EVALUATION OF SUBSTITUTE MATERIALS FOR SILICA SAND IN ABRASIVE BLASTING

CONTRACT No. 200-95-2946

Prepared For:

Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Prepared By:

KTA-Tator, Inc.
115 Technology Drive
Pittsburgh, PA 16275-1085

December 21, 1998
Phase II

ABSTRACT

Abrasive blasters using silica sand are at high risk of developing silicosis. Although NIOSH recommended in 1974 that silica sand be banned in abrasive blasting, it is still the highest used blasting abrasive in the United States. However, little objective data exists regarding the effectiveness, operating costs, and concentrations of health-related agents for abrasive blasting substitutes.

This study's objective was to compare (in a partially-controlled field site) silica sand's performance characteristics, operating costs, and airborne and bulk concentrations of thirty health-related agents to seven substitute abrasives (silica sand treated with a dust suppressant, coal slag, copper slag, garnet, nickel slag, staurolite, and steel grit). Performance characteristics included: cleaning rate, consumption rate, surface profile, breakdown rate, and abrasive embedment.

The substitute abrasives produced the desired degree of cleanliness and a surface profile suitable for paint performance. The alternative abrasives were all economically competitive to silica sand, with cleaning costs ranging from $0.69 to $1.02 per square foot, with silica sand being $0.72 per square foot. All of the substitute abrasives had substantially reduced concentrations of respirable quartz. However, all of the alternative abrasives had higher levels of at least four of the other health-related agents, as compared to silica sand.

This study suggests consideration of establishing a broad, health standard encompassing all health hazards associated with abrasive blasting operations.

DISCLAIMER

The contents of this report are reproduced herein as received from the contractor. The opinions, findings, and conclusions expressed herein are not necessarily those of the National Institute for Occupational Safety and Health, nor does mention of company names or products constitute endorsement by the National Institute for Occupational Safety and Health.

ACKNOWLEDGMENT

Project: Evaluation of Substitute Materials for Silica Sand in Abrasive Blasting

Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Contract Number 200-95-2946

This is to acknowledge the extensive effort of the Project Officer, Mr. Mark Greskevitch and Contracting Hazard Surveillance Team Leader, Mr. Dennis Groce. Mr. Greskevitch provided extensive direction throughout the project and participated in the overall design and startup of each phase of the project.

The project team who worked closely with Mr. Greskevitch was headed by Principal Investigator Mr. Kenneth A. Trimber, Vice President of KTA-Tator, Inc., immediate past-President of the Society of Protective Coatings (SSPC, an industry trade organization), and Chairman of the Surface Preparation Committee C-2 of the SSPC. Mr. Trimber was assisted by Project Technical Advisor, Mr. Daniel P. Adley CIH, CSP, in all matters relating to industrial hygiene and worker safety.

Project Manager and Supervisor for Phase 2, Mr. William D. Corbett coordinated overall project management and worked closely with Mr. Greskevitch in the design and startup phases of the project. Mr. Corbett, who was assisted by Mr. Michael F. MeLampy, Phase 1 Project Manager, also provided the day to day supervision of this phase and ensured that all material and personnel were ready at the appointed time and that the project progressed smoothly.

All industrial hygiene procedures were designed by Project Certified Industrial Hygienist, Mr. Daniel P. Adley, and approved by Mr. Greskevitch. Implementation of these procedures was performed primarily by Industrial Hygiene Technician, Mr. Robert D. Moody, and assisted by Mr. Corbett. These men provided for thorough record keeping, pre-run cleanliness, and assured the least amount of health and safety risk to those who participated in this project.

Blast Cleaning Technician, Mr. Leon Farbotnik, was the selected operator throughout the project. Mr. Farbotnik provided the least variability in work practices to ensure reliable data collection and repeatability of the test procedures. Mr. Corbett and Mr. Farbotnik were assisted by project staff Mr. Donald Points and Mr. Stanford Galloway. Data entry and verification was performed by Ms. Carol Gileot, and data analysis was undertaken by Mr. Stanford Liang, CIH, together with Messrs. Adley and MeLampy.

Consolidation Coal Company, River Division provided substrate materials, site access, and mobilization/demobilization equipment and personnel throughout the project. Port Captain, Deane Orr, and General Manager, David Kreutzer, are acknowledged for their assistance and cooperation.

Containment design and equipment supplier coordination for Phase 2 was performed by Ms. Jocelyn Wojcikewicz, P.E. and Mr. Joseph Kauffman, draftsman.

Additional acknowledgement is due to the various suppliers of abrasive blast cleaning media for their patience and efforts in providing data and comments for this project.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

APPENDED TABLES

INTRODUCTION

This report represents Phase 2 of a study commissioned by the Centers for Disease Control and Prevention (CDC) and the National Institute for Occupational Safety and Health (NIOSH). The study was outlined in an Invitation for Proposal entitled, "Evaluation of Substitute Materials for Silica Sand in Abrasive Blasting", dated June 9, 1995. KTA-Tator, Inc. (KTA) responded to the invitation with a proposal entitled, "Technical Proposal for Evaluation of Substitute Materials for Silica Sand in Abrasive Blasting", dated July 14, 1995. On September 29, 1995, Contract No. 200-95-2946, issued by the Centers for Disease Control and Prevention (Atlanta, Georgia), was awarded to KTA. The Contract directed KTA to conduct a three-phase study for the purpose of investigating relative levels of 30 different health-related agents and other attributes of surface preparation of the alternative abrasives to silica sand.

Phase 1 involved a laboratory study. The Phase 1 results are contained in a KTA report to CDC/NIOSH dated September 1998. This Phase 2 report addresses the data collected during the field study of the contract. Phase 3, which will be prepared at a later date, is a comparison of the data collected during Phases 1 and 2.

Phase 2 was conducted at the Consolidation Coal Company Shipyard, located in Elizabeth, Pennsylvania. The blast cleaning portions of Phase 2 began September 16, 1997, and were completed on September 25, 1997. Upon completion of blast cleaning, airborne particulate and bulk abrasive samples were analyzed, data entered and evaluated, and the report prepared.

The objective of the study was to collect (in a partially-controlled field site) industrial hygiene airborne levels and bulk ingredient data for thirty health-related agents; and economic and technical data; and compare the alternative abrasives' results to silica sand's results. The study entailed the collection of airborne particulate (total and respirable fractions) generated during open nozzle dry abrasive blast cleaning operations conducted on the exterior hull of a coal barge. The hull was free of any coating and consisted of heavily rusted and pitted steel. The study investigated the production characteristics of silica sand, silica sand treated with dust suppressant and six (6) alternative abrasive materials for surface cleanliness (visual), cleaning and consumption rates, breakdown rates, surface profile generation, and abrasive particle embedment. The specific abrasives evaluated in Phase 2 were selected by NIOSH from the 40 abrasives tested in Phase 1. They consisted of 5 expendable abrasives and 3 abrasives classified as recyclable for the purpose of the testing. Note that the recyclable abrasives were used only once in Phase 2.

This report presents the methodologies employed during data collection, the results of the abrasive media production characteristics, and the bulk abrasive and airborne sample data acquired.

EXECUTIVE SUMMARY

The Centers for Disease Control and Prevention (CDC), through the National Institute for Occupational Safety and Health (NIOSH), commissioned KTA-Tator, Inc. to conduct a study entitled "Evaluation of Substitute Materials for Silica Sand in Abrasive Blasting". In conjunction with NIOSH, a project design protocol was developed to evaluate the characteristics that influence abrasive performance from a surface preparation viewpoint and the potential for worker exposures to airborne contaminants. The project involved a Phase 1 laboratory study and a Phase 2 field study, which is the subject of this report. The protocol for Phase 2 of the study was used to evaluate 8 generic types of abrasives:

- coal slag
- copper slag
- garnet
- nickel slag
- silica sand
- silica sand with dust suppressant
- staurolite
- steel grit

One product from each of these generic categories was tested. Each of the abrasives was evaluated for 5 performance related characteristics, including:

- cleaning rate
- consumption rate
- surface profile
- breakdown rate
- abrasive embedment

Bulk samples of the 8 abrasive products were analyzed for 30 potential contaminants prior to and following use. During use, they were evaluated for airborne concentrations of the same 30 contaminants:

aluminum
arsenic*
barium
beryllium*
cadmium*
calcium
chromium*
cobalt
copper
iron
lead*
lithium
magnesium
manganese*
molybdenum
nickel*
phosphorous
platinum
selenium
silver*
sodium
tellerium
thallium
titanium*
vanadium*
yttrium
zinc
zirconium
quartz*
cristobalite

* While data was collected for 30 contaminants, eleven of them were selected by NIOSH for detailed analysis.

In order to ensure that the only significant variable being evaluated for each of the performance characteristics and airborne contaminants was the individual abrasive, stringent controls over operator work practices and equipment operation were implemented and maintained.

It is important to recognize that the Phase 1 results demonstrated that individual abrasives within each generic category exhibited characteristics that were often quite different than their counterparts. As a result, these Phase 2 conclusions apply only to the specific abrasives evaluated and do not represent the entire generic category of abrasive. Each abrasive must be evaluated individually for its own characteristics.

The alternative abrasives evaluated were all capable of producing the desired degree of cleaning and a surface profile suitable for paint performance. Productivity of the abrasives evaluated was both better and worse than silica sand. Based on the specific abrasives tested, the operational controls imposed on the project, and the hypothetical project conditions established for cost estimating, the cost to use the various abrasives ranged from $0.69 per square foot to $1.02 per square foot. The cost of coal slag abrasive was comparable to silica sand ($0.69 per square foot versus $0.72 for silica sand). Other abrasives were more expensive to use based on the test results (e.g., from 14 to 42% more expensive than silica sand), although without the constraints imposed on the equipment operator during the study, they will be more competitive to use in actual field applications. In addition, if hazardous waste is assumed to be present, the cost of use changes dramatically, from $0.91/square foot to $1.67/square foot, with silica sand at $1.37 per square foot. Steel grit becomes the most cost-effective abrasive at $0.91/square foot.

While this study collected data on 30 potential contaminants, the analysis focused on eleven health-related agents selected by NIOSH including: arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, respirable quartz, silver, titanium, and vanadium. While no single abrasive category had reduced levels of all eleven health-related agents, all the substitutes offer advantages over silica sand with regard to respirable quartz. However, all of the alternative abrasives have higher levels of four or more of the other health-related agents, as compared to silica sand.

The overall findings of this study are eye opening and potentially far reaching. In recent years, much of the industry focus has been directed at protecting workers from the hazards of lead and other metals in the coatings removed during abrasive blasting. NIOSH and OSHA have also directed increased attention to the hazards of silica sand. The findings of this study suggest that a much broader and holistic approach to protecting workers performing any form of abrasive blast cleaning needs to be taken. In addition to a continued focus on alternatives to silica sand abrasives or the hazard of lead in paint, consideration should be given to the establishment of a broad, vertical health standard encompassing all health hazards associated with abrasive blasting operations.

STUDY DESIGN AND TEST METHODS

Description

The study was performed in strict accordance with the NIOSH-approved Phase 2 Study Design/Protocol developed specifically for this project (copy attached as Appendix 1). The protocol provided controls and documentation forms for:

- Collection of bulk abrasive samples for additional analysis by NIOSH. A total of 8 different abrasives were included in the study (refer to the Products and Materials section of this report for a listing of the specific abrasives),

- Consistent operation of all blast cleaning and ventilation equipment,

- Consistent blast cleaning technique and cleanliness (SSPC SP-10/NACE No. 2, "Near White[1]"),

- Consistent cleaning of all equipment and containment facilities to prevent cross-contamination between runs,

- Analysis of particle size distribution, abrasive break-down rates, cleaning rates, abrasive consumption rates, surface profile, and embedment,

- Collection of samples for respirable crystalline silica, respirable radiochemical activity, total airborne radiochemical activity, and total airborne elements. A total of 28 metals/elements, and respirable quartz and cristobalite were evaluated by KTA. Refer to the Industrial Hygiene Sampling portion of this report for a listing of the elements analyzed, and for information on the number of samples collected, locations of the sampling media, the type of media used, and pump flow rates. The analysis of the filters was managed by NIOSH (using other testing laboratories), and

- Developing total cost calculations.

Products and Materials

Test Surfaces

The study was performed on the side of a coal barge which was subdivided into eight (8) sections measuring approximately 5' x 14', resulting in a maximum surface area of approximately 72 square feet (per abrasive) available for abrasive blast cleaning.

Abrasive Selection

The study involved eight (8) different abrasives. All products were commercially available materials. The silica sand abrasive containing dust suppressant had already been treated prior to purchase. The generic types of abrasive, and the alpha code assigned to each type, are as follows:

Abrasives

Coal Slag (CS-06)	1 product
Copper Slag (CP-2A)	1 product
Garnet (G-3A)	1 product
Nickel Slag (N-01)	1 product
Silica Sand (SS-04)	1 product
Silica Sand with Dust Suppressant (SSDS-03)	1 product
Staurolite (S-02)	1 product
Steel Grit (SG-2A)	1 product

The specific abrasive used within each of the above categories was selected by NIOSH from the cross-section of products used in Phase 1.

Operator Selection

In order to help ensure consistency between the Phase 1 (laboratory) and Phase 2 (field) studies, the operator chosen to conduct Phase 1 also conducted the Phase 2 blast cleaning work.

Blast Cleaning Equipment and Facilities

A portable containment was constructed on a barge at the Consolidation Coal Company Shipyard in Elizabeth, Pennsylvania. Throughout all abrasive trials, variability of the blast cleaning environment was controlled by moving the same blast containment and abrasive blast cleaning equipment to each new test area. Diagrams of this facility are provided in Appendix 2 and photographs of the facility and equipment are provided in Appendix E. The equipment utilized for the study included:

- A clean, enclosed, 16' long by 8' wide by 8' high containment constructed of plywood and Visqueen. Tarpaulins were used to cover the floor inside containment (see drawings in Appendix 2). The containment was equipped with a Lunardini Service Company, 5,000 cubic feet per minute (cfm), dust collection system. Air flow through the containment was controlled at 25 to 45 feet per minute with an average crossdraft approximately 40 feet per minute for each trial run. Air flow was measured using an Alnor Model RV rotating vane anemometer.

- A Clemco 6 cubic feet gravity feed abrasive hopper fitted with a specially designed abrasive metering valve. The metering valve plate designed by KTA utilized five fixed settings ranging from 1/4" to 1/2" in 1/16" increments. This allowed for the use of a precise valve setting for each trial run. Prior to each trial, the blast pot was loaded with a sample of abrasive, and the blast pot metering valve adjusted as required to achieve optimum flow (as judged by the blast operator). The metering valve opening was documented and is presented in appended Table A1.

- An Atlas Copco 375 cfm air compressor. The compressed air line was equipped with moisture and oil separators, and a desiccant air dryer. Prior to each abrasive trial, the supplied air was evaluated for moisture and oil in accordance with ASTM D4285, "Standard Test Method for Indicating Oil or Water in Compressed Air"[2]. No moisture, oil, or other visible contamination was detected during any of the blotter tests.

- One 15 foot length of reinforced air/abrasive hose (7/8" inside diameter), and one Boride brand No. 7 (7/16 inch orifice size) venturi blast nozzle. After each abrasive trial, the blast hose was flushed, washed inside and out with potable water, then dried with compressed air before the next day's trial.

- A Clemco nozzle orifice gage. The gage was used to monitor the nozzle orifice size prior to each abrasive blasting trial. The nozzle maintained a consistent 7/16" size throughout the field study.

- A Clemtex Model 352-02 hypodermic needle pressure gage. The gage was used to measure the blasting pressure at the nozzle prior to each abrasive trial. The pressure was maintained at approximately 100 pounds per square inch (psi) throughout the abrasive study. A fixed pressure of approximately 100 psi was selected in order to minimize the number of variables involved with the collection of the data, in an effort to enhance the reproducibility of the test methods.

