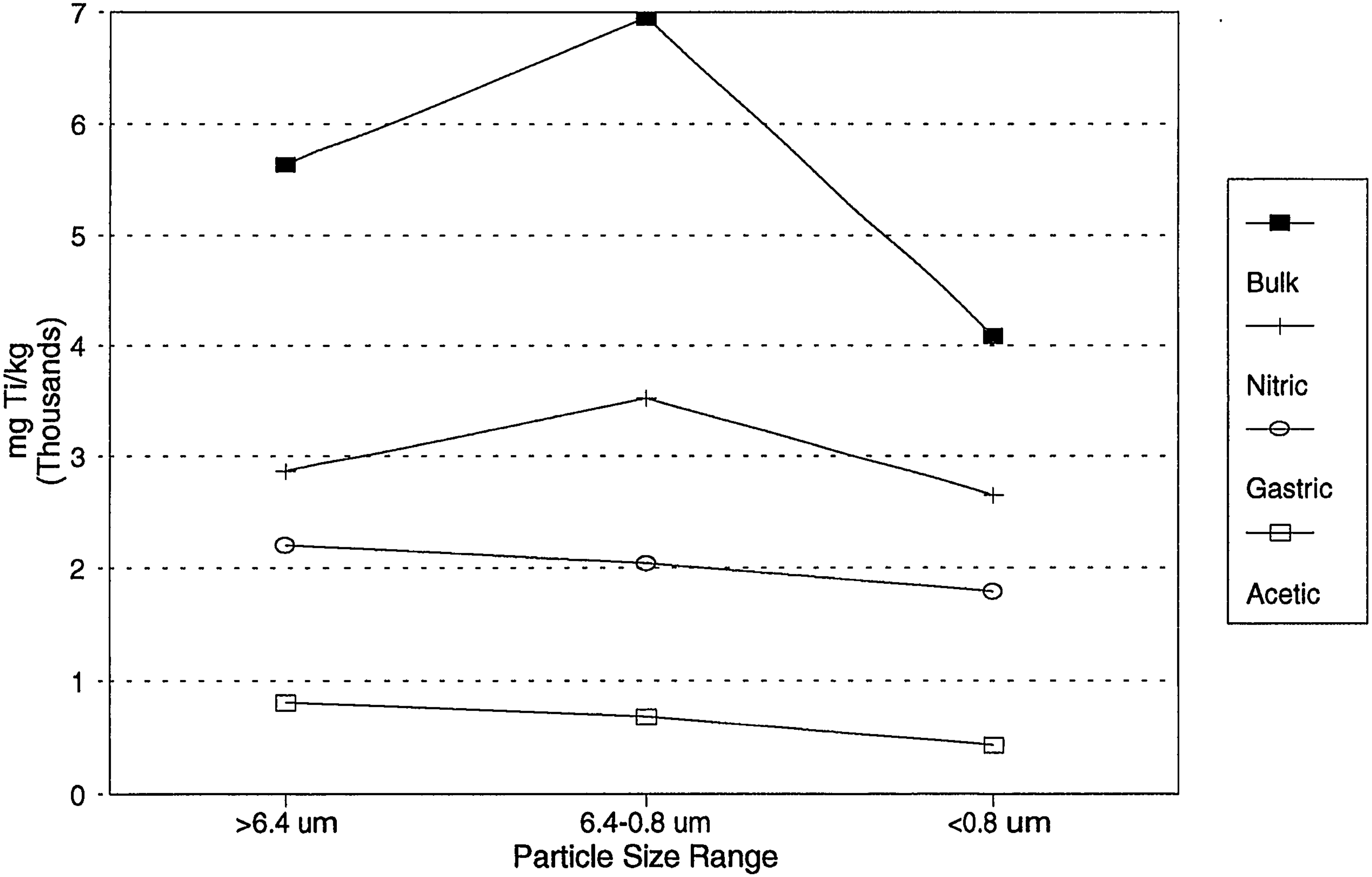


FGD Inlet

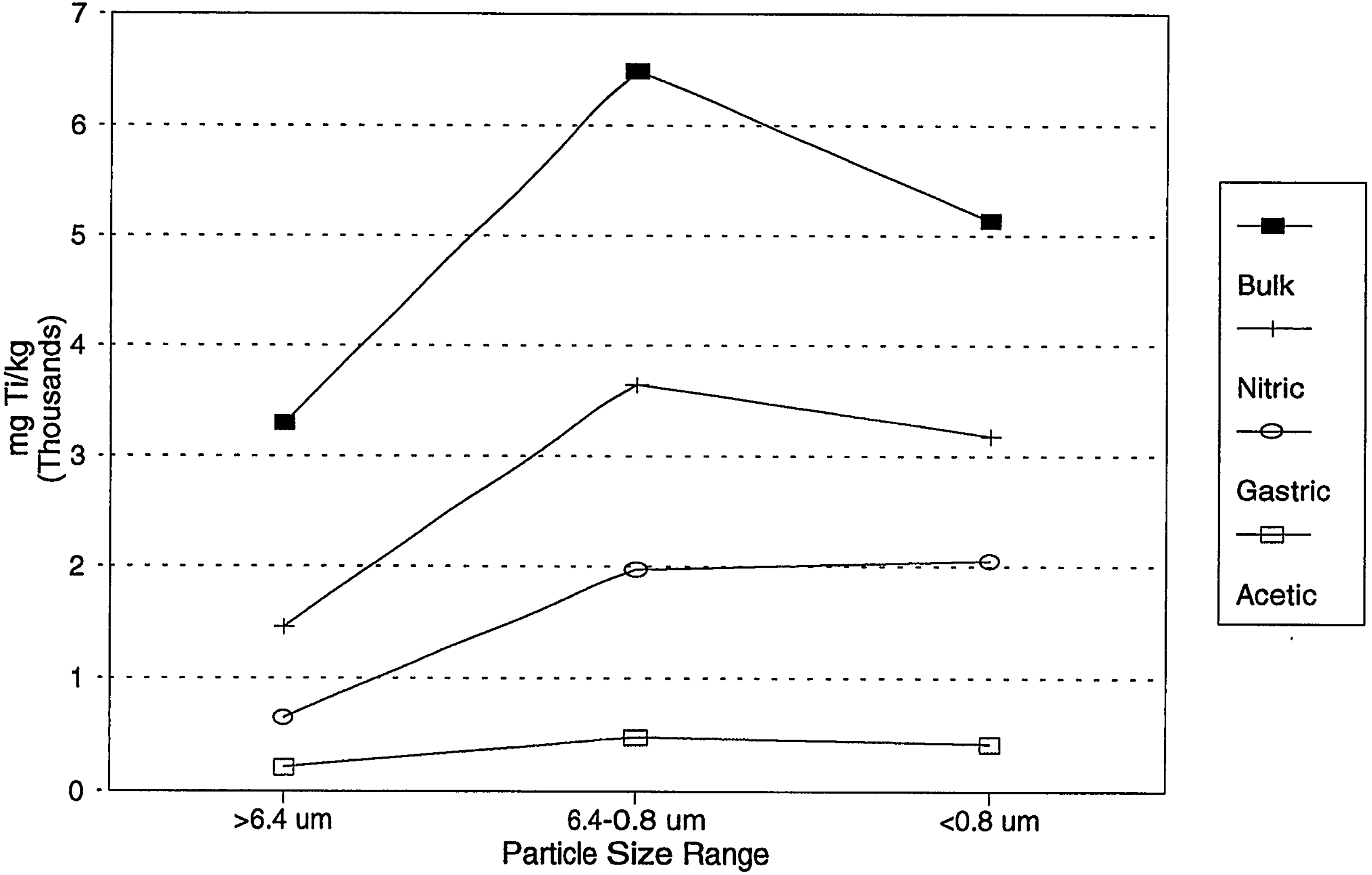
Titanium Concentration



Stack Gas - High Load
Titanium Concentration

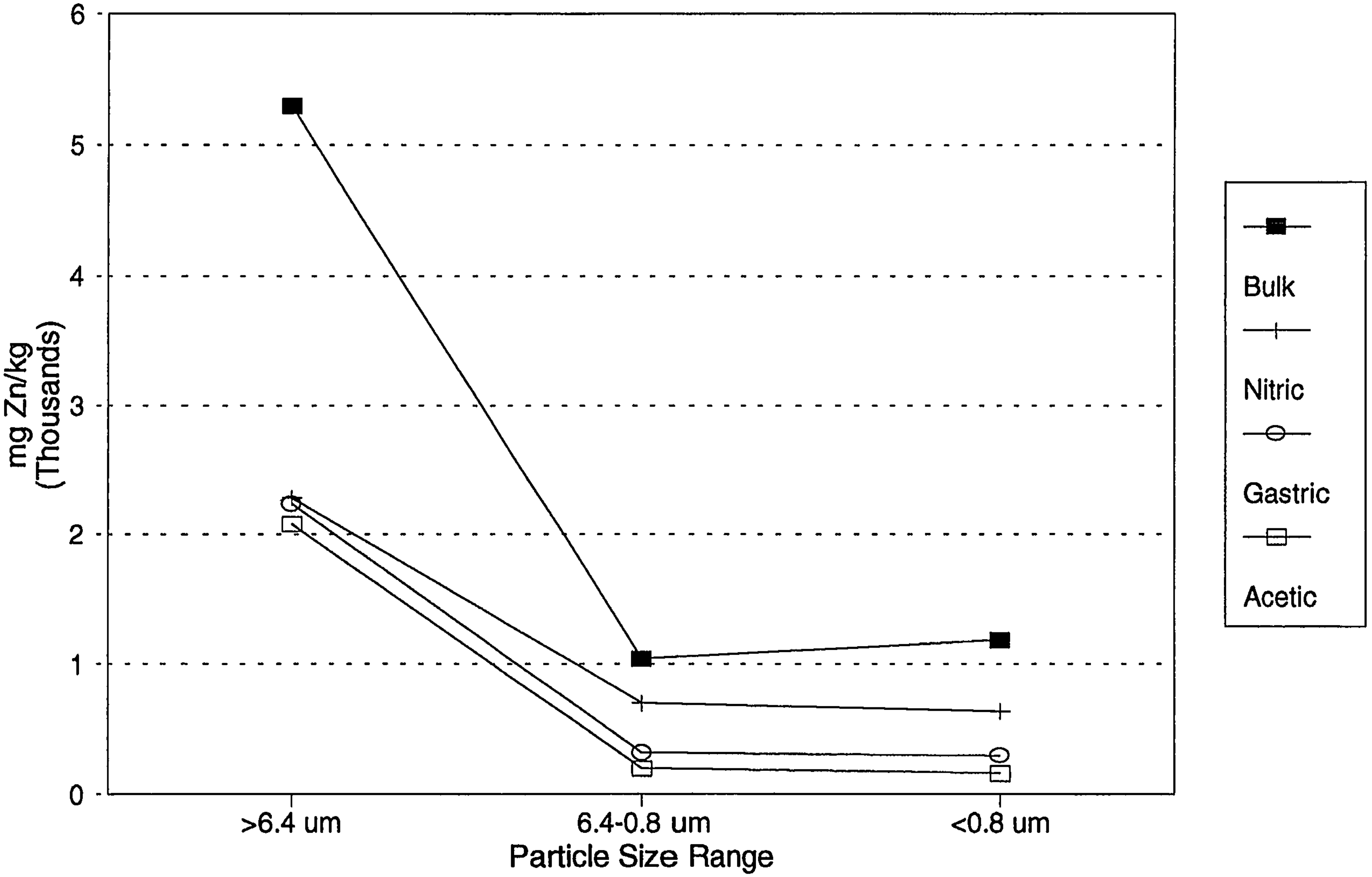


Stack Gas - Low Load
Titanium Concentration



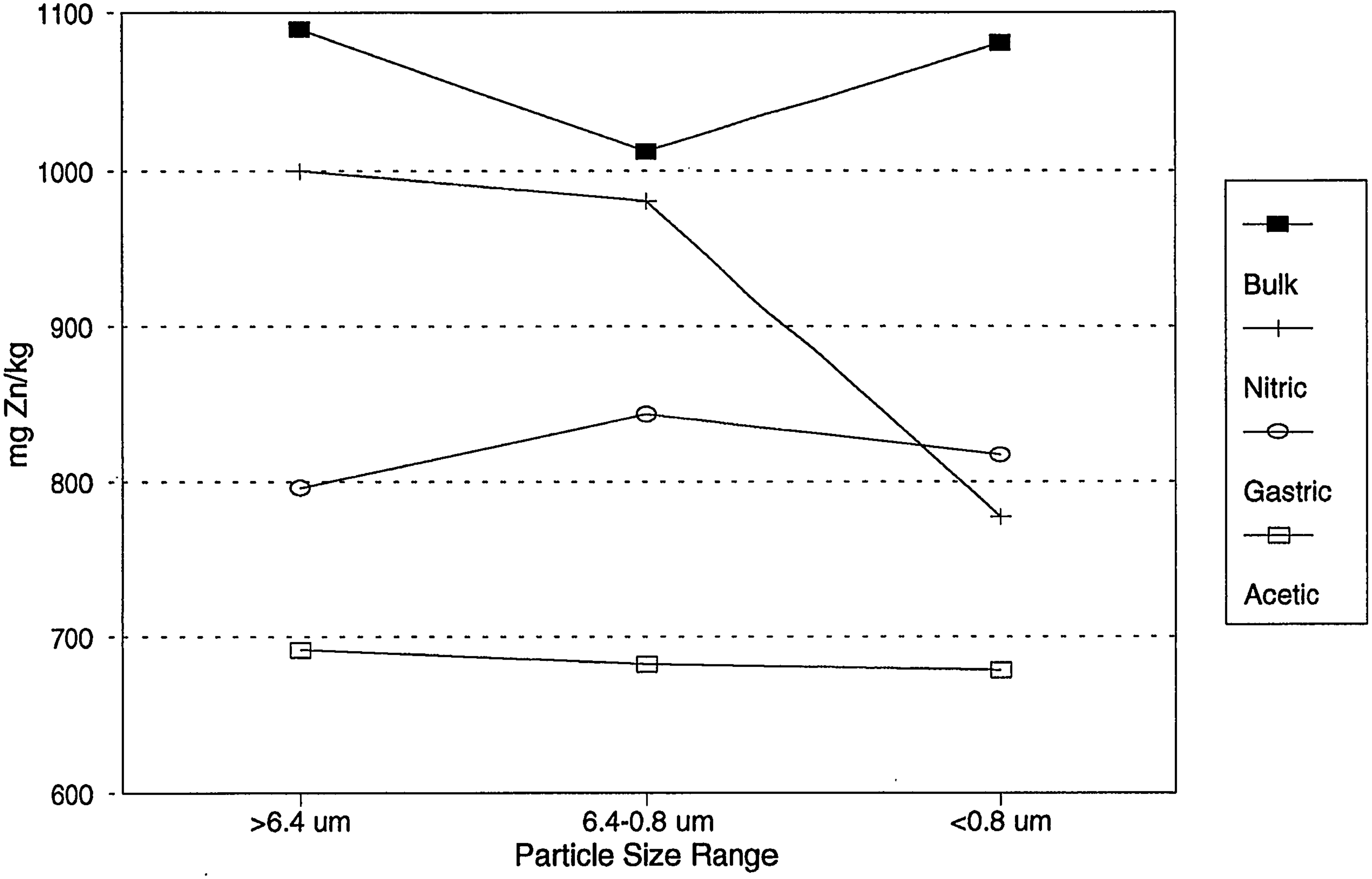
FGD Inlet

Zinc Concentration

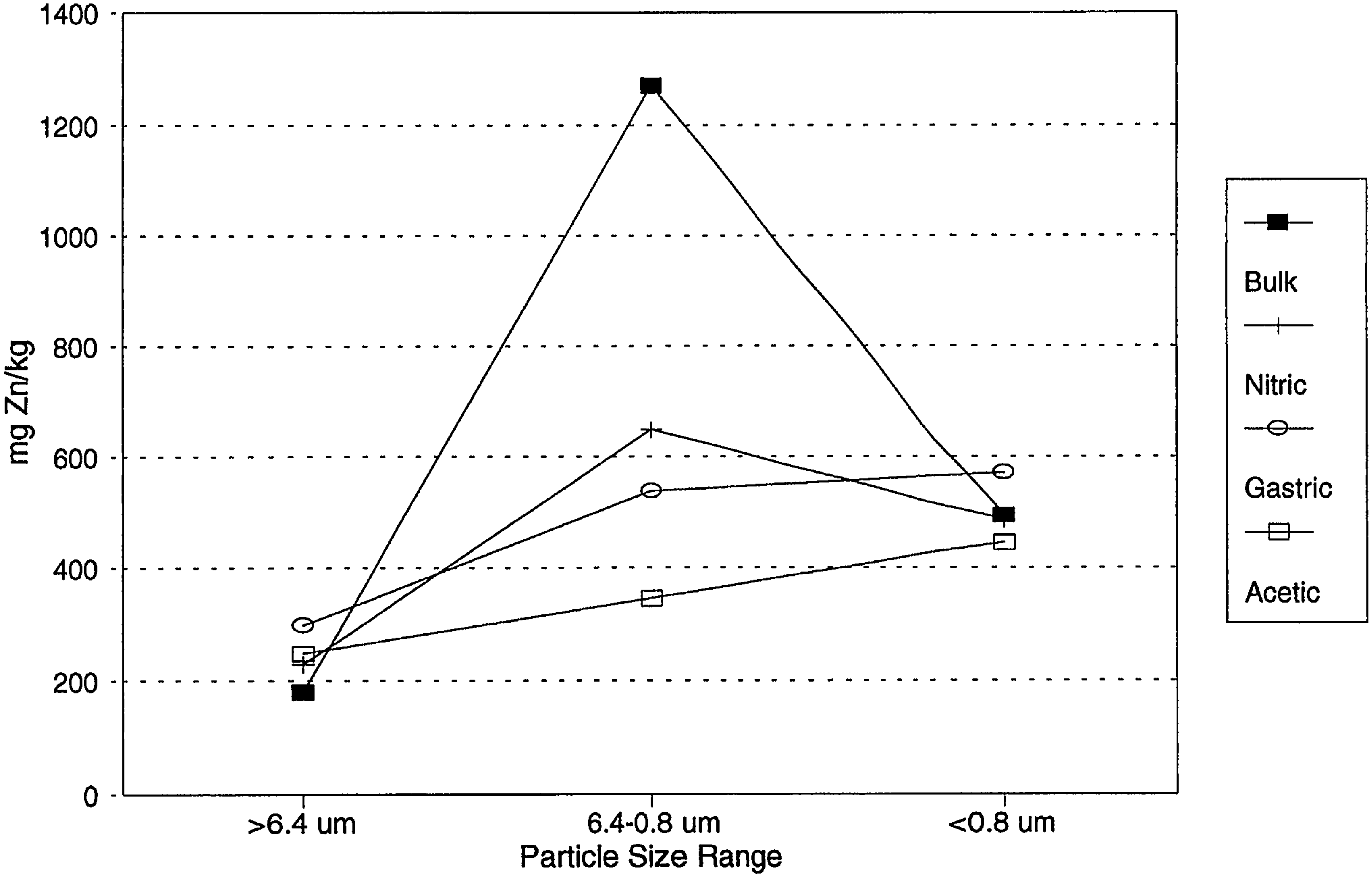


Stack Gas - High Load

Zinc Concentration



Stack Gas - Low Load
Zinc Concentration



APPENDIX E: TOXICITY PROFILES

1.0 INTRODUCTION

Toxicity assessment involves determining whether exposure to a chemical can increase the incidence of a particular adverse effect (such as cancer or birth defects) in humans. The nature and strength of the evidence that the chemical causes the particular effect is evaluated, and if sufficient data are available, the relationship between the dose of (or exposure to) a chemical and the incidence of adverse health effects is quantified.

Available toxicity information for each of the potentially toxic elements is presented in this appendix. This information includes a listing of standard toxicity values and a brief description of the adverse health effects associated with exposure to each of the chemicals. Some elements (calcium, potassium, and sodium) are essential nutrients. These elements are so nontoxic that toxicity values are not available. A summary of the physiologic role of these elements is included.

2.0 DEFINITIONS OF TOXICITY VALUES

Toxicity values are derived from the quantitative relationship between the dose (or exposure) and the incidence or magnitude of the response; this is called the dose-response relationship. These values can be used to estimate the incidence of or potential for adverse effects as a function of human exposure to a chemical.[1] EPA has performed toxicity assessments for numerous chemicals, and the resulting toxicity values have undergone extensive agency peer review. Toxicity values are developed separately for noncarcinogenic and carcinogenic effects.

2.1 Toxicity Values for Noncarcinogenic Effects

Toxicity values used to evaluate noncarcinogenic effects include reference doses (RfDs), in units of mg/kg/day, and reference concentrations (RfCs), in units of mg/m^3. The RfDs and RfCs are estimates (with uncertainty spanning an order of magnitude) of the daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk or deleterious effects during a lifetime. The RfD is used to evaluate oral and dermal exposures, and the RfC is used to evaluate inhalation exposures.

EPA establishes RfDs and RfCs on the basis of a review of the available literature and expert judgement.[2] The critical effect of a chemical is identified from the literature, and the "no observed adverse effect level" (NOAEL) is determined. The NOAEL incorporates one or more uncertainty factors. In general, EPA uses a factor of 10 to extrapolate from studies conducted in experimental animals to potential effects in humans; this process is called "interspecies extrapolation." EPA applies another factor of 10 to extrapolate from effects in health human populations (such as studies conducted on volunteers or populations of workers); this is called "intraspecies extrapolation."

EPA applies another factor of 10 to extrapolate from a study conducted using less-than-lifetime exposure to predict the effects after a lifetime of exposure; this is often called "subchronic to chronic extrapolation." Finally, EPA applies a factor of 10 when a NOAEL was not identified, and the evaluation starts with the Lowest Observed Adverse Effects Level, or LOAEL; this is called "LOAEL to NOAEL extrapolation." EPA sometimes applies a modifying factor on the basis of professional judgement. EPA determines a confidence level of high, medium, or low for each RfD and RfC. The confidence level is generally based on the amount of data available for review, the completeness of the database, the consistency of effects observed between studies, and other characteristics of the data.

The Integrated Risk Information Service (IRIS) is the consensus database for toxicity values for EPA programs. IRIS includes RfD and RfC values that have been verified by EPA work groups. The health effects assessment summary tables (HEAST) summarize risk-related toxicity information from EPA documents. HEAST may include toxicity values not available on IRIS; these values are not verified.

The Occupational Health and Safety Administration (OSHA) promulgates standards for exposure to specific chemicals in the workplace. The permissible exposure levels (PELs) may be 8-hour time-weighted average air concentrations, short-term exposure limits (15-minute averages), or ceiling values not to be exceeded. The American Conference of Governmental Industrial Hygienists (ACGIH) establishes threshold limit values (TLVs) for workplace air. The TLV is a time-weighted average concentration for a normal 8-hour work day and a 40-hour work week to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