- A Dickson Model THDX 24 hour recording hygrometer for continuous monitoring of relative humidity and dew point, and an Atkins Model 33035-F digital thermocouple for monitoring the surface temperature of the steel substrate. Barometric pressure was also documented. A sample inspection report is attached as Appendix 3, Exhibit 1 – "Blast Cleaning Inspection Report". The completed reports are provided separately from this report.

- A Nor-Tech abrasive debris vacuum system. The equipment was used to clean the interior surfaces of the containment after each trial. After thorough vacuuming and cleaning, industrial hygiene personnel inspected the containment in accordance with the procedures described later in this section.

- A 208 volt, 3 phase, 50 amp, 30 kilowatt diesel generator to supply power to the compressor, dust collector, and other miscellaneous electrical equipment/tools.

Abrasive Media Test Methods

A series of test methods was used to control the abrasive blast cleaning process and to evaluate the physical characteristics and performance of the abrasives. Each method is described below:

Blast Cleaning Procedure

A maximum of approximately 72 square feet (6 feet x 12 feet) was available for blast cleaning during each of the eight (8) trials. Approximately 50% of the surface in each test area was rusted with minor pitting (top half) and the remaining 50% was severely rusted and pitted (bottom half).

The distance that the blast nozzle was held from the surface was maintained at a constant 18 inches for all abrasive blast trials. This was accomplished through the use of a small rod attached to the blast hose that extended to the surface. The operator kept the blast nozzle perpendicular to the steel substrate at all times. This was done to provide the maximum amount of abrasive ricochet, simulating a worst case airborne dust condition. All cleaning was performed to SSPC-SP 10/NACE No. 2 "Near-White Metal Blast Cleaning"[1] or better.

Cleaning Rate

Abrasive cleaning rate was calculated from the measured amount of area blast cleaned divided by the total time needed to clean the area (square feet per hour). The surface cleanliness was verified using SSPC VIS1-89[3] pictorial standards (photographs CSP10 and DSP10 [see photographs 11 and 12 in Appendix E for an example of photographs CSP10 and DSP10]). The time required to clean the surface was measured to the nearest second using a digital stopwatch. The time to blast clean the "smooth" surfaces and the "pitted" surfaces was recorded separately, but the total combined time was used to calculate the overall cleaning rate.

In all cases, the entire surface area allotted for cleaning was completed prior to depleting the quantity of media originally loaded into the abrasive hopper. In order to provide for sufficient airborne particulate sampling time, the blaster continued to clean the prepared steel until the supply of abrasive was exhausted. However, the additional time was not reported in order to establish accurate cleaning rates.

Consumption Rate

A measured (weighed) amount of abrasive media was loaded into the abrasive blast pot for each abrasive trial. The abrasives were stored in a climate controlled shop prior to use to minimize differences that residual moisture may have on weight. The initial weight of abrasive media varied due to differences in the bulk density of the types of abrasive, but a sufficient quantity of media was loaded to permit a continuous 30 to 40 minute blast sequence. In all cases, the allotted surface area was blast cleaned without depleting the supply of abrasive. The actual amount of abrasive consumed during each trial to blast clean the square footage provided was calculated as follows:

1. The weight of abrasive used per second of blast cleaning was calculated by dividing the total time that abrasive flowed from the nozzle (in seconds), by the weight of the abrasive loaded into the pot.

2. The total amount (weight) of abrasive used for cleaning the surface was determined by multiplying the amount of abrasive used per second by the time required to prepare the test area.

3. The abrasive consumption rate was determined by dividing the weight of abrasive used during the trial, by the surface area prepared (e.g., 72 square feet). This provides abrasive usage in pounds per square feet.

Surface Profile

The surface profile resulting from each abrasive trial was measured in accordance with Method C of ASTM D4417-93 "Standard Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel."[4] X-Coarse Testex replica tape and a spring micrometer were used. Fourteen (14) surface profile measurements were obtained for each abrasive trial. Surface profile measurements were obtained on the top half of the barge only, as the bottom half was severely pitted. The top portion, while smoother than the bottom, also contained pitting and was too rough to obtain accurate surface profile data. Accordingly, the surface profile data is more likely to be due to the irregular texture of the substrate, than the abrasive.

Abrasive Particle Size Distribution

A one hundred pound sample of each abrasive, as received from the supplier or distributor, was riffled three times to ensure a homogeneous mixture of abrasive particle sizes. A one hundred gram sample of this virgin abrasive was removed from the homogeneous mix and analyzed for particle size distribution in accordance with ASTM C136 "Standard Test Method for Sieve or Screen Analysis of Fine and Coarse Aggregates"[5]. The abrasive sample was tamped and shaken through a series of sieves for seven minutes. The sieve sizes used were 10, 12, 16, 20, 30, 40, 50, 60, 70, 100, 140, 200, 270, with a pan at the bottom. An electric Ro-Tap Model B aggregate shaker was used. See example KTA Sieve Analysis Report Form (Appendix 3 – Exhibit 2).

The abrasive retained on each screen was emptied into numbered and tarred sample cups. The underside of each screen was cleaned with a brass brush to loosen trapped particulate, and the particulate was added to the appropriate sample cups. The content of each sample cup was weighed to the nearest tenth of a gram and documented. This value (weight of particles retained on each screen) was multiplied by the screen size opening (in millimeters). These numbers were summed and divided by the cumulative weight of the sample to establish an average particle size for each lot of abrasive. The average value represents the size, above which and below which, approximately 50 % of the mass of the abrasive is found.

A statistical process control was used to ensure repeatability and validity of the sieve analysis portion of the abrasive testing. Since the screens used for sieve analysis are constructed of fine wires with very close tolerance spacing, it was critical to verify that the screen size openings were not affected by repeated use. Three 100 gram samples were drawn from the same riffled mixture of one of the abrasives at the beginning of Phase 1 of this study. The samples were sieved five times to develop a control capability analysis for each sample. One sample (Sample A) was used for this study. The sample had an average particle size of 0.43 mm with no variation. Once before and once after the Phase 2 study, Sample A was sieved using the identical process. The results of the sieve analysis were identical at the beginning of Phase 2, and at the end of Phase 2 (after a total of 16 sieve analysis on 8 abrasives).

Abrasive Breakdown Rate

At the completion of each abrasive run, a one hundred pound sample of the spent abrasive was collected from several areas of the containment floor and riffled three times to obtain a homogeneous mixture. A 100 gram sample was removed and analyzed for particle size distribution using the identical process as described in the section titled "Abrasive Particle Size Distribution". The amount of abrasive breakdown was determined by comparing the average particle size of the pre-blast (virgin) abrasive to the average particle size of the post-blast abrasive. The abrasive breakdown rate was calculated and is reported as the percentage change in average particle size.

Abrasive Embedment

Abrasive embedment is defined as the percentage of abrasive particles that remain affixed to the prepared substrate and cannot be removed by cleaning with a stiff bristle brush or a focused stream of compressed air. The amount of abrasive embedment was evaluated only on the top (unpitted) portions of the barge (similar to the locations selected for the surface profile measurements). A 12.7 mm (1/2") x 12.7 mm (1/2") piece of transparent mylar with a printed grid of 100 squares (each 1.3 mm x 1.3 mm in size) was placed on the surface and viewed through a 10X illuminated magnifier to make the determination. Each of the 100 squares was evaluated for the presence of embedded abrasive particles. In the event an embedded particle fell between two or more squares, only one of the squares was counted. The number of squares containing one or more embedded particles was summed to determine the number of squares out of 100 that exhibited embedded abrasive particles. This number was reported as a percentage. Thirty-five (35) locations were evaluated on each prepared surface.

Abrasive Bulk Samples

One pound bulk samples of both pre-blast (virgin) abrasive material and post-blast abrasive material were obtained for each abrasive trial and submitted to NIOSH for analysis. Homogeneous pre-blast samples were collected as described above in the section entitled "Abrasive Particle Size Distribution." Homogeneous post-blast samples were collected as described in the section entitled "Abrasive Breakdown Rate."

Industrial Hygiene Sampling

A proposed exposure monitoring protocol was developed to ensure collection of adequate data on airborne total particulate, total dust levels for 28 metals/elements, and respirable quartz and cristobalite. At the direction of NIOSH, the total particulate samples were not required for Phase 2. The specific analytes tested in Phase 2 included:

aluminum
arsenic
barium
beryllium
cadmium
calcium
chromium
cobalt
copper
iron
lead
lithium
magnesium
manganese
molybdenum
nickel
phosphorous
platinum
selenium
silver
sodium
tellerium
thallium
titanium
vanadium
yttrium
zinc
zirconium
quartz
cristobalite

The protocol was also designed to ensure the reproducibility of the test methods and to prevent cross-contamination from abrasive media. The elements of the approved assessment protocol included:

- Protection of Human Subjects
- Sample Collection Methodology and Filter Media Positioning
- Calibration of Sampling Pumps
- Background Monitoring
- Preparation of Test Facilities
- Sample Collection During Abrasive Trials
- Post Sample Collection Procedure

Protection of Human Subjects

Protection of human subjects (e.g., blasters, laborers, quality control personnel) was monitored throughout the study. Prior to initiation of Phase 2, assigned project personnel were trained in the health effects of arsenic, cadmium, chromium, copper, iron, lead, nickel, silica, and zinc[6]. Proper use of personal protective equipment, respiratory protection, and decontamination procedures were also reviewed. Finally, a medical surveillance program was initiated to help ensure that project personnel were adequately protected during the study. Medical surveillance consisted of: blood lead and zinc protoporphyrn (ZPP) levels; cadmium in blood and in urine (grams of creatinine and beta-2 microglobulin); spirometry testing (FEV and FVC); blood chemistry profile; and complete blood count with differential. Pre- and post-project medical surveillance testing was performed by Mobile Medical Screening Corporation of Pittsburgh, Pennsylvania. Appendix 4 represents sample pre- (Exhibit 1) and post-medical (Exhibit 2) forms used in testing.

Personal protective equipment utilized by the blaster included a Bullard Model 77 Type CE supplied air helmet (APF, assigned by OSHA for worker exposures to airborne lead particulate, of 1000 and an APF of 25, assigned by NIOSH, for all other airborne particulates) with Grade D breathing air supply, cotton coveralls, gloves, boots and hearing protection (NRR 29). Separate work clothing was worn beneath coveralls, and no food, beverages, tobacco or cosmetics were permitted in the test area, which was demarcated using signage and yellow caution tape. Support personnel were similarly outfitted, except that half-face, negative-pressure, air-purifying respirators with HEPA filtration were worn, (APF of 10), instead of the blast helmet. All project personnel washed hands and face prior to eating, drinking or smoking.

Sample Collection Methodology and Filter Media Positioning

During each abrasive trial, airborne samples were collected inside the containment as well as on the operator. Containment area samples consisted of: 28 airborne metals/elements; respirable crystalline silica and cristobalite; respirable radiochemically active materials; and total airborne radiochemically active materials. Head loss was tested for the 32' 4" length tubes and compared to standard length 3' tubes at flow rates of 1.0, 1.7, and 2.0 liters per minute. The comparative head loss was determined to be minimal. Sampling was conducted under the NIOSH methods[7]: 7500 for respirable quartz, 7300 for elements, 0600 for respirable dust; and the WR-IN-314[8] standard operating procedures entitled "The Determination of Radium-226 in Solids by Alpha Spectrometry" for respirable radioactivity.

A total of fourteen (14) samples (4 make-up air area; 4 operator area; 4 exhaust area; and 2 within the operator's breathing zone) were collected for each abrasive trial. The following samples were collected at each area (or fixed station) for each abrasive trial: one elemental sample, one respirable crystalline silica sample, one respirable radioactivity sample, and one total airborne radioactivity sample. One elemental sample and one respirable crystalline silica sample were collected within the operator's breathing zone for each abrasive trial. One virgin and spent bulk sample were collected for each abrasive trial and analyzed for thirty health-related agents. The airborne and bulk samples were analyzed by the following NIOSH methods: 7500 (x-ray diffraction) for respirable quartz; 7300 for all elements, except the graphite furnace method for arsenic, beryllium, cadmium, and lead; the WR-EP-325[9] standard operating procedure titled "Determination of Gamma Emitting Isotopes" for radioactivity in bulk samples and the WR-IN-314 standard operating procedures titled "The Determination of Radium-226 in Solids by Alpha Spectrometry" for respirable radioactivity in airborne samples.

Area airborne sampling was conducted using Gilian, SKC and GAST Hi-Flow sampling pumps, tygon tubing and the appropriate collection device/filter media. In order to prevent pump damage from airborne dust concentrations inside the containment, all area sampling was performed remotely (pumps positioned outside of the containment) by traversing 32' 4" lengths of tygon tubing (3/8" O.D.) across the top and down through the ceiling of the containment to three fixed station locations. Four sample holders were positioned inside the containment in each of three (3) areas, identified as the make-up air area (fixed station #1), operator area (fixed station #2), and exhaust area (fixed station #3). Sample holders were mounted 12" from the containment wall, at breathing zone height (5- 6 feet). Individual samples were separated from each other by a clearance of 6 inches. The sampling pumps were positioned on the opposite side of the containment wall, on a shelf attached to the containment wall. Each tygon tubing was identified using a unique number (1-14); and each pump was identified using a unique letter (A-N). Independent of pump location and filter media position, all tygon tubing was of the same length and diameter, and was identical to the length of tubing used during Phase 1.

Sampling within the blaster's breathing zone was conducted using two (2) SKC programmable sampling pumps mounted on the waist of the blaster. Tygon tubing traversed from the pump up the worker's back, over the shoulders and into the breathing zone, defined as a 6-9" hemisphere from the nose downward, and forward of the shoulders. All tygon tubing for the breathing zone sampling was the same length and diameter (3' x 3/8" O.D.). The filter media for elemental sample collection was positioned over the right shoulder for each abrasive trial. A 10mm nylon cyclone equipped with PVC filter media for collection of respirable crystalline silica was positioned over the left shoulder, and centered beneath the chin area on the worker. All filter media was positioned outside the blast helmet in a downward position, forward of the shoulder, and attached to the blast helmet cape using collar clips.

Calibration of Sampling Pumps

The Gilian, SKC and GAST sampling pumps were calibrated prior to each sampling period (through the filter media) using a Gilian Model 800271 Gilibrator precision flow bubble meter equipped with a standard flow cell (20cc to 6 l/m). Each sampling pump was equipped with the respective filter media, then connected to the Gilibrator. Adjustments to each pump were made using the flow adjustment screw or flow restrictor valve (GAST pumps) until the target flow was achieved. Subsequently, five (5) flow measurements were recorded, then averaged for each sampling pump. The data was recorded on a Pump Calibration Report (example attached in Appendix 3, Exhibit 3).

The sampling pumps equipped with 10mm cyclones for collection of respirable crystalline silica and respirable radiochemically active material were calibrated in accordance with the Occupational Safety and Health Administration (OSHA) Technical Manual Chapter 1, "Personal Sampling for Air Contaminants"; Section C, Technique 3[10]. Briefly, the filter media was mounted in MSA 10mm nylon cyclones. The filter media and cyclone were then placed in a one liter vessel with two (2) ports in the screw top lid. A 12" section of tygon tubing was connected from one port on the glass vessel to the Gilibrator precision flow bubble meter. The sampling pump was connected to the second port on the vessel using the appropriate length of tygon tubing (32' 4" for area sampling in the containment and 3' for breathing zone monitoring on the worker) and the sampling pump adjusted to maintain a flow rate of 1.7 L/min.

The sampling pumps for collection of metals/elements were targeted for calibration at 2.0 liters per minute through 0.8 micron pore size, 37mm diameter, mixed cellulose ester (MCE) membrane filter media, encased in 37mm plastic cassettes. The sampling pumps for collection of respirable dust and respirable radiochemically active material were targeted for calibration at 1.7 liters per minute through pre-weighted, 0.5

micron pore size, 37mm diameter PVC filter media, also encased in 37mm plastic cassettes. Finally, the sampling pumps for collection of total radiochemically active material were targeted for calibration at 4.0 liters per minute through pre-weighed, 0.5 micron pore size, 37mm diameter, PVC filter media encased in 37mm plastic cassettes.