Occupational exposure levels such as PELs and TLVs are developed for the protection of workers and are not intended to be protective of the general public. However, some of the chemicals found in stack gas particulate matter do not have EPA-developed toxicity values but do have occupational exposure levels. These levels are also useful for evaluating the relative toxicity of the elements.

2.2 Toxicity Values for Carcinogenic Effects

EPA derives toxicity values for carcinogenic effects using a different methodology from that for noncarcinogenic effects, because agency policy dictates that carcinogenic effects are nonthreshold phenomena. That is, there is no threshold below which carcinogenic effects cannot occur; rather, any exposure is associated with a calculable risk of carcinogenic effects (however small).

Toxicity values used to evaluate carcinogenic effects include the weight of evidence classification, the slope factor with units of $(mg/kg/day)^{-1}$, and the unit risk for inhalation exposure with units of $(\mu g/m^3)^{-1}$. The weight of evidence classification is a U.S. EPA system for characterizing the extent to which the available data indicate that an agent is a human carcinogen. On the basis of evidence from epidemiological and animal studies, EPA classifies chemicals into one of the following groups:

- Group A—Human Carcinogen (sufficient evidence of carcinogenicity in humans);
- Group B—Probable Human Carcinogen (B1—limited evidence in humans; B2—sufficient evidence in animals with inadequate or lack of evidence in humans);
- Group C—Possible Human Carcinogen (limited evidence in animals and inadequate or lack of evidence in humans);
- Group D—Not Classifiable as to Human Carcinogenicity (inadequate or no evidence); or
- Group E—Evidence for Noncarcinogenicity for Humans (no evidence of carcinogenicity in adequate studies).

EPA performs quantitative carcinogenic risk assessments for chemicals in Groups A and B, and on a case-by-case basis for chemicals in Group C. Cancer slope factors are estimated by using mathematical extrapolation models, most commonly the linearized multistage model; these models estimate the largest possible linear slope (within the 95% confidence limit) at low extrapolated doses that is consistent with the data. The slope factor is characterized as a plausible upper-bound estimate of the probability of response per unit intake of chemical over a lifetime. The slope factor is used to estimate the upper-bound probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen; this is called the lifetime excess cancer risk. The unit risk for inhalation is the risk per concentration unit in air (risk per $\mu g/m^3$).

3.0 HEALTH EFFECTS SUMMARIES

This section summarizes general information on the potential health effects (noncarcinogenic and carcinogenic) resulting from exposures to the chemicals of potential concern. Toxicity information on noncarcinogenic effects is provided for each contaminant, and includes the data that form the basis for the derivation of the RfD, RfC, or PEL/TLV. Information on the potential carcinogenic risk of each chemical is provided, along with supporting data for the EPA weight-of-evidence classification. Unless otherwise stated, the information presented below is summarized from the data available on IRIS as of June 1994.

3.1 Aluminum

Workers in the aluminum industry were shown to have an increased incidence of asthma, coughing, decreased pulmonary function, and several types of cancer. However, aluminum cannot be definitively identified as the causal agent in these studies because of the concurrent exposure of the workers to other toxic chemicals. In addition, smoking was not considered in the evaluation. Case reports show that some aluminum workers develop lung fibrosis when exposed to aluminum dusts. Exposure to aluminum was not well quantified in these studies, and the men were also breathing other dusts and fumes, so it is not clear that aluminum caused the fibrosis. However, it is likely that the aluminum dust did have irritant properties.[3]

A TLV of 2 mg/m^3 for the soluble salts of aluminum and aluminum alkyls has been recommended. The basis for the TLV is the amount of hydrolyzed acid and the corresponding TLV. No human toxicity studies are available for aluminum salts and essentially no toxicity information exists on any of the alkyls.[4]

Despite the widespread occurrence of aluminum in food, drinking water, and soil, there is little indication that aluminum is toxic by ingestion unless it is present in high quantities. Aluminum compounds can affect the absorption of other elements in the gastrointestinal tract and alter intestinal function, leading to a variety of complications. Other systemic toxicities can be caused by oral exposure to relatively high levels of aluminum. However, aluminum compounds are widely used in many ways, including antiperspirants, without harmful effects to the skin or other organs.[5]

No RfD or slope factor is currently available for aluminum on IRIS or in HEAST.

3.2 Antimony

Occupational exposure to antimony trioxide and/or pentoxide dust resulted in antimony pneumoconiosis, a disease of the lungs caused by habitual inhalation of irritant mineral or metallic particles. Alterations in pulmonary function (airway obstruction, bronchospasm, and hyperinflation) have been reported in workers exposed to airborne antimony. Other respiratory effects reported in workers include chronic bronchitis, chronic emphysema, inactive tuberculosis, pleural adhesions, and irritation. The respiratory irritation reported in the workers diagnosed as having pneumoconiosis was characterized by chronic coughing, wheezing, and upper airway inflammation. Inhalation exposure to antimony trisulfide dust resulted in degenerative changes in the heart muscle and related EKG abnormalities in a variety of animal species.

A variety of gastrointestinal disorders have occurred in factory workers engaged in activities that expose them to antimony, including repeated prolonged exposure to airborne antimony trichloride, antimony trisulfide or antimony oxide. These disorders include abdominal pain, diarrhea, vomiting, and ulcers. Inflammation of the membranes of the eyes and dermatosis have also have been observed from airborne antimony coming into contact with the skin and/or eyes.[6] IRIS reports a higher incidence of spontaneous abortion in workers exposed to antimony. A high rate of premature deliveries among the workers in an antimony smelting and processing plant has also been observed.

ACGIH lists a TLV of 0.5 mg/m^3 for antimony and antimony compounds. This value was calculated for antimony pentachloride and based on the TLV for hydrochloric acid. The TLV of 0.5 mg/m^3 is recommended for all antimony compounds as well as antimony trioxide handling and use.[7]

The oral RfD for antimony is listed in IRIS as 4E-04 mg/kg/day. This value is supported by a lifetime study of rats. HEAST lists a subchronic oral RfD of 4.00E-04 mg/kg/day. No carcinogenicity data exist on IRIS or in HEAST for antimony.

3.3 Arsenic

Workers exposed to arsenic dusts in air often experience irritation of the mucous membranes of the nose and throat. This may lead to laryngitis, bronchitis, or inflammation of the nasal membranes. High exposures can cause perforation of the nasal septum. Changes in skin pigmentation patterns may also be experienced. The level at which these effects are likely to occur in humans is uncertain, but is probably above 100 μg/m^3. These effects usually are not serious, but inhaled inorganic arsenic has been reported to increase the risk of lung cancer.[8]

Long term inhalation of inorganic arsenic may injure blood vessels or the heart. Several studies have reported the occurrence of nausea, vomiting, and diarrhea in workers exposed to high levels of inorganic arsenic dusts or fumes. Several case reports and epidemiological studies indicate that inhalation of inorganic arsenic can lead to neurological injury in humans. This may include both degeneration of the nervous system as well as damage to the brain. Babies born to women exposed to arsenic dusts during pregnancy had a higher than expected incidence of congenital malformations, and birth weights were slightly below average. Also, the incidence of spontaneous abortion in women who lived near a smelter tended to decrease as a function of distance from the smelter.[9]

The TLV is listed by ACGIH as 0.01 mg/m^3. This value is based on a study in which workers were exposed to concentrations of arsenic averaging about 0.01 mg/m^3 with no definite evidence of intoxication. Another study found workers with urinary arsenic levels of 0.8 mg/L, reasonably interpreted to an average exposure of 0.01 mg/m^3, exhibiting dermatitis and perforation of the nasal septum as well as eye and throat irritation. It is probable that some workers were exposed at much higher concentrations.[10]

Large oral doses (above 60,000 ppb in food or water) of inorganic arsenic can produce death in humans. Lower levels of inorganic arsenic (300-30,000 ppb in food or water), if swallowed, may result in irritation of the stomach and intestines, with symptoms such as pain, nausea, vomiting, and diarrhea. Other effects associated with ingestion of arsenic include decreased production of red and white blood cells, abnormal heart function, blood-vessel damage, and impaired nerve function.[11] Long-term oral exposure to inorganic arsenic often results in changes in the skin. These skin changes generally are not considered to be a health concern but could ultimately develop into skin cancer. Ingestion of arsenic has also been reported to increase the risk of cancer of the liver, bladder, kidney, and lung.[12]

The oral RfD for arsenic is listed in IRIS as 3.0E-04 mg/kg-day. This value is supported by two studies using human populations exposed to arsenic in well water. The incidence of blackfoot disease, hyperpigmentation and keratosis increased with dose and age. The critical effect was hyperpigmentation, keratosis, and possible vascular complications.

Arsenic is classified as Group A—Human Carcinogen. The inhalation unit risk is listed in IRIS as 4.3E-03 (μg/m^3)$^{-1}$. HEAST lists a value of 5.0E+01 (mg/kg-day)$^{-1}$ for the inhalation slope factor. Observed lung cancer incidence was significantly increased over expected values. The available evidence does not currently support the inference that arsenic is carcinogenic by the oral route of exposure.

3.4 Barium

Studies involving toxicoses following inhalation of barium have only been documented in workers exposed to barium dust. Abdominal cramps, nausea, vomiting, pulmonary lesions, muscle weakness, and renal failure was observed in a factory worker accidentally exposed to high levels of barium carbonate powder. Disturbances in spermatogenesis, including decreased number of sperm, decreased percentage of motile sperm, and decreased osmotic resistance of sperm, were reportedly observed in male rats exposed by inhalation to 15.8 mg/m^3 as barium carbonate dust.[13]

Soluble compounds of barium have a TLV of 0.5 mg/m^3. This recommendation is based on a lack of definitive data. Therefore, the TLV committee is reviewing the TLV and documentation for barium and its soluble compounds based on the 1990 ATSDR and WHO comprehensive profiles.

The majority of the studies evaluating the health effects of barium used the oral route of exposure. Acute ingestion of high levels of barium can result in respiratory weakness, abnormalities in heart rhythm, hypertension, gastrointestinal disturbances, progressive muscle weakness, and renal insufficiency. The occurrence and severity of these symptoms decrease with decreasing levels of exposure. The only well-documented adverse effect following low-level, chronic exposure is compromise of the cardiovascular system.[14]

IRIS lists the chronic RfD for barium as 7.0E-02 mg/kg/day. HEAST lists this value as the subchronic oral RfD. These values are based primarily on two studies. In the first study, 11 healthy male volunteers were administered 0 to 10 mg/L barium in drinking water for 10 weeks. The second study was a retrospective epidemiological study, which compared human mortality and morbidity rates in populations ingesting elevated barium levels (2 to 10 mg/L) in drinking water. The critical effect of interest was increased blood pressure.