Background Monitoring

Prior to initiation of the study, background sampling was conducted for eight (8) hours to determine the existing airborne concentrations of the targeted metals/elements, respirable crystalline silica and radiochemically active materials, and total radiochemically active materials. The ventilation system was activated, drawing cross-sectional air flow through the facility. Otherwise, the containment remained undisturbed during background monitoring.

Preparation of Containment Facility

To prevent cross-contamination of abrasive media after each abrasive trial, the containment floor, dust clinging to the walls, ceiling, floor, sample holders, test plate rack, and other surfaces were vacuumed to collect spent abrasive debris and dust. Subsequently, prior to each abrasive trial, the containment was visually inspected for the presence of abrasive debris from the previous blast trial. Additionally, a "white glove" examination was conducted on a minimum of five (5) random surfaces. The presence of "swipe marks" left by the glove was case for rejection and recleaning as necessary.

In addition to the containment, support equipment used for the blast cleaning process was also cleaned and visually examined for residual dust. This equipment included the blast nozzle and hoses, blast pot, personal protective equipment (blast helmet and cape), and protective clothing.

After the cleanliness inspection, a ventilation system inspection was performed by measuring the cross-sectional air flow through the containment using an Alnor Model RV Rotating Vane Anemometer. Twelve (12) measurements of cross-draft air flow were obtained midway through the containment. Four (4) measurements were obtained near the ceiling (7-8' above floor level), four (4) measurements were obtained at the breathing zone height (5' above floor level), and four (4) measurements were obtained 6-12" from the floor. The twelve measurements were averaged, and the results of the ventilation assessment and containment cleanliness recorded on a Mechanical Ventilation Evaluation Form and Industrial Hygiene Report Form, respectively (examples attached in Appendix 3, Exhibit 4 and Exhibit 5).

Sample Collection During Abrasive Trials

Prior to initiating each blast trial, the unique number assigned to each filter media by NIOSH was transcribed to the Industrial Hygiene Report Form. Concurrently, a position number was assigned to each filter media to ensure proper positioning/tygon tubing connection once inside the containment. Each filter cassette/cyclone assembly was carefully mounted in the holders inside the containment. The inlet ports of the cassettes remained plugged until the operator was ready to begin blast cleaning (exception - cyclone-mounted media). Subsequently, the personal pumps were mounted on the blaster and the cassette inlet port plugs were removed.

The two (2) personal sampling pumps mounted on the blaster were programmable SKC personal sampling pumps. The pumps were programmed to initiate sampling 3 minutes after the abrasive trial began in order to provide time to allow airborne concentrations of dust to equilibrate, and to stop sampling 24 minutes into the sampling period (to prevent overloading of the filter media). The total elapsed time of 27 minutes was based on information collected in a pilot study conducted prior to the Phase 1 laboratory study to estimate the best sampling rates to avoid overloading of the sample filters for elemental dust and to allow enough time to collect a minimum of respirable crystalline silica dust.

Similarly, the sampling pumps collecting airborne debris in the make-up air, operator, and exhaust areas were also turned on after 3 minutes had elapsed and stopped 24 minutes later.

Post Sample Collection Procedure

Post sample collection procedures included sample security, removal of samples from the operator and containment, pump flow rate verification and sampling equipment cleaning. Sample security was accomplished by plugging the inlet port of the filter media, then removing the media from the sampling hose and plugging the outlet port. This procedure was conducted on the operator first, then the containment area samples. Support personnel were prohibited from entering the blast facility until all inlet ports were sealed. Subsequently, the cyclones were carefully removed, kept in a vertical position, then placed in a customized holder. The holder kept the cyclones vertical to ensure the large debris which accumulated in the grit pot at the base of the cyclones did not come in contact with the PVC filter media. The filter cassettes were removed from the containment, and the cassettes sealed using 9/16" x 3-7/16" labels, each containing the date and technician's initials. This was done to prevent tampering with the samples, as well as accidental dislodging of the inlet port caps. The samples were sorted according to required analysis, then boxed for transportation by KTA personnel to NIOSH in Morgantown, West Virginia for analysis in accordance with the appropriate NIOSH analytical methods. A Sample Submittal Form and Chain-of-Custody accompanied the samples (example included in Appendix 3, Exhibit 6 and Exhibit 7). Additionally, 20% field "blank" samples were added to the shipment (also categorized by type of analysis). Four field blanks were submitted for respirable quartz and cristobalite analysis and one field blank each was submitted for respirable and total radium-226. Neither respirable quartz, cristobalite, respirable radium-226, nor total radium-226 were detected in any of the field blanks, so the sample results did not need to be adjusted for the field blanks.

After all samples were secure, post-sampling pump flow rate verification was conducted by connecting each pump to the Gilian Gilibrator precision flow bubble meter (through the respective media) and recording five flow rates as well as the average flow rate (in LPM) on the Pump Flow Verification Report Form (example included in Appendix 3, Exhibit 8). The pre- and post-sampling flow rates for each pump were averaged to create an average flow rate for the actual sampling period. This flow rate was reported to NIOSH to calculate the total volume of air sampled on each filter cassette.

After post-calibration, operator breathing zone pumps and hoses were wiped with a dampened cloth to remove residual dust. The 10mm nylon cyclones were cleaned in accordance with the OSHA Technical Manual, Chapter 1, Section C.3(6)e. "cyclone cleaning". The grit pot was removed from the base of the cyclone and gently tapped on a counter top to remove the large particles. The size selective inlet was disassembled and the components were thoroughly rinsed using tepid tap water. Subsequently, all nylon components were cleaned in a 22-watt ultrasonic bath manufactured by Fisher Scientific (Model FS-3). A mild solution of Alconox detergent powder in tap water was used to clean the parts for approximately ten (10) minutes. Each component was then thoroughly rinsed with tepid tap water and dried. After drying, the cyclones were inspected for wear, then reassembled for the next abrasive trial.

Documentation

The following documentation report forms were used for the collection of all data. Examples of each form are included in Appendix 3. Actual forms completed during the study were provided to NIOSH under separate cover.

Blast Cleaning Inspection Report # QPF-WDC345R.1 – Report form is for collection and record keeping of all data and variables associated with first and last runs during abrasive testing.

Sieve Analysis Report # MATF 100R.2 – Report form is for the collection and record keeping of data associated with screening for particle size. Calculations to develop average particle size and charting results are also included on report form.

Industrial Hygiene Report – Report form is for collection of data and acts as a checklist to ensure completion of pretest industrial hygiene practices. The report records air filter cassette sample numbers, type of filter media, duration of air flow over cassette, and total volume of air to flow over air sample media.

Pump Calibration Report – Report of calibration and actual air flow prior to test.

Pump Flow Verification Report – Report to verify post run actual air flow.

Mechanical Ventilation Evaluation – Form used for collection and calculation of air flow through the blast room.

Sample Submittal Form – Used to provide sample identification and sample collection parameters for submission to NIOSH for corresponding industrial hygiene analysis.

Chain-of-Custody – Used to verify the integrity of the samples and resulting data throughout the collection, transport, and analysis activities.

Concerns

The size and scope of the testing program resulted in a few deficiencies in both the development of the testing protocol and execution of the abrasive blasting trials. Each concern, its cause, and resolution is described in the sections that follow.

Abrasive Metering Valve

The abrasive metering valve is an integral part of any blast cleaning pressure pot. The purpose of the valve is to meter the amount of abrasive that is fed into the stream of compressed air, which propels the abrasive particles.

For the Phase 2 study, KTA fabricated a metering valve plate with five (5) fixed settings in order to achieve a greater consistency in valve adjustment than is possible with the standard valve. The valve was adjusted by the "feel" of the operator prior to each run for each abrasive. This was done without any input from the abrasive manufacturers. The valve settings are documented in Table A1.

Production Rates

The factors that effect abrasive blast cleaning productivity are:

- Abrasive Type – The specific abrasive selected from within a given generic category can effect the results. As was demonstrated in the Phase 1 laboratory study, the results between the individual abrasives varied (e.g., the cleaning rate of 4 copper slag abrasives ranged from 28 to 61 square feet/hour). Only one of each abrasive type was selected for the Phase 2 study. Depending upon which abrasive was selected, the results for the generic category may appear to be better or worse than the other abrasives on a relative basis.

- Metering Valve Setting – Each operator and abrasive supplier will likely have their own "feel" as to the appropriate setting to optimize productivity. Small adjustments may have a significant effect on abrasive consumption and productivity.

- Nozzle Size – Abrasive blast nozzles with larger openings produce a larger blast pattern on the surface being cleaned. Blast nozzles typically range in size from 1/8 inch to 1/2 inch orifice diameter, in 1/16 inch increments. Larger sized nozzles also permit more abrasive impacts per unit area since more abrasive particles exit the nozzle over a given unit of time. During this Phase 2 study, KTA used a 7/16 inch nozzle which is reasonably typical of production work.

- Nozzle Type – There are currently two types of blast nozzles used during field blasting operations. These are categorized by the nozzle geometry. Straight bore nozzles have a constant orifice diameter for the length of the nozzle. Venturi nozzles converge to the nozzle's size at a point approximately half of the nozzle's length and then diverge for the remainder of the nozzle. The converging portion of the nozzle accelerates the air and abrasive particles resulting in increased impact energy which, in turn, enhances productivity. The diverging portion of the venturi nozzle also provides an increased blast pattern. KTA used the same venturi nozzle for all abrasive trials.

- Standoff Distance – The standoff distance is the distance that the nozzle is held in relation to the item being cleaned. This distance is critical to abrasive blasting production. Blast operators typically optimize the distance to achieve the desired blast pattern and cleaning rate. This distance could range from 6 inches to 24 inches. Generally, nozzles are held closer to the substrate to clean tightly adherent mill scale or coatings which require a smaller blast pattern to achieve the specified surface cleanliness. When surfaces being cleaned exhibit loosely adherent coatings or flaking mill scale and rust, the larger blast pattern produced at greater standoff distances allows for faster cleaning. The standoff distance was held constant for all abrasive trials at 18 inches to measure the effectiveness of the different abrasives independent of the operators' skill or experience. This would also provide consistent, repeatable results, but the fixed distance will affect the ability of different abrasives to clean.

- Angle of Attack – The angle of attack is the angle that the nozzle is held to the work-piece. Most field abrasive blast cleaning is performed with the nozzle held between 60° to 120° to the surface. Nozzles held perpendicular (90°) to the surface provide more impact energy, which fractures tightly adherent coatings and mill scale. Nozzles held at angles greater than or less than 90° scour the surface. Experienced abrasive blast operators use a combination to achieve high productivity. During this abrasive study, the KTA operator held the nozzle perpendicular to the surface being cleaned so that the greatest amount of dust would be produced for industrial hygiene monitoring. Such restrictions, however, can affect cleaning rates.

- Dwell Time – Dwell time is the amount of time required to achieve the desired surface cleanliness before the nozzle can be moved to the next area on the substrate. This factor is highly influenced by the size of the blast pattern. For small blast patterns, where the nozzle is held close to the surface being cleaned, the dwell time is very short. When a larger blast pattern is used, the dwell time may be longer. Once again, the operator's skill and knowledge of the cleanliness specification help to reduce dwell time, thus increase productivity. Some of this control was removed from the operator during the study by fixing the nozzle distance and angle of attack.

- Nozzle Pressure – The pressure of the air/abrasive stream during blasting operations greatly influence cleaning productivity. For most abrasives, increased pressure results in increased production. Generally, abrasive blasting pressure is increased to the maximum capacity of the air compressor used. With the exception of abrasives such as steel grit, diminishing returns occur at pressures significantly above 100 psi. Some abrasives however, efficiently produce the desired surface cleanliness at lower pressures. The garnet supplier used during the study preferred nozzle pressures in the range 60 to 80 psi in order to reduce breakdown rate and improve the reuse characteristics. During each abrasive trial run conducted as a part of this study, the nozzle pressure was held constant at 100 psi. This was necessary to limit the number of variables in the study.

- Substrate Type – The type and condition of the substrate will effect productivity. In this case, the barge was heavily pitted, which will reduce productivity compared with smooth steel, by virtue of the time required to clean the pits and rust scale.

Each of these factors affected the cleaning rate and consumption rate results. Many of the factors are dependent on the skill or experience of the blast nozzle operator. The goal of this study design was to produce comparable abrasive blast cleaning results with the abrasive type being the variable. As compared to Phase 1, the Phase 2 field study had less control over environmental variables (wind velocity and direction, relative humidity, air temperature, temperature of the substrate blasted, etc.) and less control over some blast conditions (barge steel substrate blasted on, metering valve setting varied), and were therefore more representative of real-world conditions. Also, the operator used for the study was chosen based upon consistent results obtained during the operator variability study, which was conducted in the Phase 1 laboratory study to determine the operator with the lowest variability based on productivity results, not the operator displaying the highest productivity or having the most experience.

Ventilation Rate

The protocol called for a nominal cross-sectional flow rate (velocity) of air of 50 to 75 feet per minute (fpm). Due to the size and configuration of the required containment and the capacity of the available dust collector, the actual average cross-sectional flow rate was 40 fpm. This reduction in air flow could result in concentrations slightly above those in Phase 1, where air flow was maintained at the target 50 to 75 fpm.

In conclusion, the Study Design/Protocol was developed to measure the health effects and effectiveness of 8 different abrasives. The factors affecting the abrasive blast cleaning process were held constant so that a comparative evaluation of the abrasives could be made independent of the substrate, surface cleanliness, equipment setup, or operator. KTA did not deviate from the Study Design/Protocol during the entire field site testing phase of the project.

TEST RESULTS AND DISCUSSION

This section discusses and analyzes the results of the physical property evaluation of the abrasives and the industrial hygiene data that was collected. A total of 8 different abrasives were evaluated in this study. For convenience, the generic abrasive type, an alpha code assigned to each, and the number of individual products evaluated under each type are as follows:

Expendable Abrasives

Coal Slag (CS-06)	1 product
Nickel Slag (N-01)	1 product
Staurolite (S-02)	1 product
Silica Sand (SS-04)	1 product
Silica Sand with Dust Suppressant (SSDS-03)	1 product

Recyclable Abrasives (used only one time for Phase 2)

Copper Slag (CP-2A)	1 product
Garnet (G-3A)	1 product
Steel Grit (SG-2A)	1 product

The testing clearly demonstrated that a wide range in physical properties and in heavy metal content exists between the abrasive types tested.

Physical Property Evaluations

The results of abrasive media testing are summarized from the "Blast Cleaning Inspection Reports" prepared for each abrasive trial. The data was obtained in order to quantify the production and performance-related attributes of each of the abrasives tested. The specific attributes examined were:

- Abrasive cleaning rate
- Abrasive consumption rate
- Surface profile
- Abrasive breakdown rate (pre and post blast average particle size comparison)
- Abrasive embedment

Many of these attributes affect the amount of time that abrasive blast operators are subject to possible inhalation and ingestion hazards. Additionally, these attributes affect the cleanliness of prepared surfaces, the amount of waste generated, and cost of abrasive blast cleaning operations. Since abrasive blast cleaning is most often used for preparing surfaces to properly accept coating systems, an evaluation of particle embedment was performed because contaminants carried from abrasives to the surface being prepared may lead to premature coating failures. Premature failures of the paint system will unnecessarily subject workers to additional exposures by virtue of the unscheduled repair work that will be required.

The results of the testing for each of the individual abrasives are presented in the tables attached as Appendix A. Separate tables have been prepared for each of the attributes evaluated. This section describes the type of information found in each of the tables, and provides a general summary and discussion of the results.