Although not listed in IRIS, a chronic inhalation RfC of 5.0×10^{-4} mg/m^3 is listed in HEAST. The subchronic inhalation RfC is given as 5.0E-03 mg/m^3. A risk assessment for exposure to barium via inhalation is currently under review by an U.S. EPA work group. Barium is not considered carcinogenic at this time.

3.5 Cadmium

Exposure to high levels of cadmium via inhalation severely damages the lungs and can cause death. Inhalation of lower levels for a period of years results in accumulation of cadmium in the kidneys that can cause kidney disease. Long-term exposure to cadmium by inhalation may also cause fragile bones.

Long-term exposure of workers to cadmium via inhalation in an occupational setting may increase the risk of developing lung cancer. Inhalation of cadmium also causes liver damage, changes in the immune system, and reproductive problems in rats and mice. Currently, it is not known whether inhalation of cadmium affects the ability of humans to reproduce or has harmful effects on the fetus, liver, heart, nervous system, or immune system.[15]

ACGIH has adopted a TLV of 0.002 mg/m^3 for respirable dusts of cadmium. This value is recommended for the prevention of emphysema, pulmonary edema, and kidney problems such as protein in the urine. A proposed revision of the TLV to 0.01 mg/m^3 has been placed on the Notice of Intended Changes. It is anticipated that this lower limit will protect the lower respiratory tract and reduce the possibility of cancer.[16]

Consumption of very high levels of cadmium in food or drink severely irritates the stomach and causes vomiting and diarrhea. Deaths from cadmium ingestion have only been documented in cases of suicide. Similar to exposure via inhalation, ingestion of lower levels of cadmium results in accumulation in the kidneys, resulting in kidney damage and fragile bones. Dermal contact with cadmium is not known to cause adverse health effects in animals or humans.[17]

IRIS lists the oral RfD for cadmium in water as 5.0E-04 mg/kg-day and in food as 1.0E-03 mg/kg-day. The RfD is based on the highest level of cadmium in the human renal cortex (200 μg cadmium/g wet renal cortex) not associated with significant proteinuria, the critical effect of interest. A toxicokinetic model was used to determine the highest level of exposure associated with the lack of a critical effect. HEAST lists an additional oral RFD for cadmium in food as 1.0E-03 mg/kg-day. An inhalation RfC is currently under review.

EPA has classified cadmium as a Group B1—Probable Human Carcinogen. Limited evidence of its carcinogenicity in humans is available from several epidemiologic studies which demonstrated a possible association with lung and prostate cancers. EPA has not established an oral slope factor for cadmium. An inhalation unit risk of 1.8E-03 (μg/m^3)$^{-1}$ has been established based primarily on an epidemiologic study of cadmium smelter workers in which an increased risk of lung, trachea, and bronchus cancer mortality was observed. HEAST lists a value of 6.1E+00 (mg/kg/day)$^{-1}$ for the inhalation slope-factor.

3.6 Chromium

The absorption of inhaled chromium compounds depends on a number of factors, including physical and chemical properties of the particles (oxidation state, size, and solubility) and the ability of the alveolar macrophage in the lungs to clear the particles.

Chromium in soils exists predominantly in the trivalent state. For example, soil samples obtained during a remedial investigation conducted at 42 sites in a county where chromium processing had been ongoing from 1905 to 1971, indicated that the average chromium VI concentration was 2.6 percent.[18] In the same study, samples of airborne chromium-contaminated dust were collected at 17 different locations within the county. The outdoor chromium VI concentrations were between 16% and 26% of the total chromium concentrations. In addition, organic matter in soil is expected to convert soluble chromate (chromium VI) to insoluble chromium III oxide (Cr_2O_3).[19]

Chromium III

Trivalent chromium (chromium III) is much less toxic and more abundant in nature than the hexavalent form (chromium VI).[20] Respiratory effects have been observed in workers exposed to chromium III; however, other forms of chromium were also present. The respiratory system is the primary target for injury following inhalation exposure in laboratory animals. Rats and mice inhaling various levels of chromium III oxide had increased lung weights, marked hyperplasia, interstitial fibrosis, and epithelial necrosis.[21]

A TLV of 0.5 mg/m^3 is recommended to reduce the potential for pulmonary disease or other toxic effects. This is based on the relatively low toxicity of chromium metal and divalent and trivalent chromium compounds.

IRIS lists the chronic oral RfD as 1.0E+00 mg/kg/day which is the same value listed in HEAST as the subchronic oral RfD. These values are based upon a chronic feeding study in rats.

Chromium III is not believed to be carcinogenic at this time.

Chromium VI

Chromate sensitive workers acutely exposed to chromium VI develop asthma and other signs of respiratory distress. Symptoms include redness of the face, intense itching in the nasopharyngeal area, nasal blockage, coughing and wheezing. In a retrospective mortality study, intermediate- to chronic-duration occupational exposure to chromium VI showed an increased risk of death due to noncancer respiratory disease. Occupational exposure has also been associated with adverse effects on the gastrointestinal system and severe liver injury. Additionally, chromium VI has been associated with an increased incidence of bronchogenic and nasal cancer following chronic occupational exposure.[22]

A TLV of 0.05 mg/m^3 is recommended for chromium IV compounds although little environmental data are available. With the data available, however, this TLV provides an adequate margin of safety.[23]

IRIS lists a chronic oral RfD for chromium VI as 5.0E-03 mg/kg/day. HEAST provides a subchronic oral RfD of 2.0E-02 mg/kg/day. Chromium VI is considered to be carcinogenic only by inhalation and is classified as Group A - Human Carcinogen. IRIS lists an inhalation unit risk value of 1.2E-02 (μg/m^3)$^{-1}$. The corresponding inhalation slope factor is 4.1E+01 (mg/kg/day)$^{-1}$.

3.7 Cobalt

The respiratory system is one of the primary target organs of inhaled cobalt. The effects of chronic occupational exposure on the respiratory system in humans is well documented. These effects include respiratory irritation, wheezing, asthma, pneumonia, and fibrosis. They occurred at exposure levels ranging from 0.003 to 0.893 mg/m^3. Acute exposure (0.038 mg/m^3 for six hours) resulted in a significant decrease in ventilatory function due to chronic bronchial obstruction. Occupational exposure of humans to cobalt dust has been shown to result in cardiomyopathy characterized by functional effects on the ventricles and enlargement of the heart. Congestion of the liver, kidneys and burning of the eyes has also been reported.[24]

A TLV of 0.05 mg/m^3 is recommended by ACGIH for the prevention of pulmonary irritation, bronchial congestion, and occupational asthma (ACGIH, 1994). This value is based on a study which resulted in the early appearance of pulmonary disease in swine exposed to 0.1 mg cobalt/m^3.

Oral exposure to cobalt can lead to cardiomyopathy syndrome. Acute effects include nausea, vomiting and diarrhea. Signs of heart failure may subsequently appear. Liver injuries and severe visual disturbances have also been reported.

No RfD or RfC values are available for cobalt in IRIS or HEAST. Cobalt is classified as Group D—Not Classifiable as a Human Carcinogen. Classification of a chemical as Group D precludes quantitative toxicity assessment. Therefore, no slope factor was listed in IRIS or HEAST.

3.8 Copper

In humans, copper is a respiratory irritant. Factory workers exposed to copper dust experienced mucosal irritation of the mouth, eyes and nose, anorexia, nausea, and occasional diarrhea. A portion of the airborne copper was probably swallowed; thus, the gastrointestinal effects were probably the result of oral exposure to copper. Headache, vertigo, drowsiness, sexual impotence, and enlargement of the liver have also been reported in factory workers exposed to copper dust.[25]

A TLV of 1 mg/m^3 is recommended for copper dusts and mists. This level is considered sufficiently low to provide protection from adverse health effects such as irritation of the throat and nasal mucous membranes.[26]

Unusually high oral intakes of copper can cause liver and kidney damage, and may result in death. Young children are sensitive to copper and long-term exposure to copper in food and water may cause liver damage and death. Copper is not known to cause cancer and the potential for copper to cause reproductive/developmental effects in humans is currently unknown as well.[27]

IRIS currently does not list an RfD for copper. HEAST uses the current drinking water standard of 1.3 mg/L as the oral chronic and subchronic RfD based on local gastrointestinal irritation with a single 5.3 mg oral dose in humans. A daily dose associated with this concentration of 4.0E-02 mg/kg-day can be calculated. There are no values for the inhalation RfC.