The results are categorized by generic abrasive type. Five (5) expendable abrasives and three (3) abrasives classified as recyclable were used. The recyclable abrasives were used only one time for this Phase 2 study. Refer to the Abrasive Media Test Methods section of this report for a description of the test methods and associated industrial standards used for each of the evaluations.

Abrasive Cleaning and Consumption Rates

Table A1 (Appendix A) provides the results of the cleaning and consumption rates for each of the abrasives tested. The table presents the cleaning rate in square feet/hour and the abrasive consumption rate in pounds per square foot.

As indicated in the Study Design and Test Methods section of this report, the blast cleaning trials were conducted using a 7/16" orifice nozzle at 100 psi. Blast distance was fixed at 18" from the surface with the nozzle maintained at right angles at all times. Such restrictions were invoked in order to control as many variables as possible between each of the runs. One variable that was not held constant involved the metering valve setting. The metering valve was set uniquely for each abrasive prior to use. The setting was based on the "feel" of the operator.

While all of the controls previously described were designed to allow for a more accurate comparison of the properties between abrasives, a disadvantage also occurs. The equipment and operational controls can restrict productivity and adversely affect abrasive consumption rates. Despite these concerns, the cost data that is calculated in the Cost Evaluation section of this Discussion is based on the consumption rates obtained. It is important to recognize that the Phase 1 Study demonstrated that the cleaning rate between various abrasives within a given class was variable. For example, the laboratory cleaning rate for the four copper slag abrasives ranging from 28 to 61 square feet/hour and the two steel grit abrasives were 29 and 39 square feet/hour. For Phase 2, only 1 of the abrasives within each generic type was selected. As a result, conclusions regarding an entire class of abrasives based on the specific abrasive evaluated are inappropriate. In addition, when optimum operating conditions for each abrasive is selected for field use, dramatically different cleaning and consumption rates will result, both in an absolute and relative sense.

Cleaning Rates – As can be seen in Table A1, the cleaning rates derived from the study show:

- Coal slag abrasive – 144 square feet/hour.

- Nickel abrasive – 104 square feet/hour.

- Staurolite abrasive – 140 square feet/hour.

- Silica sand abrasive – 127 square feet/hour.

- Silica sand abrasive treated with dust suppressant – 146 square feet/hour. Note that this was not the same silica sand abrasive that was untreated.

- Copper slag abrasive – 102 square feet/hour.

- Garnet abrasive – 173 square feet/hour.

- Steel grit abrasive – 83 square feet/hour.

The cleaning rate for the silica sand abrasive was 127 square feet/hour. Based on the study parameters, the specific abrasive evaluated within a generic type exceeding the cleaning rate for silica sand included:

- coal slag – 144 square feet/hour
- staurolite – 140 square feet/hour
- silica sand with dust suppressant – 146 square feet/hour
- garnet – 173 square feet/hour

Abrasives with cleaning rates less than silica sand under the test parameters were:

- nickel – 104 square feet/hour
- copper slag – 102 square feet/hour
- steel grit – 83 square feet/hour

Consumption Rates - As can be seen in Table A1, the consumption rates derived from the study show:

- Coal slag abrasive – 7.2 pounds/square foot.

- Nickel abrasive – 9.2 pounds/square foot.

- Staurolite abrasive – 8.1 pounds/square foot.

- Silica sand abrasive – 8.5 pounds/square foot.

- Silica sand abrasive treated with dust suppressant – 8.8 pounds/square foot. Note that this was not the same silica sand abrasive that was untreated.

- Copper slag abrasive – 8.5 pounds/square foot.

- Garnet abrasive – 8.0 pounds/square foot.

- The "consumption rate" for the steel grit abrasive was 15.6 pounds/square foot. Note that "consumption" refers to the amount of abrasive that was used to clean each square foot, rather than the amount actually consumed and disposed.

The consumption rate for the silica sand abrasive on a weight basis was 8.5 pounds/square foot. Based on the study parameters, the specific abrasive evaluated within a given generic type that utilized less (or comparable) abrasive per square foot on a weight basis included:

- coal slag – 7.2 lbs/ft^2
- staurolite – 8.1 lbs/ft^2
- copper slag – 8.5 lbs/ft^2
- garnet – 8.0 lbs/ft^2

Abrasives with consumption rates greater than silica sand under the test parameters were:

- nickel slag – 9.2 lbs/ft^2
- silica sand with dust suppressant – 8.8 lbs/ft^2
- steel grit – The waste per square foot not calculated, but will be substantially less than silica sand because of the multiple recycles. The actual weight used was 15.6 lbs/sq ft.

Cleaning and Consumption Rate Summary

The test results can be summarized as follows:

1 – The cleaning and consumption rates obtained from the study are not fully representative of industry rates[11,12] due to the study design's equipment and operating constraints.

2 – The cleaning and consumption rates based on the individual abrasive tested within each generic type should not be assumed to apply to the cleaning rate for any generic category as a whole. Each abrasive needs to be evaluated individually for its own cleaning and consumption rates rather than rely on generalized characteristics.

3 – The data show that 4 of the 7 alternative abrasives exhibit cleaning rates equivalent to or in excess of the silica sand (based on a 1 time use for the recyclable abrasives).

4 – The data show that 4 of the 7 alternative abrasives exhibit consumption rates (on a weight basis) less than or equivalent to silica sand (based on a 1 time use for the recyclable abrasives).

5 – Dust suppressant was used on 1 silica sand abrasive. The cleaning rate showed an increase over untreated silica sand, and the consumption rate also increased. However, the two silica sands were not the same, so conclusions regarding the influence of the dust suppressant on these results can not be made.

Surface Profile

The results of fourteen (14) individual and average surface profile measurements for each of the abrasives is shown in the attached Table A2.

The abrasive manufacturers' were asked to provide an abrasive sized to provide a surface profile from 2 to 3 mils for the Phase 1 work (which was based on using a No. 4 nozzle to clean mill scale). The same abrasive was used for Phase 2, which involved cleaning heavily rusted and pitted steel, using a No. 7 nozzle. The profile measurements on the badly pitted steel exceeded the 2 to 3 mil target in every case, but all were reasonably consistent within each other, ranging from an average of 3.9 to 4.4 mils. The average profile results are summarized below:

- coal slag – 4.2 mils
- nickel slag – 4.1 mils
- staurolite – 3.9 mils
- silica sand – 4.3 mils
- silica sand with dust suppressant – 4.0 mils
- copper slag – 4.4 mils
- garnet – 4.4 mils
- steel grit – 4.3 mils

The consistency of the 14 profile readings obtained with each product was evaluated. The data below shows the total spread in profile readings between the minimum and maximum measurements obtained for each abrasive type. Note that much of the spread is likely to be due to the texture of the steel substrate rather than the abrasive itself.

- coal slag – 0.9 mil spread
- nickel slag – 1.2 mil spread
- staurolite – 2.4 mil spread
- silica sand – 0.6 mil spread
- silica sand with dust suppressant – 1.1 mil spread
- copper slag – 0.5 mil spread
- garnet – 0.5 mil spread
- steel grit – 0.5 mil spread

The surface profile results can be summarized as follows:

1 – One abrasive (staurolite) provided an average profile less than 4.0 mils (3.9 mils). The remaining 7 abrasives provided profiles ranging from 4.0 to 4.4 mils.

2 - Dust suppressant was used on 1 silica sand abrasive. The surface profile compared to untreated silica sand was less (4.0 mils vs. 4.3 mils). However, since the silica sands were not the same, the influence of the dust suppressant on profile can not be ascertained.

3 – The consistency in surface profile readings across the surface varied considerably with the specific product (from a range of 0.5 mils to 2.4 mils). However, it is believed that the rough, pitted texture of the substrate, rather than the abrasive itself, is responsible for the apparent lack of consistency, and formal conclusions should not be drawn.

Breakdown Rate (pre-blast and post-blast average particle size comparison)

Table A3 shows the change in average abrasive particle size after use. The breakdown percentages are reflected in two different manners in the last two columns of the tables. One column shows the spent abrasive in terms of percent reduction in average particle size (Average Particle Size is Reduced by X%). The other shows the average particle size of the spent abrasive as a percent of the original particle size (Average Particle Size is X% of Original). For the purpose of the discussion below, the data entitled, "Average Particle Size is Reduced by X%" is used. The lower the percentage, the more conducive is the abrasive for multiple uses. The lower percentages may also produce less airborne dust. The percent reduction in average particle size for each abrasive is as follows:

- coal slag – 58.82% reduction
- nickel slag – 57.69% reduction
- staurolite – 29.41% reduction
- silica sand – 54.17% reduction
- silica sand with dust suppressant – 41.03% reduction
- copper slag – 65.82% reduction
- garnet – 50.00% reduction
- steel grit – 3.92% reduction

The results can be summarized as follows:

1 – The breakdown percentage (average particle size reduction) for silica sand was 54.17%. Using this value, the abrasives showing lower breakdown percentages are staurolite (29.45% reduction in particle size), silica sand treated with dust suppressant (41.03%), garnet (50.00% reduction), and steel grit (3.92% reduction).

2 – Based on breakdown percentages after first use, the hierarchy of abrasives most likely to be used more than one time under the conditions of the test (arbitrarily using 40.00%

reduction in average particle size as the threshold) are: steel grit (3.92% reduction in average particle size) and staurolite (29.41% reduction). It should be noted that the supplier of the garnet abrasive recommends that pressures less than 100 psi be used in order to reduce breakdown for recyclibility.

Abrasive Embedment

A total of 35 individual abrasive embedment evaluations were made for each blast cleaning run. The results are attached in Table A4. The results represent the number of 1.3 mm x 1.3 mm squares out of 100 (covering a surface area of one-half square inch) which contained embedded abrasive particulate. The results are presented as a percentage, summarized as follows (the lower the number, the less is the embedment):

- coal slag – 16.6% embedment
- nickel slag – 2.7% embedment
- staurolite – 1.6% embedment
- silica sand – 4.5% embedment
- silica sand with dust suppressant – 1.8% embedment
- copper slag – 11.0% embedment
- garnet – 5.0% embedment
- steel grit – 11.1% embedment

The results can be summarized as follows:

1 – The percentage of embedment for silica sand is 4.5%. Using 4.5% as the target embedment, the abrasives showing comparable or lower embedment percentages are nickel slag (2.7%), staurolite (1.6%), and silica sand with dust suppressant (1.8%). The remaining abrasives exhibited greater embedment.

2 - The use of dust suppressant on the silica sand abrasive showed reduced embedment than untreated silica sand (1.8% vs. 4.5%). However, since the silica sands were not the same, the influence of dust suppressant on embedment can not be ascertained.

Comparisons Between Abrasive Types

A comparison of the general performance characteristics of the 8 abrasives is presented below. Since many characteristics of an abrasive effect its performance, selection of abrasive type should not be restricted to only a single characteristic. Experimental results were graphed in order to determine the influence that one abrasive attribute has on another. A linear regression was performed for various combinations of attributes to determine trends. These graphs are attached in Appendix C. The conclusions presented below are based upon this analysis for the removal of heavy rust from pitted steel.

- Surface profile was directly proportional to the abrasive particle size (the larger the abrasive particle size, the deeper the profile, but the heavily pitted steel may have had a significant influence on these results)

- Cleaning rate was inversely proportional to the abrasive particle size (the larger the abrasive particle size, the slower the cleaning rate)

- Consumption rate was directly proportional to the abrasive particle size (the larger the abrasive, the greater was the abrasive consumption on a weight per square foot basis)

- Breakdown rate was directly proportional to microhardness (the harder the abrasive, the greater its friability). The microhardness values were obtained during Phase 1.

Based upon these observations, optimal abrasive materials for the removal of rust and for cleaning pitted steel would be as small as possible while maintaining the surface profile requirements. (It should be noted that when removing heavy rust scale and heavy paint, the size of the abrasive is often increased to benefit from the greater mass of the abrasive in removing the heavy material, rather than "wearing it" away as would be the case with the smaller abrasive.) If the objective is to reuse the abrasive and/or reduce dusting, the hardness should be considered. Harder abrasives (with the exception of steel) tend to break down more rapidly than softer abrasives. Abrasives should also be low in soluble contaminants in order to minimize negative effects on coatings performance.

With consideration of the above, the attributes of the 7 alternative generic abrasive types are reviewed.

Coal Slag

Prior to use, the specific abrasive of interest should be investigated individually for its own merits rather than relying on the results of only one coal slag abrasive. Based on the product evaluated, the cleaning and consumption rates (144 square feet/hour and 7.2 pounds/square foot) are better than silica sand (127 square feet/hour and 8.5 pounds/square foot). The surface profile averaged 4.2 mils, with the variation in profile across the surface (spread of 0.9 mils) outside of the tolerances of silica sand (0.6 mils), but this is more likely due to the substrate than the abrasive. The breakdown rate (58.82%) was slightly greater than silica sand (54.17%). The amount of embedment (16.6%) was in excess of silica sand (4.5%).

Nickel Slag

Prior to use, the specific abrasive of interest should be investigated individually for its own merits rather than relying on the results of only one nickel slag abrasive. Based on the product evaluated, the cleaning and consumption rates (104 square feet/hour and 9.2 pounds/square foot) are not as favorable as silica sand (127 square feet/hour and 8.5 pounds/square foot). The surface profile averaged 4.1 mils, with a variation across the surface (spread of 1.2 mils) outside of the tolerances of silica sand (0.6 mils). However, this is more likely due to the substrate than the abrasive. The breakdown rate (57.69%) was slightly greater than silica sand (54.17%). The amount of embedment (2.7%) was slightly better than silica sand (4.5%).

Staurolite

Prior to use, the specific abrasive of interest should be investigated individually for its own merits rather than relying on the results of only one staurolite abrasive. Based on the product evaluated, the cleaning and consumption rates (140 square feet/hour, and 8.1 pounds/square foot) are an improvement over silica sand (127 square feet/hour and 8.5 pounds/square foot). The surface profile averaged 3.9 mils, with a variation in profile across the surface (spread of 2.4 mils) outside of the tolerances of silica sand (0.6 mils). However, this is more likely due to the substrate than the abrasive. The breakdown rate (29.41%) was better than silica sand (54.17%). The amount of embedment (1.6%) was better than silica sand (4.5%).

Silica Sand with Dust Suppressant

Prior to use, the specific abrasive of interest should be investigated individually for its own merits rather than relying on the results of only one silica sand with dust suppressant. Based on the product evaluated, the cleaning rate (146 square feet/hour) is an improvement over silica sand (127 square feet/hour). The consumption rate (8.8 pounds/square foot) is slightly greater than untreated silica sand (8.5 pounds/square foot). The surface profile averaged 4.0 mils, with a variation in profile across the surface (spread of 1.1 mils) outside the tolerances of silica sand (0.6 mils). However, this is more likely due to the substrate than the abrasive. The breakdown rate (41.03%) was better than silica sand (54.17%). The amount of embedment (1.8%) was better than silica sand (4.5%).

The silica sand with dust suppressant could not be compared directly with untreated silica sand because the silica sands were different.

Copper Slag

Copper slag was classified as a recyclable abrasive for the purpose of the study, but it was used only one time in Phase 2. Prior to use, the specific abrasive of interest should be investigated individually for its own merits rather than relying on the results of only one copper slag.

Based on the products evaluated, the cleaning rate (102 square feet/hour) is less than silica sand (127 square feet/hour). The consumption rate (8.5 pounds/square foot) is comparable to silica sand (8.5 pounds/square foot), but may not be a valid comparison since the abrasive can be recycled a few times, and as such, the value represents the amount of abrasive that impacts the surface rather than the amount of abrasive "consumed."

The surface profile averaged 4.4 mils with a variation in profile across the surface (spread of 0.5 mils) that was within the tolerances of silica sand (0.6 mils). Note that the substrate most likely had a greater influence on the consistency of the profile than the abrasive. The breakdown rate (65.82%) was worse than silica sand (54.17%). The amount of embedment (11.0%) exceeded silica sand (4.5%).

Garnet

Garnet was classified as a recyclable abrasive for the purpose of the study, but it was used only one time in Phase 2. Prior to use, the specific abrasive of interest should be investigated individually for its own merits rather than relying on the results of only one garnet.

Based on the product evaluated, the cleaning rate (173 square feet/hour) is greater than silica sand (127 square feet/hour). The consumption rate (8.0 pounds/square foot) is less than silica sand (8.5 pounds/square foot), but even then may not be a valid comparison since the abrasive can be recycled a few times, and as such, the value represents the amount of abrasive that impacts the surface rather than the amount of abrasive "consumed."

The surface profile averaged 4.4 mils, with a variation in profile across the surface (spread of 0.5 mils) that was within the tolerances of silica sand (0.6 mils). Note that the substrate most likely had a greater influence on the consistency of the profile than the abrasive. The breakdown rate (50.00%) was slightly better than silica sand (54.17%). The amount of embedment (5.0%) was comparable to silica sand (4.5%).

Steel Grit

Steel grit was classified as a recyclable abrasive for the purpose of the study, but it was used only one time in Phase 2. Prior to use, the specific abrasive of interest should be investigated individually for its own merits rather than relying on the results of only one steel grit.

Based on the product evaluated, the cleaning rate (83 square feet/hour) was less than silica sand (127 square feet/hour). The consumption rate (15.6 pounds/square foot) is not a valid comparison since the abrasive is capable of being recycled over 100 times, and as such, the value represents the amount of abrasive that impacts the surface rather than the amount of abrasive "consumed." As a point of reference, the consumption rate for silica sand in Phase 2 was 8.5 pounds/square foot.

The surface profile averaged 4.3 mils with a variation in profile across the surface (spread of 0.5 mils) which was within the tolerances of silica sand (0.6 mils). Note that the substrate most likely had a greater influence on the consistency of the profile than the abrasive. The breakdown rate (3.92%) was far less than silica sand (54.17%). The amount of embedment (11.1%) exceeded silica sand (4.5%).

Calculation of Operating Costs

In order to develop comparative costs for the use of the abrasives, a hypothetical project has been developed. The project involves 40,000 to 50,000 square feet of rusty, pitted steel. The crew size for the project consists of three workers: two abrasive blast nozzle operators, and one laborer. The key factors effecting surface preparation cost were taken into account. A discussion of these factors, as well as a brief description of how each factor effects the costs, follows.

Cleaning and Consumption Rates

As discussed in the "Concerns" section of this report, because of the restrictions placed on the equipment used for the Phase 2 testing, the cleaning and consumption rates may not be completely representative of field work. Despite this concern, costs were evaluated using the data obtained from the study. The cleaning and consumption rates based on the hypothetical project are shown on Table D1, together with costs/square foot.

Abrasive Flow (Consumption) Rate

The abrasive flow rate is the amount of abrasive actually used during the blast cleaning operations. This is commonly expressed in units of tons of abrasive used per hour of operation. This factor is highly dependent on the abrasive material itself, the blast cleaning equipment utilized, nozzle sizes, pressures, equipment adjustments, the number of blast nozzle operators, the type and integrity of the paint coating being removed, and the configuration of the structure being cleaned. The rates obtained under the study parameters were used.

Abrasive Material Cost

The cost of abrasive materials varies by generic type, manufacturer, geographic location, and the quantity of material purchased. Each manufacturer and/or supplier of abrasive media used for the Phase 1 study was interviewed to determine material costs. The unit cost was based on approximately 20 tons without any delivery charge. See Table D1 for an itemization of material costs.

The material costs ranged from $13.00 per ton to $494.00 per ton. Within a single class or type of abrasive, the cost of the most expensive material was up to 64 percent greater than the cost of the least expensive. For the purpose of this cost analysis, the average material cost for each of the generic abrasive types from Phase 1 was used. Many factors could affect the final purchase price of the products, but they were not investigated as part of this project.

Abrasive Disposal Cost

The cost to properly dispose of the surface preparation waste varies somewhat by location, but is not dependent on abrasive type. The disposal cost used for this economic analysis was for solid material categorized as non-hazardous. A non-hazardous classification was used since historically abrasive waste free of paint or other constituents has not been tested by the Toxicity Characteristic Leaching Procedure (TCLP)[13]. Since TCLP was not used on the abrasive waste from this study, there is no basis under this cost analysis for assuming that any of the abrasives would test hazardous for disposal. A value of $30.00 per ton was used based upon previous experience with painting project cost estimating and the actual cost for disposal of the abrasive waste generated during this phase of the study.

Equipment Costs

The equipment used for dry abrasive blast cleaning operations is contingent upon whether abrasive recycling will be employed. The surface preparation equipment used for expendable abrasives is less sophisticated than for recycled abrasives. For the purpose of this economic analysis, the equipment used for expendable abrasives was assumed to include:

120 cubic feet (six ton) abrasive blast pot	$1,587 per month[14]
750 cfm of air for the two #7 nozzles	$2,534 per month[14]

When abrasives are recycled during field surface preparation work, highly specialized equipment is typically used to reclaim and clean the abrasive, as well as to remove fine particles in an effort to maintain consistent surface profile. The equipment used for steel grit abrasive blast cleaning typically involves the use of an integral pressure pot, vacuum, and reclaiming blast machine equipped with air driers ($3,000[15] per month rental rate) requiring the use of a 1200 cfm compressed air supply ($3,956[14] per month rental rate). Recyclable abrasives other than steel grit require the same equipment used for expendable abrasives, and a less sophisticated reclaiming system ($1,500[16] per month rental rate) than is necessary for steel grit.

Equipment costs were obtained from rental rates published in the 1998 AED Green Book[14], published by the Machinery Information Division of K-III Directory Corp. The Green Book averages national rental rates for construction equipment (the 1998 version was the latest book in print at the time of the writing of this report). The costs used for the analysis were based on a rental term of one month, and values were converted to units of dollars per hour assuming a 40-hour workweek and a month consisting of four weeks.

Labor Costs

Labor rates for two abrasive blast cleaning nozzle operators and one laborer were averaged from eleven cities. The published prevailing wage rates for Pittsburgh, Pa. were used as the baseline. These rates were adjusted for the various cities using cost of living adjustment provided in Real Estate Tables[17]. The rate for a Pittsburgh painter was $30.15/hour and $22.69 per hour for a laborer. The labor rate for the crew totaled $82.99 per hour. Adjusted labor rates for the other cities were as follows:

Pittsburgh, Pennsylvania	$82.99	Lincoln, Nebraska	$84.39
New York, New York (Manhattan)	$228.24	Helena, Montana	$78.15
Los Angeles, California	$117.42	Houston, Texas	$75.64
Jacksonville, Florida	$84.20	Bangor, Maine	$83.87
Montgomery, Alabama	$83.27	Seattle, Washington	$92.32
		Anchorage, Alaska	$97.61

The labor rates, in units of dollars per hour, include the costs for benefits and insurance. No provisions were made to account for overtime work. For the purpose of the cost analysis an average rate of $100.74 was used.

Number Of Recycles

The number of times the abrasive is used effects the overall abrasive blast cleaning costs. Even if the material unit cost of a recyclable abrasive is higher, the overall cost per square foot will typically be lower due to savings in material quantities and lower waste disposal costs. This factor was recognized during the cost analysis. The following recycling rates were used: copper slag – 2x, garnet – 2x, steel grit – 100x, and all other abrasives – 1x.

Abrasive Cleaning Rate

The abrasive cleaning rate profoundly effects the surface preparation costs, as the cleaning rate influences nearly all of the other economic factors described above. The cleaning rate of an abrasive is dependent upon many variables, including abrasive particle size distribution, shape, hardness, specific gravity, the degree of substrate cleanliness, blast equipment operating conditions, and the type and condition of the substrate (i.e., mill scale, light corrosion, heavy rust and pitting, coated, etc.). Generally, abrasive types and sizes are chosen to obtain an optimum cleaning rate while maintaining the surface profile required for adequate coating adhesion.

Cost Analysis

The overall abrasive blast cleaning costs were calculated using the following equation:

$$\text{Cleaning Costs} = \frac{\left[\frac{A(P+D)}{R} + E + L\right]}{X}$$

Where:
Cleaning Costs ($/square foot)
A = Abrasive Flow Rate (ton/hour)
P = Material Cost of Abrasive ($/ton)
D = Disposal Cost ($/ton)
E = Equipment Cost ($/hour)
L = Labor Cost ($/hour)
R = Number of Time the Abrasive is Used
X = Abrasive Cleaning Rate (square feet/hour)

The following is an example for the use of the formula based on abrasive SS-04 (silica sand).

A = 2 nozzles x 8.47 lb./sq. for (consumption rate) x 127.2 sq. ft/hr (cleaning rate) ÷ 2,000 lb./ton
A = 1.07738 ton/hour

P = $24.08/ton

D = $30.00/ton

R = 1

E = [$1,587/month (blast pot) + $2,534/month (air)] ÷ (4.333 weeks x 40 hours/week)
E = $23.78/hour

L = $100.74/hour

X = 2 nozzles x 127.2 sq. ft/hr (cleaning rate)
X = 254.4 sq. ft/hour

$$\text{Cleaning Costs} = \frac{\left[\frac{1.07738(24.08+30.00)}{1} + 23.78 + 100.74\right]}{254.4}$$

Cleaning Costs = $0.72/sq. ft.

The results of the economic analysis are summarized in Table D1. Coal slag, silica sand, and silica sand treated with dust suppressant are least expensive and comparable ($0.69 to $0.72/square foot). Copper slag (recycled 2 times) was slightly more expensive at $0.82/square foot. Garnet (recycled 2 times) and steel grit (recycled 100 times) were comparable at $0.89/square foot. The most expensive abrasives were nickel slag and staurolite ($0.96 to $1.02/square foot). It should be noted that if hazardous waste is assumed to be present, the costs of use change dramatically (see Table

D2) The average cost of hazardous waste disposal per ton based on an SSPC study[18] is $184.00. When the hypothetical example is modified to include hazardous waste disposal, the costs range from $0.91/square foot to $1.67/square foot, with silica sand costing $1.37/square foot. Steel grit is the least costly at $0.91/square foot.

Industrial Hygiene Results

KTA collected a total of 64 airborne dust samples and 16 bulk samples of abrasives (pre and post run) for this study in accordance with the protocol described in the Study Design and Methods portion of this report. Thirty-two of the airborne samples were analyzed for up to 28 metals/elements. In addition, 32 air samples of respirable dust were analyzed gravimetrically and for quartz and cristobalite. The samples were submitted directly to NIOSH for analysis by their contract laboratory.

The results of all airborne dust and bulk abrasive sample results are presented in Appendix B, with tabs for each analyte evaluated. Within each tab, the results for a single specific analyte (e.g., arsenic) are summarized for all of the eight abrasives included in this study. In addition to a brief description of health hazards and recommended exposure limits, a total of 4 tables are used to present all of the data associated with each analyte. The general content of each table, and the sequence, in which they occur, is as follows.

Air Sample Results

The Air Sample Results table for each contaminant provides basic information on sampling parameters (e.g., sample number, sample volume, and abrasive code), as well as laboratory analytical results (e.g., mass per filter, detection/quantification limits, and concentration). The results are reported as average concentrations over the sampling period. Any data reported in the "Filter Notes" column 7 as "<LOQ" means that the associated result reported in column 8 is less than the limit of quantification (LOQ), but greater than the limit of detection (LOD). These results are "semi-quantitative", meaning the respective agent could be detected, but the result can only be accurately quantified as being in a range between the LOD and LOQ.

Airborne Sample Data Analysis

The Airborne Sample Data Analysis table is used to present a comparison of the airborne sample results collected at three fixed stations (Make-up Air Area, Operator Area, and Exhaust Area), and Operator's Breathing Zone (OBZ), for each unique abrasive used in the study. While the data presented is not for an 8 hour (time weighted average) period, it provides an indication of the relative concentrations collected during the sampling period.

Bulk Elemental Analysis

The Bulk Elemental Analysis table within each tab provides data on the concentration of the specific analyte (as well as laboratory limits of detection/quantification) in the virgin abrasive and in the post-blast abrasive for each of the individual abrasive media evaluated. Any data reported in the "Filter Notes" columns as "<LOQ" means that the associated result reported in column 8 is less than the limit of quantification (LOQ), but greater than the limit of detection (LOD). These results are

"semi-quantitative", meaning the respective agent could be detected, but the result can only be accurately quantified as being in a range between the LOD and LOQ.

Comparison of Airborne Dust Concentrations to Bulk Concentrations

The Comparison of Airborne Dust Concentrations to Bulk Concentrations table within each tab provides a comparison of the airborne concentrations recorded for the specific analyte at all of the fixed sampling stations (i.e., Make-up Air Area, Operator Area, and Exhaust Area) and the Operator's Breathing Zone to the concentration of the analyte in the virgin abrasive. This table provides an indication of the range of concentrations of the analyte in virgin bulk materials that might be associated with airborne exposure levels.

Identical tabular presentations of all of the data for each of the 28 metals/elements, as well as respirable quartz and cristobalite, are presented in Appendix B.

Health-Related Agent Summary

The goal of the field study was to collect airborne samples under partially controlled field site conditions. As a result, there was less control over certain environmental factors (e.g., wind velocity and direction, relative humidity, air temperature, temperature of the substrate blasted, etc.) and some blast conditions (e.g., barge steel substrate blasted on, metering valve setting, etc.) than in the prior Phase 1 laboratory study. However, the Study Design/Protocol followed by KTA during the field study was designed to produce comparable abrasive blast cleaning results, with the abrasive type being the primary variable. Therefore, the different abrasives can confidently be compared to each other, and specifically with the silica sand abrasive. For comparison purposes, NIOSH selected 12 health-related agents for comparative analysis, including: arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, respirable quartz, silver, titanium, vanadium, and radium-226. The results of all background samples were largely non-detectable or below the limit of quantification. No adjustments were made due to any measurable background concentrations.

Figures 1 to 10 on pages 49 to 58 show the range of measured and geometric mean concentrations for the airborne levels of eleven hazardous health-related agents for each of the 8 generic categories of abrasives tested. The airborne levels, derived from the airborne sample data analysis tables in Appendix B, included results of four samples that were collected for each blast run conducted for each abrasive product: make-up area sample, operator area sample, exhaust or dust collector area sample, and the personal sample collected in the operator's breathing zone, but outside of the blasting helmet. The range and geometric mean are indicated by a bar chart and a small square, respectively. Radium-226 is reported separately.

Any abrasive product or generic category of abrasive with all airborne samples having results below the limit of detection (LOD) for the given health-related agent are represented by only a small square (these abrasives will have no bar since there is no range to display). For abrasives having any samples below the limit of detection for the given health-related agent, the geometric mean was calculated by using LOD÷2, which is the method used to estimate the average concentration in the presence of nondetectable values described by Hornung and Reed[19]. The limits of detection for abrasive products sometimes varied slightly when analyzing a given health-related agent. Therefore, it is possible that an airborne concentration for one abrasive detected above the limit of detection could be less than the LOD÷2 for another abrasive which had a higher limit of detection associated with its analysis. The standard for comparison of all health-related agents will use the geometric mean for the silica sand generic abrasive category.

Arsenic

Figure 1 illustrates the range and geometric mean for the airborne levels of arsenic for each of eight generic categories of abrasive.

All eight of the generic abrasive categories had at least one airborne sample with results above the limit of detection for arsenic. In order from the highest to the lowest geometric mean level, the generic abrasive can be ranked as follows: steel grit, copper slag, garnet, coal slag, silica sand with dust suppressant, nickel slag, silica sand, and staurolite.

The silica sand generic abrasive category had 3 out of 4 airborne samples with results above the limit of detection for arsenic. The arsenic results for these samples were 0.645 to 11.28 $\mu g/m^3$. The geometric mean concentration of arsenic for the silica sand generic abrasive category was 4.225 $\mu g/m^3$. This will be used as the standard of comparison.