Copper is classified as Group D—Not Classifiable as to Human Carcinogenicity. Classification of a chemical as Group D precludes quantitative toxicity assessment. Therefore, there is no slope factor for copper.

3.9 Iron

In contrast to the wealth of data available on the human toxicology of ingested iron salts, the data on the potential for adverse health effects after inhalation is extremely limited. Inhalation of ferric salts as dusts and mists is considered irritating to the respiratory tract. They are also regarded as skin irritants.[28]

A TLV of 1 mg/m^3, as Fe, is recommended in order to reduce the likelihood of respiratory irritation and skin irritation from exposure to aerosols and mists of soluble iron salts.

The clinical toxicology of ingested iron salts is fairly well known. Toxic effects include gastrointestinal disturbances, cardiovascular disturbances, and CNS disturbances (shock, coma, and death are possible). The probable oral lethal dose for a 70 kg person is expected to be between one ounce to one pint (0.25-1.0 pound). Iron salts are of moderate to low toxicity upon oral ingestion. Ingestion by children causes a mild poisoning and severe intoxication occurs after ingestion of large amounts. Elemental iron is far less toxic than soluble iron salts, and acute toxicity data gathered from animal studies are consistent with its designation as a moderately toxic agent.[29]

Currently, there is no toxicity information listed for iron or its soluble salts in IRIS or HEAST.

3.10 Magnesium

Magnesium is an essential nutrient whose deficiency causes neuromuscular irritability, calcification and cardiac and renal damage. Magnesium is a cofactor of many enzymes.

Freshly generated magnesium oxide can cause metal fume fever analogous to the effect caused by zinc oxide if inhaled in sufficient amounts. Inhalation of both zinc and magnesium produce similar effects in animals. Inflammation of the mucous membranes lining the eyelids and nose as well as coughing up of discolored sputum results from industrial inhalation exposure.[30]

No TLV is has been established for elemental magnesium; however, a TLV of 10 mg/m^3 has been recommended for magnesium oxide fume. Exposure to this fume caused mild irritation to the eyes and nose of workers exposed to it. The recommended TLV is believed to be adequate to protect nearly all workers from adverse health effects.[31]

No information is currently available in either IRIS or HEAST. Magnesium has not been classified by EPA as to its carcinogenic potential.

3.11 Manganese

Inhalation of manganese particulates can lead to an inflammatory response in the lungs. This reaction has been observed in both man and laboratory animals and is not unique to manganese. It is characteristic of nearly all inhalable particulate matter. There is conclusive evidence in humans, however, that inhaling high levels of manganese can result in a disabling neurological syndrome that is accompanied by apathy, general weakness, dullness, anorexia, and muscle pain. Impotence and loss of libido are common signs in male workers exposed to relatively high levels of manganese in the air.[32]

A TLV of 5 mg/m^3 has been established for manganese dust and compounds based on a study of 48 workers exposed to air concentrations of fume or dust at 5 mg/m^3. No toxic effects were reported. For manganese fumes, a TLV of 1 mg/m^3 is recommended. Workers exposed to manganese fumes developed symptoms at airborne concentrations below those affecting workers exposed to the dust.[33]

IRIS lists the chronic oral RfD for manganese in water as 5.0E-03 mg/kg-day and in food as 1.4E-01 mg/kg-day. HEAST lists the subchronic oral RfD for manganese in food as 1.4E-01 mg/kg-day. An inhalation RfC of 5.0E-05 mg/m^3 is also listed in IRIS and is based on an impairment of neurobehavioral function in workers occupationally exposed to inorganic manganese. HEAST lists a subchronic inhalation RfC of 4.0E-04 mg/m^3.

EPA has classified manganese as a Group D Carcinogen—Not Classifiable as to Human Carcinogenicity. Classification of a chemical as Group D precludes quantitative toxicity assessment. Therefore, no slope factor was listed for manganese in either IRIS or HEAST.

3.12 Mercury

Short-term exposure to high levels of inorganic and organic mercury has caused similar health effects, but full recovery is more likely to occur following short-term exposures. Long-term exposure to organic or inorganic mercury can cause permanent damage to the brain, kidneys, and developing fetus. The form of mercury and the route of exposure determine which of these effects will predominate. Maternal exposure to organic mercury may lead to brain damage in fetuses while adults exposed to metallic mercury vapor may develop tremors, memory loss, and kidney disease.[34]

Metallic mercury vapor is readily absorbed by diffusion through the alveolar membrane. On contact with the distal airways, mercury vapor causes pulmonary edema, pneumonia and loss of cells from the bronchiolar epithelium. Workers accidentally exposed to metallic mercury vapors at an estimated concentration of 1.1-44.0 mg/m^3 for 4-8 hours exhibited chest pains, labored respiration, cough, expectoration of blood, impairment of pulmonary function, diffuse pulmonary infiltrates and evidence of interstitial pneumonitis.

Gastrointestinal effects were noted in humans following acute inhalation exposure to metallic mercury vapor. Several other commonly reported symptoms from acute exposure to mercury vapor include nausea, vomiting, and inflammation of the mouth. In a chronic case study, two workers exposed daily to high unspecified concentrations of mercury oxide particles for 60-80 hours every week exhibited debilitating muscular pains of the lower back and extremities, severe burning sensation of the feet and lower legs, muscle cramps, and muscle twitching.[35]

Severe effects in the kidney include glomerular dysfunction, acute nephrotic syndrome characterized by protein, albumin, and hyaline casts in the urine, as well as edema. Serious degenerative effects have been observed in the kidneys of animals exposed to moderate-to-high levels of metallic mercury vapors following acute and intermediate durations. Workers chronically exposed to low concentrations of mercury exhibited double vision and a peculiar grayish-brown or yellow haze on the outer surface of their lenses.[36]

A TLV of 0.05 mg/m^3 is recommended for mercury vapor based on a study of workers exposed to 0.1 mg/m^3 with no significant toxic effect and incorporating a safety factor. A TLV of 0.1 mg/m^3 is recommended for aryl and inorganic mercury compounds. This is based on the evidence that very little mercury was deposited in the brain following exposure to these compounds.[37]

HEAST lists a value of 3.0E-04 for inorganic mercury's chronic oral RfD (mg/kg/day), subchronic oral RfD (mg/kg/day), chronic inhalation RfC (mg/m^3), and subchronic inhalation RfC (mg/m^3).

EPA has classified inorganic mercury as Group D - Not Classifiable as to Human Carcinogenicity. Classification of a chemical as Group D precludes quantitative toxicity assessment. Therefore, no slope factor was listed for mercury in either IRIS or HEAST.

3.13 Molybdenum

Molybdenum is an essential metal as a cofactor for enzymes and is ubiquitous in food. While molybdenum exists in various valence forms, biologic differences with respect to valence are not clear.

Inhalation of molybdenum by guinea pigs has resulted in increased liver and kidney levels and endocrine glands were also exceptionally high in molybdenum content.[38] Signs and symptoms of acute toxicity from molybdenum include loss of appetite, weight, and hair, as well as diarrhea, and muscular incoordination. Fatty degeneration has been seen in the livers and kidneys of severely poisoned animals. Chronic toxicity results in loss of appetite, listlessness, diarrhea, and reduced growth rate. Anemia is common, and animals may have deformities of joints and long bones as well as bony outgrowths from the mandibula. A gout-like disease has been seen in people living in high-molybdenum areas of Armenia. Daily intakes have been estimated at 100 to 500 μg.

A TLV of 5 mg/m^3 for soluble compounds and more active molybdenum compounds is recommended. For the insoluble compounds and metals, a TLV of 10 mg/m^3 is recommended. Weakness, fatigue, headaches, and joint and muscle pains have been associated with exposure to 60-600 mg/m^3 in mining and metallurgy workers. The TLV includes a large safety factor.[39]

IRIS lists a chronic oral RfD for molybdenum of 5E-03 mg/kg-day which is the same value given in HEAST for the subchronic oral RfD. This value has been derived from a 6-year to lifetime dietary study in humans where increased uric acid levels was the critical effect. The EPA has not classified molybdenum as to carcinogenicity.