The steel grit generic abrasive category had all 4 airborne samples with results above the limit of detection for arsenic. The arsenic levels for these samples ranged from 6.834 to 185.8 $\mu g/m^3$, with a geometric mean level of 22.654 $\mu g/m^3$. The geometric mean level of arsenic for the steel grit generic abrasive category is nearly 5.4 times higher than silica sand's geometric mean level of 4.225 $\mu g/m^3$.

The copper slag generic abrasive category had all 4 airborne samples with results above the limit of detection for arsenic. The arsenic levels for these samples ranged from 10.92 to 33.13 $\mu g/m^3$, with a geometric mean level of 21.82 $\mu g/m^3$. The geometric mean level of arsenic for the copper slag generic abrasive category is over 5 times higher than silica sand's geometric mean level of 4.225 $\mu g/m^3$.

The garnet generic abrasive category had all 4 airborne samples with results above the limit of detection for arsenic. The arsenic levels for these samples ranged from 5.605 to 11.89 $\mu g/m^3$, with a geometric mean level of 9.292 $\mu g/m^3$. The geometric mean level of arsenic for the treated garnet generic abrasive category is nearly 2.2 times higher than silica sand's geometric mean level of 4.225 $\mu g/m^3$.

The coal slag generic abrasive category had all 4 airborne samples with results above the limit of detection for arsenic. The arsenic levels for these samples ranged from 7.182 to 10.54 μg/m^3, with a geometric mean level of 8.588 μg/m^3. The geometric mean level of arsenic for the treated coal slag generic abrasive category is about 2 times higher than silica sand's geometric mean level of 4.225 μg/m^3.

The silica sand with dust suppressant generic abrasive category had all 4 airborne samples with results above the limit of detection for arsenic. The arsenic levels for these samples ranged from 4.196 to 7.937 μg/m^3, with a geometric mean level of 6.190 μg/m^3. The geometric mean level of arsenic for the treated silica sand with dust suppressant generic abrasive category is about 1.5 times higher than silica sand's geometric mean level of 4.225 μg/m^3.

The nickel slag generic abrasive category had all 4 airborne samples with results above the limit of detection for arsenic. The arsenic levels for these samples ranged from 2.099 to 6.114 μg/m^3, with a geometric mean level of 4.306 μg/m^3. The geometric mean level of arsenic for the nickel slag generic abrasive category is slightly higher than silica sand's geometric mean level of 4.225 μg/m^3.

The staurolite generic abrasive category had 2 out of 4 airborne samples with results above the limit of detection for arsenic. The arsenic levels for these samples ranged from 0.615 to 1.446 μg/m^3. The geometric mean level for this category is 1.229 μg/m^3. The geometric mean level of arsenic for the staurolite generic abrasive category is less than 30% of silica sand's geometric mean level of 4.225 μg/m^3.

Beryllium

Figure 2 illustrates the range and geometric mean for the airborne levels of beryllium for each of the eight generic categories of abrasive. The steel grit generic category of abrasive had all airborne beryllium results below the limit of detection.

The following generic abrasive categories had at least one airborne sample with results above the limit of detection for beryllium, and in order from the highest to the lowest geometric mean level include: coal slag, silica sand, copper slag, staurolite, garnet, nickel slag, silica sand with dust suppressant.

The silica sand generic abrasive category had 3 out of 4 airborne samples with results above the limit of detection for beryllium. The concentration of beryllium levels for these samples ranged from 0.108 to 4.83 μg/m^3. The geometric mean concentration of beryllium for the silica sand generic abrasive category was 0.792 μg/m^3. This will be used as the standard of comparison.

The coal slag generic abrasive category had all 4 airborne samples with results above the limit of detection for beryllium. The beryllium levels for these samples ranged from 0.86 to 5.87 μg/m^3, with a geometric mean level of 3.334 μg/m^3. The geometric mean level of beryllium for the coal slag generic abrasive category is about 4.2 times higher than silica sand's geometric mean level of 0.792 μg/m^3.

The copper slag generic abrasive category had all 4 airborne samples with results above the limit of detection for beryllium. The beryllium levels for these samples ranged from 0.38 to 1.24 μg/m^3, with a geometric mean level of 0.766 μg/m^3. The geometric mean level of beryllium for the copper slag generic abrasive category is slightly lower than silica sand's geometric mean level of 0.792 μg/m^3.

The staurolite generic abrasive category had all 4 airborne samples with results above the limit of detection for beryllium. The beryllium levels for these samples ranged from 0.33 to 0.80 μg/m^3, with a geometric mean level of 0.577 μg/m^3. The geometric mean level of beryllium for the steel grit generic abrasive category is about 72% of silica sand's geometric mean level of 0.792 μg/m^3.

The garnet generic abrasive category had all 4 airborne samples with results above the limit of detection for beryllium. The beryllium levels for these samples ranged from 0.39 to 0.64 μg/m^3, with a geometric mean level of 0.505 μg/m^3. The geometric mean level of beryllium for the garnet generic abrasive category is less than two-thirds of silica sand's geometric mean level of 0.792 μg/m^3.

The nickel slag generic abrasive category had all 4 airborne samples with results above the limit of detection for beryllium. The beryllium levels for these samples ranged from 0.08 to 0.23 μg/m^3, with a geometric mean level of 0.150 μg/m^3. The geometric mean level of beryllium for the steel grit generic abrasive category is less than 20% of silica sand's geometric mean level of 0.792 μg/m^3.

The silica sand with dust suppressant generic abrasive category had 3 out of 4 airborne samples with results above the limit of detection for beryllium. The beryllium levels for these samples ranged from 0.042 to 0.14 μg/m^3, with a geometric mean level of 0.094 μg/m^3. The geometric mean level of beryllium for the silica sand with dust suppressant generic abrasive category is about 12% of silica sand's geometric mean level of 0.792 μg/m^3.

Cadmium

Figure 3 illustrates the range and geometric mean for the airborne levels of cadmium for each of the eight generic categories of abrasive.

All eight categories had results above the detection. In order from the highest to the lowest geometric mean level, the generic categories of abrasive can be categorized as follows: garnet, coal slag, copper slag, steel grit, nickel slag, staurolite, silica sand with dust suppressant, and silica sand.

The silica sand generic abrasive category had all 4 airborne samples with results above the limit of detection for cadmium. The concentration of cadmium levels for these samples ranged from 0.065 to 0.316 µg/m^3. The geometric mean concentration of cadmium for the silica sand generic abrasive category was 0.185 µg/m^3. This will be used as the standard of comparison.

The garnet generic abrasive category had all 4 airborne samples with results above the limit of detection for cadmium. The cadmium levels for these samples ranged from 0.685 to 1.507 µg/m^3, with a geometric mean level of 1.105 µg/m^3. The geometric mean level of cadmium for the garnet generic abrasive category is nearly 6 times higher than silica sand's geometric mean level of 0.185 µg/m^3.

The coal slag generic abrasive category had all 4 airborne samples with results above the limit of detection for cadmium. The cadmium levels for these samples ranged from 0.275 to 1.032 µg/m^3, with a geometric mean level of 0.496 µg/m^3. The geometric mean level of cadmium for the coal slag generic abrasive category is about 2.7 times higher than silica sand's geometric mean level of 0.185 µg/m^3.

The copper slag abrasive category had all 4 airborne samples with results above the limit of detection for cadmium. The cadmium levels for these samples ranged from 0.119 to 3.73 µg/m^3, with a geometric mean level of 0.448 µg/m^3. The geometric mean level of cadmium for the copper slag generic abrasive category is about 2.4 times higher than silica sand's geometric mean level of 0.185 µg/m^3.

The steel grit generic abrasive category had all 4 airborne samples with results above the limit of detection for cadmium. The cadmium levels for these samples ranged from 0.084 to 12.25 µg/m^3, with a geometric mean level of 0.426 µg/m^3. The geometric mean level of cadmium for the steel grit generic abrasive category is 2.3 times higher than silica sand's geometric mean level of 0.185 µg/m^3.

The nickel slag generic abrasive category had all 4 airborne samples with results above the limit of detection for cadmium. The cadmium levels for these samples ranged from 0.231 to 0.569 µg/m^3, with a geometric mean level of 0.344 µg/m^3. The geometric mean level of cadmium for the steel grit generic abrasive category is nearly 2 times higher than silica sand's geometric mean level of 0.185 µg/m^3.

The staurolite generic abrasive category had all 4 airborne samples with results above the limit of detection for cadmium. The cadmium levels for these samples ranged from 0.205 to 0.307 µg/m^3, with a geometric mean level of 0.248 µg/m^3. The geometric mean level of cadmium for the staurolite generic abrasive category is slightly higher (approximately 1.34 times) than silica sand's geometric mean level of 0.185 µg/m^3.

The silica sand with dust suppressant category had all 4 airborne samples with results above the limit of detection for cadmium. The cadmium levels for these samples ranged from 0.105 to 0.511 µg/m^3, with a geometric mean level of 0.216 µg/m^3. The geometric mean level of cadmium for the silica with dust suppressant generic abrasive category is slightly higher than silica sand's geometric mean level of 0.185 µg/m^3.

Chromium

Figure 4 illustrates the range and geometric mean for the airborne levels of chromium for each of the eight generic categories of abrasives.

All eight generic abrasive categories had at least one airborne sample with results above the limit of detection for chromium, and in order from the highest to the lowest geometric mean level include: nickel slag, steel grit, coal slag, garnet, staurolite, copper slag, silica sand, and silica sand with dust suppressant.

The silica sand generic abrasive category had 3 out of 4 airborne samples with results above the limit of detection for chromium. The chromium concentrations for these samples ranged from 5.375 to 94.53 $\mu g/m^3$. The geometric mean concentration of chromium for the silica sand generic abrasive category was 36.08 $\mu g/m^3$. This will be used as the standard of comparison.

The nickel slag category had all 4 airborne samples with results above the limit of detection for chromium. The chromium levels for these samples ranged from 1931 to 5435 $\mu g/m^3$, with a geometric mean level of 3513.1 $\mu g/m^3$. The geometric mean level of chromium for the nickel slag generic abrasive category is over 97 times higher than silica sand's geometric mean level of 36.08 $\mu g/m^3$.

The steel grit category had all 4 airborne samples with results above the limit of detection for chromium. The chromium levels for these samples ranged from 310.6 to 8756 $\mu g/m^3$, with a geometric mean level of 1025 $\mu g/m^3$. The geometric mean level of chromium for the steel grit generic abrasive category is about 28 times higher than silica sand's geometric mean level of 36.08 $\mu g/m^3$.

The coal slag category had all 4 airborne samples with results above the limit of detection for chromium. The chromium levels for these samples ranged from 62.37 to 162.4 $\mu g/m^3$, with a geometric mean level of 111.4 $\mu g/m^3$. The geometric mean level of chromium for the coal slag generic abrasive category is about 3 times higher than silica sand's geometric mean level of 36.08 $\mu g/m^3$.

The garnet category had all 4 airborne samples with results above the limit of detection for chromium. The chromium levels for these samples ranged from 56.05 to 131.6 $\mu g/m^3$, with a geometric mean level of 94.37 $\mu g/m^3$. The geometric mean level of chromium for the garnet generic abrasive category is about 2.6 times higher than silica sand's geometric mean level of 36.08 $\mu g/m^3$.

The staurolite category had all 4 airborne samples with results above the limit of detection for chromium. The chromium levels for these samples ranged from 54.26 to 98.18 $\mu g/m^3$, with a geometric mean level of 74.08 $\mu g/m^3$. The geometric mean level of chromium for the staurolite generic abrasive category is about 2 times higher than silica sand's geometric mean level of 36.08 $\mu g/m^3$.

The copper slag category had all 4 airborne samples with results above the limit of detection for chromium. The chromium levels for these samples ranged from 39.7 to 101.5 μg/m^3, with a geometric mean level of 73.7 μg/m^3. The geometric mean level of chromium for the copper slag generic abrasive category is just over 2 times higher than silica sand's geometric mean level of 36.08 μg/m^3.

The silica sand with dust suppressant category had all 4 airborne samples with results above the limit of detection for chromium. The chromium levels for these samples ranged from 14.69 to 46.81 μg/m^3, with a geometric mean level of 33.52 μg/m^3. The geometric mean level of chromium for the silica sand with dust suppressant generic abrasive category is slightly lower than silica sand's geometric mean level of 36.08 μg/m^3.

Lead

Figure 5 illustrates the range and geometric mean for the airborne levels of lead for each of the eight generic categories of abrasives.

All of the generic abrasive categories had at least one airborne sample with results above the limit of detection for lead, and in order of the highest to the lowest geometric mean level include: staurolite, coal slag, silica sand with dust suppressant, garnet, steel grit, nickel slag, copper slag, and silica sand.

The silica sand generic abrasive category had three out of four airborne samples with results above the limit of detection. The lead levels for these samples ranged from 1.075 to 14.21 μg/m^3. The geometric mean concentration of lead for the silica sand generic abrasive category was 6.052 μg/m^3. This will be used as a standard of all comparisons.

The staurolite category had all 4 airborne samples with results above the limit of detection for lead. The lead levels for these samples ranged from 31.3 to 57.86 μg/m^3, with a geometric mean level of 42.82 μg/m^3. The geometric mean level of lead for the staurolite generic abrasive category is 7 times higher than silica sand's geometric mean level of 6.052 μg/m^3.

The coal slag category had all 4 airborne samples with results above the limit of detection for lead. The lead levels for these samples ranged from 9.93 to 12.04 μg/m^3, with a geometric mean level of 11.33 μg/m^3. The geometric mean level of lead for the coal slag generic abrasive category is nearly 1.9 times higher than silica sand's geometric mean level of 6.052 μg/m^3.

The silica sand with dust suppressant category had all 4 airborne samples with results above the limit of detection for lead. The lead levels for these samples ranged from 4.62 to 11.24 μg/m^3, with a geometric mean level of 8.563 μg/m^3. The geometric mean level of lead for the silica sand with dust suppressant generic abrasive category is about 1.4 times higher than silica sand's geometric mean level of 6.052 μg/m^3.

The garnet category had all 4 airborne samples with results above the limit of detection for lead. The lead levels for these samples ranged from 5.19 to 11.67 μg/m^3, with a geometric mean level of 8.558 μg/m^3. The geometric mean level of lead for the garnet generic abrasive category is about 1.4 times higher than silica sand's geometric mean level of 6.052 μg/m^3.

The steel grit category had all 4 airborne samples with results above the limit of detection for lead. The lead levels for these samples ranged from 1.92 to 24.5 μg/m^3, with a geometric mean level of 7.137 μg/m^3. The geometric mean level of lead for the steel grit generic abrasive category is slightly higher than silica sand's geometric mean level of 6.052 μg/m^3.

The nickel slag category had all 4 airborne samples with results above the limit of detection for lead. The lead levels for these samples ranged from 5.04 to 8.38 μg/m^3, with a geometric mean level of 6.880 μg/m^3. The geometric mean level of lead for the nickel slag generic abrasive category is slightly higher than silica sand's geometric mean level of 6.052 μg/m^3.

The copper slag category had all 4 airborne samples with results above the limit of detection for lead. The lead levels for these samples ranged from 3.18 to 10.14 μg/m^3, with a geometric mean level of 6.785 μg/m^3. The geometric mean level of lead for the copper slag generic abrasive category is slightly higher than silica sand's geometric mean level of 6.052 μg/m^3.

Manganese

Figure 6 illustrates the range and geometric mean for the airborne levels of manganese for each of the eight generic categories of abrasive.

All of the generic categories of abrasives had at least 1 airborne sample result above the limit of detection for manganese, and in order of the highest to lowest geometric mean level include: garnet, steel grit, copper slag, nickel slag, coal slag, staurolite, silica sand, and silica sand with dust suppressant.

The silica sand generic category had all four airborne samples with results above the limit of detection. The results ranged from 64.52 to 947.5 μg/m^3. The geometric mean level of manganese for the silica sand generic abrasive category is 383.6 μg/m^3. This will be used as the standard of comparison.

The garnet category had all 4 airborne samples with results above the limit of detection for manganese. The manganese levels for these samples ranged from 5,813 to 13,585 μg/m^3, with a geometric mean level of 9,489 μg/m^3. The geometric mean level of manganese for the garnet generic abrasive category is nearly 25 times higher than silica sand's geometric mean level of 383.6 μg/m^3.

The steel grit category had all 4 airborne samples with results above the limit of detection for manganese. The manganese levels for these samples ranged from 1,595 to 38,798 μg/m^3, with a geometric mean level of 4,943 μg/m^3. The geometric mean level of manganese for the steel grit generic abrasive category is nearly 13 times higher than silica sand's geometric mean level of 383.6 μg/m^3.

The copper slag category had all 4 airborne samples with results above the limit of detection for manganese. The manganese levels for these samples ranged from 1,092 to 3,313 μg/m^3, with a geometric mean level of 2,182 μg/m^3. The geometric mean level of manganese for the copper slag generic abrasive category is about 5.7 times higher than silica sand's geometric mean level of 383.6 μg/m^3.

The nickel slag category had all 4 airborne samples with results above the limit of detection for manganese. The manganese levels for these samples ranged from 881.6 to 2,264 μg/m^3, with a geometric mean level of 1,576 μg/m^3. The geometric mean level of manganese for the nickel slag generic abrasive category is about 4 times higher than silica sand's geometric mean level of 383.6 μg/m^3.

The coal slag category had all 4 airborne samples with results above the limit of detection for manganese. The manganese levels for these samples ranged from 633.7 to 903.2 μg/m^3, with a geometric mean level of 746.8 μg/m^3. The geometric mean level of manganese for the coal slag generic abrasive category is nearly 2 times higher than silica sand's geometric mean level of 383.6 μg/m^3.

The staurolite category had all 4 airborne samples with results above the limit of detection for manganese. The manganese levels for these samples ranged from 480 to 818.2 μg/m^3, with a geometric mean level of 638.7 μg/m^3. The geometric mean level of manganese for the staurolite generic abrasive category is about 1.7 times higher than silica sand's geometric mean level of 383.6 μg/m^3.

The silica sand with dust suppressant category had all 4 airborne samples with results above the limit of detection for manganese. The manganese levels for these samples ranged from 102.8 to 325.6 μg/m^3, with a geometric mean level of 226.6 μg/m^3. The geometric mean level of manganese for the silica sand with dust suppressant generic abrasive category is about 60% of silica sand's geometric mean level of 383.6 μg/m^3.

Nickel

Figure 7 illustrates the range and geometric mean for the airborne levels of nickel for each of the eight generic categories of abrasive.

All of the generic abrasive categories had at least one airborne sample with results above the limit of detection for nickel, and in order from the highest to the lowest geometric mean level include: nickel slag, steel grit, coal slag, copper slag, silica sand, staurolite, garnet, and silica sand with dust suppressant.

The silica sand generic abrasive category had all 4 airborne samples with results above the limit of detection. The nickel level in these samples ranged from 10.8 to 46.21 μg/m^3. The geometric mean level of nickel for the silica sand generic abrasive category was 28.33 μg/m^3. This will be used as the standard for comparison.

The nickel slag category had all 4 airborne samples with results above the limit of detection for nickel. The nickel levels for these samples ranged from 483 to 1,540 μg/m^3, with a geometric mean level of 948.4 μg/m^3. The geometric mean level of nickel for the nickel slag generic abrasive category is nearly 34 times higher than silica sand's geometric mean level of 28.33 μg/m^3.

The steel grit category had all 4 airborne samples with results above the limit of detection for nickel. The nickel levels for these samples ranged from 130 to 4,697 μg/m^3, with a geometric mean level of 523.6 μg/m^3. The geometric mean level of nickel for the nickel generic abrasive category is nearly 19 times higher than silica sand's geometric mean level of 28.33 μg/m^3.

The coal slag category had all 4 airborne samples with results above the limit of detection for nickel. The nickel levels for these samples ranged from 33.6 to 101.5 μg/m^3, with a geometric mean level of 70.6 μg/m^3. The geometric mean level of nickel for the coal slag generic abrasive category is about 2.5 times higher than silica sand's geometric mean level of 28.33 μg/m^3.

The copper slag category had all 4 airborne samples with results above the limit of detection for nickel. The nickel levels for these samples ranged from 15.9 to 47.62 μg/m^3, with a geometric mean level of 33.39 μg/m^3. The geometric mean level of nickel for the copper slag generic abrasive category is slightly higher (about 1.2 times) than silica sand's geometric mean level of 28.33 μg/m^3.

The staurolite category had all 4 airborne samples with results above the limit of detection for nickel. The nickel levels for these samples ranged from 12.3 to 42.96 μg/m^3, with a geometric mean level of 23.94 μg/m^3. The geometric mean level of nickel for the staurolite generic abrasive category is about 85% of silica sand's geometric mean level of 28.33 μg/m^3.

The garnet category had three out of four airborne samples with results above the limit of detection for nickel. The nickel levels for these samples ranged from 5.19 to 29.72 μg/m^3, with a geometric mean level of 16.38 μg/m^3. The geometric mean level of nickel for the garnet generic abrasive category is about 60% of silica sand's geometric mean level of 28.33 μg/m^3.

The silica sand with dust suppressant category had 3 out of 4 airborne samples with results above the limit of detection for nickel. The nickel levels for these samples ranged from 5.25 to 23.55 μg/m^3, with a geometric mean level of 14.58 μg/m^3. The geometric mean level of nickel for the silica sand with dust suppressant generic abrasive category is about 50% of silica sand's geometric mean level of 28.33 μg/m^3.

Respirable Quartz

Figure 8 illustrates the range and geometric mean for the airborne levels of respirable quartz for each of the eight generic categories of abrasives. The following generic categories of abrasives had all airborne results below the limit of detection for respirable quartz: copper slag, nickel slag, and steel grit. NIOSH did not detect cristobalite in any of the airborne or bulk samples.

The following generic abrasive categories had at least 1 airborne sample with results above the limit of detection for respirable quartz, and in order of the highest to lowest geometric mean level, include: silica sand, silica sand with dust suppressant, garnet, staurolite, and coal slag.

The silica sand generic abrasive category had all four airborne samples with results above the limit of detection for respirable quartz. The respirable quartz levels for these samples ranged from 9.91 to 50.52 mg/m^3 The geometric mean level of respirable quartz for the silica sand generic abrasive category was 27.6 mg/m^3. This will be used as the standard for comparison.

The silica sand with dust suppressant category had all 4 airborne samples with results above the limit of detection for respirable quartz. The respirable quartz levels for these samples ranged from 9.18 to 28.2 mg/m^3, with a geometric mean level of 19.04 mg/m^3. The geometric mean level of respirable quartz for the silica sand with dust suppressant generic abrasive category is about 68% of silica sand's geometric mean level of 27.6 mg/m^3.

The garnet category had all 4 airborne samples with results above the limit of detection for respirable quartz. The respirable quartz levels for these samples ranged from 0.87 to 7.28 mg/m^3, with a geometric mean level of 2.6 mg/m^3. The geometric mean level of respirable quartz for the garnet generic abrasive category is less than 10% of silica sand's geometric mean level of 27.6 mg/m^3.

The staurolite category all 4 airborne samples with results above the limit of detection for respirable quartz. The respirable quartz levels for these samples ranged from 1.01 to 5.03 mg/m^3, with a geometric mean level of 2.306 mg/m^3. The geometric mean level of respirable quartz for the staurolite generic abrasive category is about 8% of silica sand's geometric mean level of 27.6 mg/m^3.

The coal slag category had one airborne sample with results above the limit of detection for respirable quartz. The respirable quartz level for this sample was 0.25 mg/m^3. The geometric mean for this category was 0.148 mg/m^3. The geometric mean level of respirable quartz for the coal slag generic abrasive category is less than 1% of silica sand's geometric mean level of 27.6 m g/m^3.

Silver

The silica sand generic abrasive category had no measured results above the limit of detection. The geometric mean for the silica sand generic abrasive category equals the limit of detection for each abrasive divided by two, which is 0.861 µg/m^3. This will be used as the standard for comparison.

The only generic abrasive category with at least one airborne sample with results above the limit of detection for silver was silica sand with dust suppressant. There was one result above the detection limit, with a concentration of 2.04 µg/m^3. The geometric mean for this category was 1.045 µg/m^3, which is slightly higher than silica sand's geometric mean of 0.861 µg/m^3.

Titanium

Figure 9 illustrates the range and geometric mean for the airborne levels of titanium for each of eight generic categories of abrasives.

All of the generic abrasive categories had airborne samples with results above the limit of detection for titanium, and in order of the highest to the lowest geometric mean level include: staurolite, coal slag, copper slag, silica sand, garnet, nickel slag, silica sand with dust suppressant, and steel grit.

The silica sand generic category of abrasive had all 4 samples with results above the limit of detection for titanium. The results ranged from 103.2 to 2,731 µg/m^3. The geometric mean level of titanium for the silica sand generic abrasive category was 749.6 µg/m^3. This will be used as the standard for comparison.

The staurolite category had all 4 airborne samples with results above the limit of detection for titanium. The titanium levels for these samples ranged from 4,591 to 5,166 µg/m^3, with a geometric mean level of 4,892 µg/m^3. The geometric mean level of titanium for the staurolite generic abrasive category is about 6.5 times higher than silica sand's geometric mean level of 749.6 µg/m^3.

The coal slag category had all 4 airborne samples with results above the limit of detection for titanium. The titanium levels for these samples ranged from 1,011 to 2,933 µg/m^3, with a geometric mean level of 1,786 µg/m^3. The geometric mean level of titanium for the coal slag generic abrasive category is about 2.4 times higher than silica sand's geometric mean level of 749.579 µg/m^3.

The copper slag category had all 4 airborne samples with results above the limit of detection for titanium. The titanium levels for these samples ranged from 635.2 to 2,070 µg/m^3, with a geometric mean level of 1,289 µg/m^3. The geometric mean level of titanium for the copper slag generic abrasive category is about 1.7 times higher than silica sand's geometric mean level of 749.6 µg/m^3.

The garnet category had all 4 airborne samples with results above the limit of detection for titanium. The titanium levels for these samples ranged from 228.4 to 339.6 μg/m^3, with a geometric mean level of 284.3 μg/m^3. The geometric mean level of titanium for the garnet generic abrasive category is about 40% of silica sand's geometric mean level of 749.6 μg/m^3.

The nickel slag category had all 4 airborne samples with results above the limit of detection for titanium. The titanium levels for these samples ranged from 90.26 to 217.4 μg/m^3, with a geometric mean level of 150.8 μg/m^3. The geometric mean level of titanium for the nickel slag generic abrasive category is about 20% of silica sand's geometric mean level of 749.6 μg/m^3.

The silica sand with dust suppressant category had all 4 airborne samples with results above the limit of detection for titanium. The titanium levels for these samples ranged from 15.74 to 38.82 μg/m^3, with a geometric mean level of 27.79 μg/m^3. The geometric mean level of titanium for the silica sand with dust suppressant generic abrasive category is less than 4% of silica sand's geometric mean level of 749.6 μg/m^3.

The steel grit category had all 4 airborne samples with results above the limit of detection for titanium. The titanium levels for these samples ranged from 6.26 to 81.68 μg/m^3, with a geometric mean level of 21.7 μg/m^3. The geometric mean level of titanium for the steel grit generic abrasive category is less than 3% of silica sand's geometric mean level of 749.6 μg/m^3.

Vanadium

Figure 10 illustrates the range and geometric mean for the airborne levels of vanadium for each of the eight generic categories of abrasives.

All of the generic abrasive categories had at least one airborne sample with results above the limit of detection for vanadium, and in order from the highest to the lowest geometric mean level include: coal slag, copper slag, steel grit, nickel slag, silica sand, staurolite, garnet, and silica sand with dust suppressant.

The silica sand generic abrasive category had all four airborne samples with results above the limit of detection for vanadium. The results ranged from 4.3 μg/m^3 to 109.2 μg/m^3. The geometric mean for the silica sand generic abrasive category was 32.62 μg/m^3. This will be used as the standard for comparison.

The coal slag category had all 4 airborne samples with results above the limit of detection for vanadium. The vanadium levels for these samples ranged from 45.16 to 171.5 μg/m^3, with a geometric mean level of 106.3 μg/m^3. The geometric mean level of vanadium for the coal slag generic abrasive category is nearly 3.3 times higher than silica sand's geometric mean level of 32.62 μg/m^3.

The copper slag category had all 4 airborne samples with results above the limit of detection for vanadium. The vanadium levels for these samples ranged from 39.7 to 122.2 μg/m^3, with a geometric mean level of 77.16 μg/m^3. The geometric mean level of vanadium for the copper slag generic abrasive category is approximately 2 times higher than silica sand's geometric mean level of 32.62 μg/m^3.

The steel grit category had all 4 airborne samples with results above the limit of detection for vanadium. The vanadium levels for these samples ranged from 19.05 to 490.1 μg/m^3, with a geometric mean level of 59.16 μg/m^3. The geometric mean level of vanadium for the steel grit generic abrasive category is about 1.8 times higher than silica sand's geometric mean level of 32.62 μg/m^3.

The nickel slag category had all 4 airborne samples with results above the limit of detection for vanadium. The vanadium levels for these samples ranged from 23.09 to 58.88 μg/m^3, with a geometric mean level of 39.56 μg/m^3. The geometric mean level of vanadium for the nickel slag generic abrasive category is slightly higher than silica sand's geometric mean level of 32.62 μg/m^3.

The staurolite category had all 4 airborne samples with results above the limit of detection for vanadium. The vanadium levels for these samples ranged from 18.78 to 28.93 μg/m^3, with a geometric mean level of 24.88 μg/m^3. The geometric mean level of vanadium for the staurolite generic abrasive category is approximately 76% of silica sand's geometric mean level of 32.62 μg/m^3.

The garnet category had all 4 airborne samples with results above the limit of detection for vanadium. The vanadium levels for these samples ranged from 14.53 to 25.47 μg/m^3, with a geometric mean level of 20.37 μg/m^3. The geometric mean level of vanadium for the garnet generic abrasive category is about 60% of silica sand's geometric mean level of 32.62 μg/m^3.

The silica with dust suppressant category had all 4 airborne samples with results above the limit of detection for vanadium. The vanadium levels for these samples ranged from 2.04 to 4.71 μg/m^3, with a geometric mean level of 3.01 μg/m^3. The geometric mean level of vanadium for the silica sand with dust suppressant generic abrasive category is less than 10% of silica sand's geometric mean level of 32.62 μg/m^3.