3.14 Nickel

Inhalation of nickel (usually in the form of nickel oxide, metallic nickel, or nickel refinery dust) by humans and/or laboratory animals has resulted in respiratory, hepatic, renal, and dermal effects as well as an increased incidence of lung and nasal cancers. Studies in both humans and animals show that the respiratory system is the target of nickel toxicity following exposure via inhalation. An increased incidence in deaths from respiratory disease was found in workers occupationally exposed to 0.04 mg/m^3 or greater as nickel oxide or metallic nickel. Respiratory effects in the workers included chronic bronchitis, emphysema, and reduced vital capacity, although it cannot be concluded that nickel was the sole causative agent since the workers were exposed to a variety of other heavy metals. The carcinogenic potential of nickel refinery dust is well documented in occupationally exposed workers. Lung and nasal cancer were the predominant forms of cancer in the workers exposed to nickel refinery dust.[40]

A TLV of 1 mg/m^3 is recommended for elemental nickel and insoluble nickel compounds based on an animal inhalation study that showed no increase in respiratory cancer risk when exposed to 1-3 mg/m^3 of insoluble nickel dust. For soluble nickel compounds, a TLV of 0.1 mg/m^3 is recommended based on a study that showed mild respiratory irritation in rats exposed to soluble nickel chloride.[41]

Contact dermatitis is the most prevalent toxic effect of nickel in the general population. This generally results after dermal exposure but it has also been reported in several studies following oral exposure. Oral exposure can also result in varying effects on the respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, and dermal systems. However, evidence on oral toxicity is limited in animals and there are very few studies in humans so it is difficult to definitively assess the critical effects of nickel toxicity.

IRIS lists a chronic oral RfD for nickel (soluble salts) as 2.0E-02 mg/kg-day. HEAST lists the same value for the subchronic oral RfD. Inhalation RfCs are not available in IRIS or HEAST; however, an EPA work group is currently reviewing information.

Nickel is not currently considered carcinogenic by the oral route. The EPA does, however, classify particulate nickel as a Group A (Human Carcinogen) by the inhalation route. The unit risk factor listed in IRIS is 2.4E-04 (μg/m^3)$^{-1}$ and the inhalation slope factor is 8.4E-01 (mg/kg-day)$^{-1}$.

3.15 Selenium

The selenium compounds that are most likely to be encountered in air in occupational settings or near hazardous waste sites are dusts of elemental selenium, hydrogen selenide and selenium dioxide, although other volatile selenium compounds might also be encountered in some situations. In humans, the respiratory tract is the primary site of injury after inhalation of selenium dust or selenium compounds. Bronchial spasms, symptoms of asphyxiation and persistent bronchitis have been noted in workers briefly exposed to high concentrations of selenium dioxide. Rats exposed to selenium dust at levels of 30 mg/m^3 experienced severe respiratory effects including hemorrhage, edema of the lungs, and death. Gastrointestinal distress including indigestion and nausea were observed in humans following inhalation of selenium, selenium dioxide or hydrogen selenide. Following an acute episode of exposure to selenium dioxide fumes, several workers had lower blood pressure but an elevated pulse rate which normalized within three hours. Brief exposure to clouds of elemental selenium dust resulted in lacrimation, irritation and redness of the eyes. Acute exposure to selenium dioxide burned the eyes and skin upon contact.[42]

A TLV of 0.2 mg/m^3 is recommended for selenium and selenium compounds for the prevention of systemic toxicity and minimization of upper respiratory tract infection. Although many cases of selenium poisoning upon ingestion have been reported, there are no documented cases of disabling chronic disease or death from industrial exposures.[43]

Ingestion of selenium at greater than the recommended daily allowance over a long period of time can result in brittle hair, deformed nails, and in severe cases, loss of feeling and control in arms and legs. Selenium compounds have not been shown to cause cancer in humans. Selenium sulfide was found to be carcinogenic in animals; however, this compound is not present in food or the environment. Exposure to selenium compounds has not been shown to cause birth defects in humans or other mammals. It did, however, cause birth defects in birds.[44]

The chronic oral RfD for selenium is listed in IRIS as 5E-03 mg/kg-day. HEAST lists this value as the subchronic oral RfD. This is based on a human epidemiological study of populations living in an area with high environmental concentrations of selenium. Persistent clinical signs (e.g. "garlic odor" in breath and urine; thick, brittle nails; hair loss; lowered hemoglobin levels; mottled teeth; skin lesions; and CNS abnormalities) of selenosis were seen in 5/349 adults. The lowest correlative selenium intake causing overt signs of selenosis was 1.261 mg, corresponding to 1.35 mg/L in whole blood. There are currently no values listed for the inhalation RfD or RfC. Selenium is classified as Group D—Not Classifiable as a Human Carcinogen. Classification of a chemical as Group D precludes quantitative toxicity assessment. Therefore, no slope factor is listed.

3.16 Strontium

Strontium is found widely found in the environment, generally in association with calcium. Acute strontium toxicity causes death by respiratory failure. Evidence for chronic effects of strontium is limited and difficult to interpret. There is a tendency toward disturbances of mineral metabolism. Strontium appears to substitute for calcium in many normal mechanisms.[45]

No TLV exists for elemental strontium; however, a TLV of 5E-04 mg/m^3 is recommended for strontium chromate as Cr. This TLV is based on a study in which strontium chromate was found to be more potent than calcium chromate. Therefore, a TLV of one-half that of calcium chromate is recommended for the prevention of bronchial irritation and lung cancer.[46]

In general, the salts of strontium are of little toxicologic concern, particularly upon oral administration, due to the extremely limited gastrointestinal bioavailability of the strontium ion. Prolonged feeding of strontium can interfere calcium absorption and has induced bone toxicity in pigs. However, the chronic oral toxicity can be attributed to the chromate moiety.[47]

IRIS lists a chronic oral RfD for strontium of 6.0E-01 mg/kg-day which is the same value given in HEAST for the subchronic oral RfD. This value is based on three different studies in rats where the critical effect was rickets. Implantation-site tumors have been observed in rats but EPA has not evaluated strontium for human carcinogenicity.

3.17 Titanium

Titanium oxide, the most widely used titanium compound, is a white pigment used in paints and plastics, as a food additive to whiten flour, dairy products and confections, and as a whitener in cosmetic products. Because of its resistance to corrosion and inertness, it has many metallurgical applications, particularly as a component of surgical implants and protheses.[48]

The estimated body burden of titanium is about 15 mg. Most of it is in the lungs, probably as a result of inhalation exposure. Inhaled titanium tends to remain in the lungs for long periods. It has been estimated that about one-third of the inhaled titanium is retained in the lungs.[49] A weak fibrogenic response was seen in the lugs of rats inhaling titanium nitride for six months. Titanium hydride, boride, and carbide also caused slight fibrosis in rats.[50]

Titanium dioxide is classified as a "nuisance particulate" in the workplace with a TLV of 10 mg/m^3. This level is based on a study in which titanium dioxide dust was associated with pulmonary irritation and cancer at concentrations greater than 10 mg/m^3. At 10 mg/m^3, the architecture of the lung air spaces remained intact, there was no significant fibrosis, and there was no irreversible tissue damage.[51]

Titanium tetrachloride liquid is corrosive to the skin and eyes. Ingestion of titanium potassium oxalate resulted in a significant reduction in the number of rats surviving to the third generation.[52]

There currently is no information listed for titanium in IRIS or HEAST.

3.18 Vanadium

Vanadium is used in making steel; thus, most exposure to vanadium dusts occurs in workers who are involved with metallurgy and boiler cleaning. Workers exposed chronically have shown signs of mild respiratory distress, such as coughing wheezing, chest pain, runny nose, or sore throat. Symptoms were reversed within days or weeks of exposure. In most cases, chest x-rays and pulmonary function tests were normal, and no other systemic effects were observed. Workers chronically exposed to vanadium dusts in factories had slight to moderate eye irritation in addition to respiratory distress. The other significant peripheral finding was a green discoloration of the tongue in some workers attributed to direct deposition of vanadium. Workers showed no increase in dermatitis as compared to controls.[53]

No TLV is given for elemental vanadium, however, a TLV of 0.05 mg/m^3 is recommended for vanadium pentoxide dusts and fumes. Exposure to vanadium dusts can induce acute bronchitis, persistent and productive cough, profuse nasal discharge, burning of the eyes, nasal hemorrhage, wheezing, and green to black tongue. The TLV is recommended to minimize the potential of upper respiratory tract irritation, pulmonary disease, and systemic vanadium intoxication.[54]

There are no studies available regarding dermal exposure to vanadium in humans or laboratory animals, and only a few studies investigate the oral toxicity of vanadium. These studies suggest that the compound is not particularly toxic by the oral or dermal route.[55]

HEAST lists an oral RfD of 7.0E-03 mg/kg-day for vanadium. This value is based on a chronic drinking water study conducted in rodents. However, no effects were observed, and this RfD is currently under review and subject to change. The EPA has not evaluated vanadium for carcinogenicity.

3.19 Zinc

In humans, death has resulted from acute exposure to a high concentration (estimated at 86,000 mg zinc/m^3) of zinc chloride smoke. Zinc particles cause inflammation and tissue damage in the lung periphery. Metal fume fever, a well-documented acute disease induced by intense inhalation of metal oxides, especially zinc, temporarily impairs pulmonary function but does not progress to chronic lung disease. The most prominent respiratory effects of metal fume fever are chest pain, cough and labored breathing. Headaches and malaise have been reported in association with metal fume fever.[56]

Zinc chloride, a corrosive inorganic salt, is more damaging than zinc oxide to the mucous membranes of the nasopharynx and the respiratory tract upon contact. An estimated exposure level of 4,075 mg/m^3 resulted in cough, dyspnea, burning throat, diffuse infiltrates throughout the lung, chemical pneumonitis, and decreased lung capacity. Stomach and intestinal irritation have also been reported. More severe effects can occur, which include ulcerative and edematous changes in mucous membranes, subpleural hemorrhage, advanced pulmonary fibrosis and fatal respiratory distress syndrome.

No relationship between the occurrence of cancer in humans and occupational exposure (primarily inhalation) to zinc has been established.[57]

A TLV for elemental zinc has not been established; however, TLVs for both zinc chromate and zinc oxide are available. A TLV of 5 mg/m^3 has been established for zinc oxide fumes and 10 mg/m^3 for total dust in order to prevent metal fume fever. This condition is characterized by chills, muscular aches, nausea and vomiting. Mild chills have been reported in foundry workers having inhaled concentrations below the TLV. It is believed that the incidence of metal fume fever will be mild and in low frequency if concentrations are kept below the TLV.[58]

Zinc is an important essential element and is only acutely toxic at relatively high levels. For most species, overt signs of toxicoses appear around 1000 ppm in a natural-ingredient diet. Signs of intoxication may include gastrointestinal distress, emesis, decreased food consumption, decreased growth, anemia, poor bone mineralization, damage to the pancreas, arthritis, and internal hemorrhaging. Patients taking 10 times the Recommended Daily Allowance for zinc for a chronic duration have not shown any adverse health effects.

IRIS lists an oral RfD of 3.0E-01 mg/kg-day for zinc. This value was based on a clinical study which investigated the effects of oral zinc supplements on copper and iron balance. This study is supported by several other studies which indicate that zinc supplementation can alter copper and iron biochemistry.

Zinc is classified as Group D—Not Classifiable as to Human Carcinogenicity. Classification of a chemical as Group D precludes quantitative toxicity assessment. Therefore, no slope factor is listed for zinc. This classification reflects the lack of both human and animal evidence.

3.20 Potassium

Potassium is a principal intracellular cation. The small percentage of extracellular potassium is, however, of great physiological importance, contributing to the transmission of nerve impulses, to the control of skeletal muscle contractility and to the maintenance of normal blood pressure. More than 90% of ingested potassium is absorbed from the gastrointestinal tract. In the absence of markedly increased losses of potassium from the body, acute intoxication (hyperkalemia) will result from sudden enteral or parental increases in potassium intake to levels about 12.0 g/m^2 of surface area per day—about 18 g for an adult. Although urinary excretion provides some protection, acute hyperkalemia can prove fatal because it can cause cardiac arrest.[59]

3.21 Calcium

The adult human body contains approximately 1,200 g of calcium, approximately 99% of which is present in the skeleton. Although no adverse effects have been observed in many healthy adults consuming up to 2,500 mg of calcium per day, high intakes may induce constipation and place up to half of otherwise healthy hypercalciuric males at increased risk of urinary stone formation. A high calcium intake may inhibit the intestinal absorption of iron, zinc and other essential minerals. Ingestion of very large amounts may result in hypercalciuria, hypercalcemia and deterioration in renal function in both sexes. Supplementation to a total calcium intake much above the RDA is not recommended.[60]

3.22 Sodium

Sodium, the principal cation of extracellular fluid, is the primary regulator of extracellular fluid volume. In addition to its role in regulating extracellular fluid volume, sodium is important in the regulation of osmolarity, acid-base balance, and the membrane potential of cells. Sodium is also involved in active transport across cell membranes and must be pumped out in exchange for potassium in order to maintain an appropriate intracellular milieu. Acute excessive intake of sodium chloride leads to an increase in the extracellular space as water is pulled from cells to maintain sodium concentrations. The end result is edema and hypertension. Sustained overconsumption of sodium, particularly as salt, has been related to development of hypertension in sensitive individuals.[61]

4.0 ESSENTIAL NUTRIENTS

Essential nutrients which are present at concentrations only slightly elevated above background levels and which are toxic orally only at very high doses may be levels from consideration as chemicals of potential concern.[62] The table below shows the maximum concentrations and recommended dietary

Nutrient	RDA (mg/day)
Calcium	800
Iron	10
Magnesium	350
Potassium	2000
Sodium	500

allowances (RDA) for the essential nutrients detected at the site. A maximum daily intake was calculated assuming daily ingestion of 200 mg of soil or 2 liters of water having the maximum detected concentrations. As the table shows, the resulting maximum intakes are essential nutrients listed (i.e., calcium, iron, magnesium, potassium, and sodium) were eliminated from further considerations.

4.1 Iron

The disposition of iron is regulated by a complex mechanism to maintain homeostasis. There are about 3 to 5 grams of iron in the body. About two-thirds is bound to the iron storage proteins ferritin and hemosiderin. Normally, excess ingested iron is excreted, and some is contained within shed intestinal cells and in bile and urine. Total iron excretion is usually in the order of 0.5 mg/day.

Acute iron toxicity is nearly always due to accidental ingestion of iron-containing medicines and most often occurs in children. Severe toxicity occurs after ingestion of more than 0.5 grams of iron or 2.5 grams of ferrous sulfate. Toxicity becomes manifest with vomiting, one to six hours after ingestion. Late effects may include renal failure and hepatic cirrhosis.

Inhalation of iron oxide fumes or dust by workers in metal industries may result in deposition of iron particles in lungs producing an x-ray appearance resembling silicosis. These effects are seen in hematite miners, iron and steel workers and arc welders. A report of autopsies of hematite miners noted an increase in lung cancer, as well as tuberculosis and interstitial fibrosis. The etiology of the lung cancer may be related to concomitant factors such as cigarettes or other workplace carcinogens. Dose levels of iron among iron workers developing pneumoconiosis have been reported to exceed 10 mg Fe/m^3.[63]

4.2 Potassium

Potassium is a principal intracellular cation. The small percentage of extracellular potassium is, however, of great physiological importance, contributing to the transmission of nerve impulses, to the control of skeletal muscle contractility and to the maintenance of normal blood pressure. More than 90% of ingested potassium is absorbed from the gastrointestinal tract. In the absence of markedly increased losses of potassium from the body, acute intoxication (hyperkalemia) will result from sudden enteral or parental increases in potassium intake to levels about 12.0 g/m^2 of surface area per day—about 18 g for an adult. Although urinary excretion provides some protection, acute hyperkalemia can prove fatal because it can cause cardiac arrest.[64]

4.3 Calcium

The adult human body contains approximately 1,200 g of calcium, approximately 99% of which is present in the skeleton. Although no adverse effects have been observed in many healthy adults consuming up to 2,500 mg of calcium per day, high intakes may induce constipation and place up to half of otherwise healthy hypercalciuric males at increased risk of urinary stone formation. A high calcium intake may inhibit the intestinal absorption of iron, zinc and other essential minerals. Ingestion of very large amounts may result in hypercalciuria, hypercalcemia and deterioration in renal function in both sexes. Supplementation to a total calcium intake much above the RDA is not recommended.[65]

4.4 Sodium

Sodium, the principal cation of extracellular fluid, is the primary regulator of extracellular fluid volume. In addition to its role in regulating extracellular fluid volume, sodium is important in the regulation of osmolarity, acid-base balance, and the membrane potential of cells. Sodium is also involved in active transport across cell membranes and must be pumped out in exchange for potassium in order to maintain an appropriate intracellular milieu. Acute excessive intake of sodium chloride leads to an increase in the extracellular space as water is pulled from cells to maintain sodium concentrations. The end result is edema and hypertension. Sustained overconsumption of sodium, particularly as salt, has been related to development of hypertension in sensitive individuals.[66]

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