FIGURE 1 – ARSENIC AIR SAMPLE RESULTS

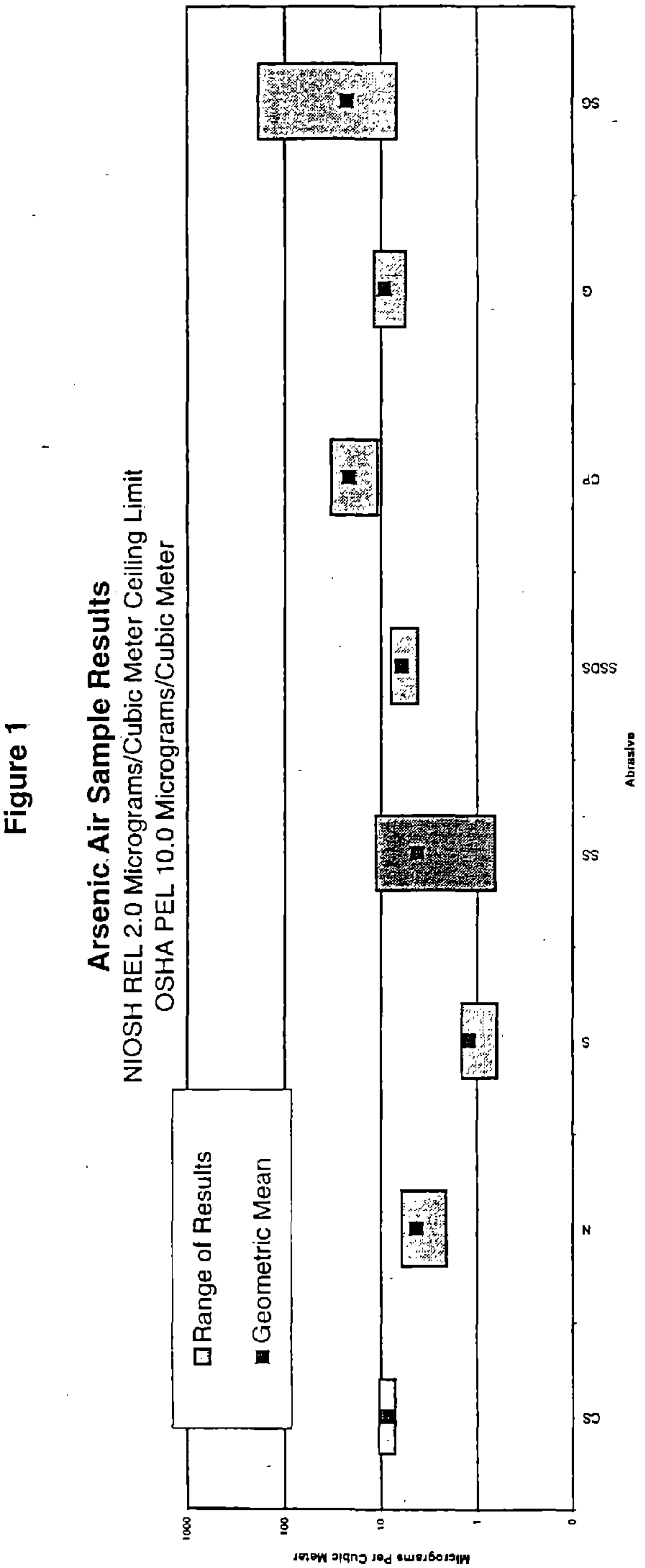


Fig_1.xls

FIGURE 2 – BERYLLIUM AIR SAMPLE RESULTS

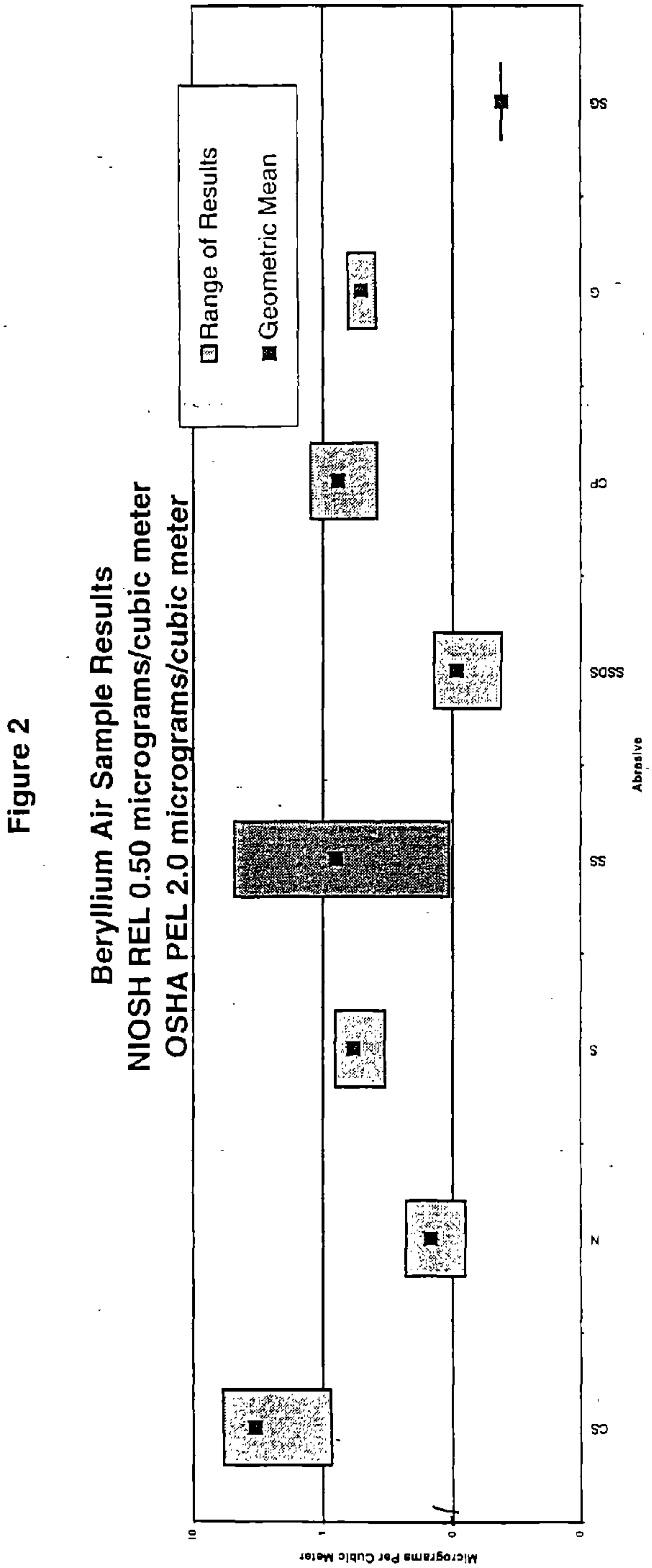


Fig_2.xls

FIGURE 3 – CADMIUM AIR SAMPLE RESULTS

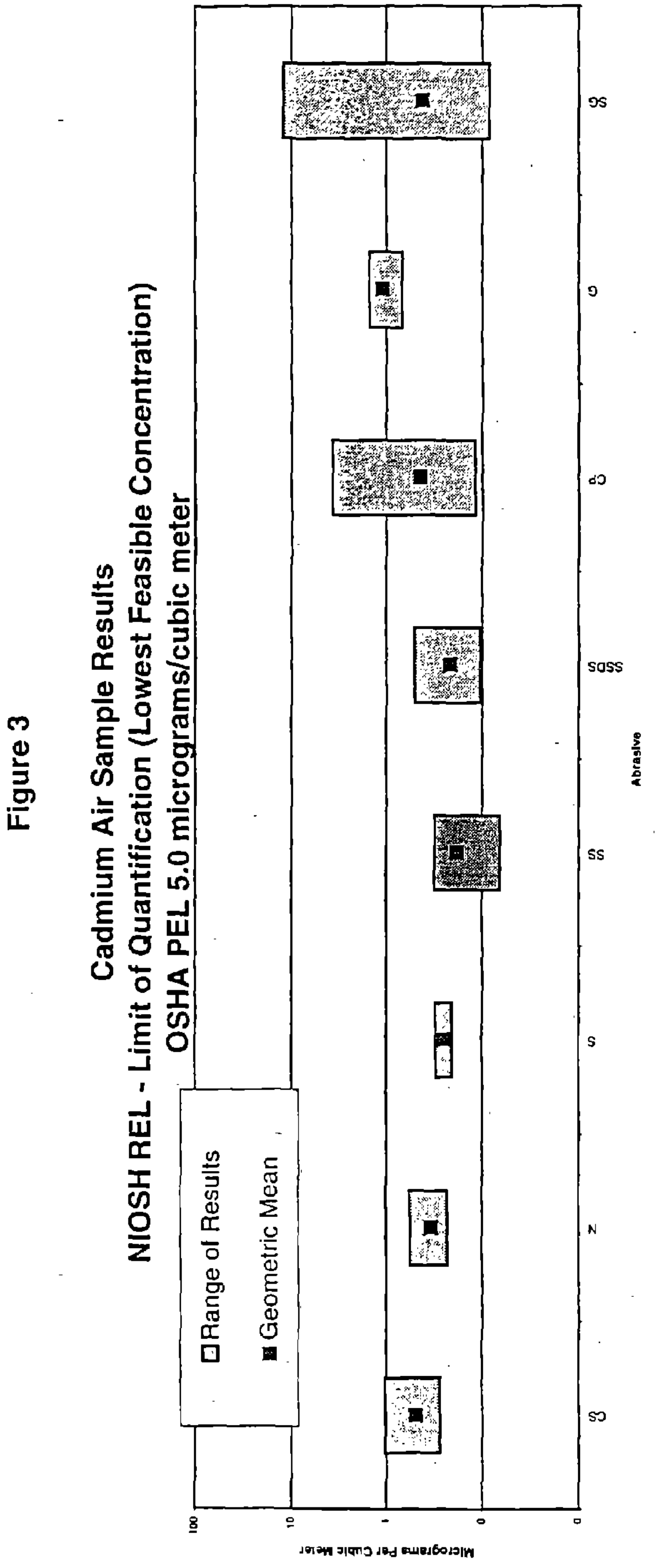


Fig_3.xls

FIGURE 4 – CHROMIUM AIR SAMPLE RESULTS

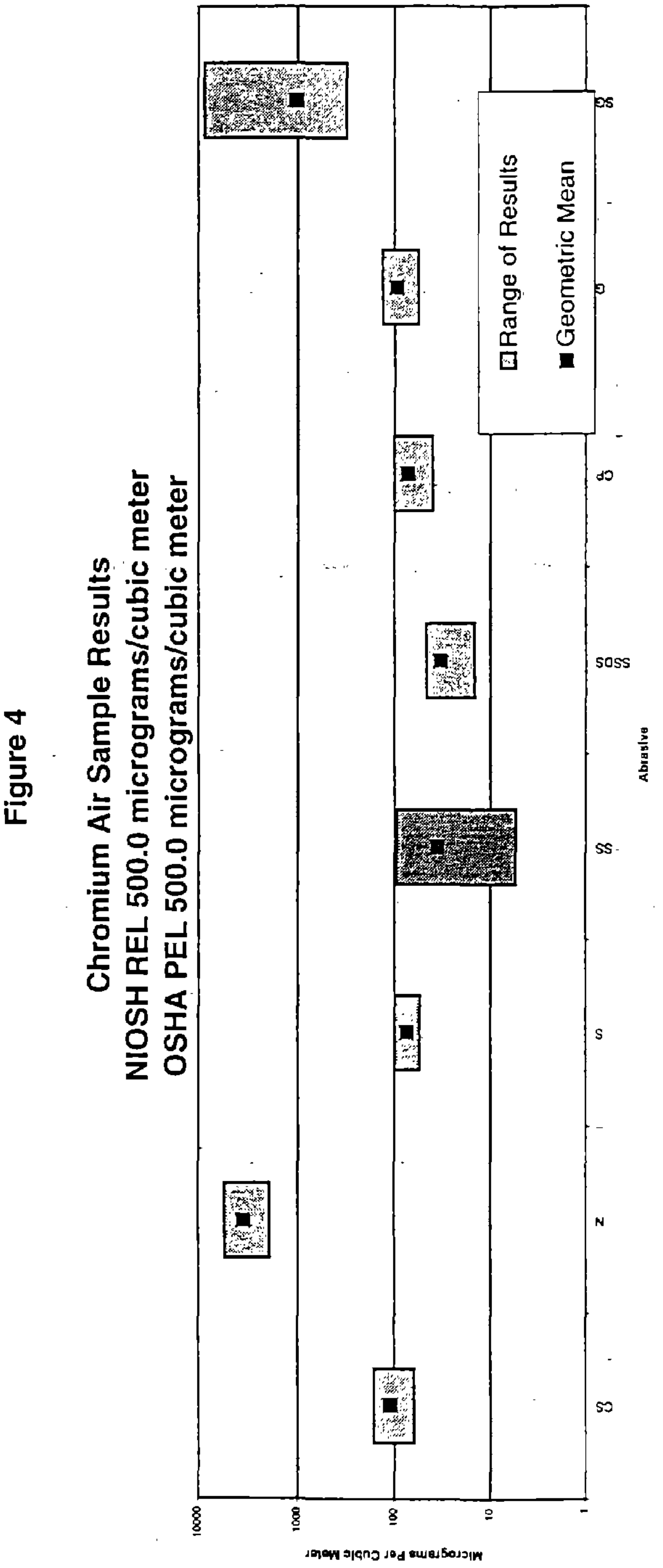


Fig_4.xls

FIGURE 5 – LEAD AIR SAMPLE RESULTS

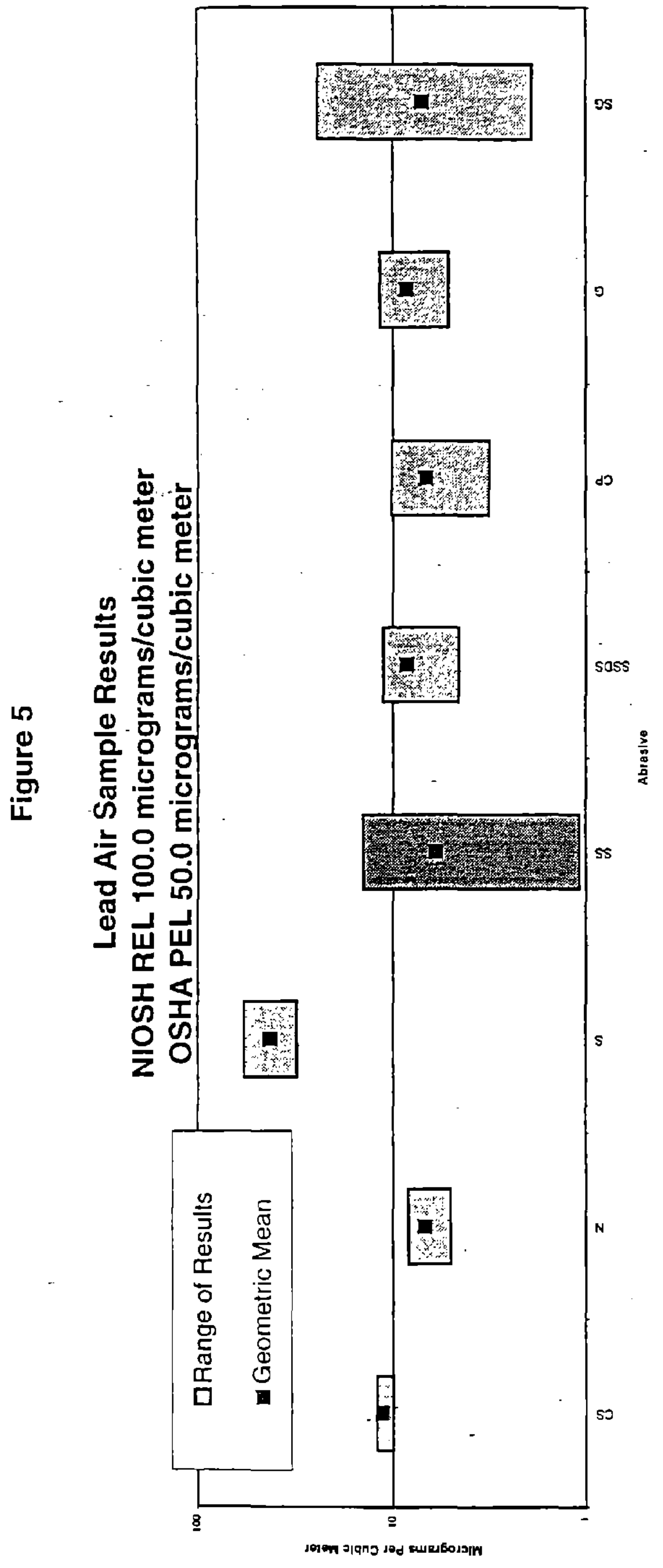


Fig_5.xls

FIGURE 6 – MANGANESE AIR SAMPLE RESULTS

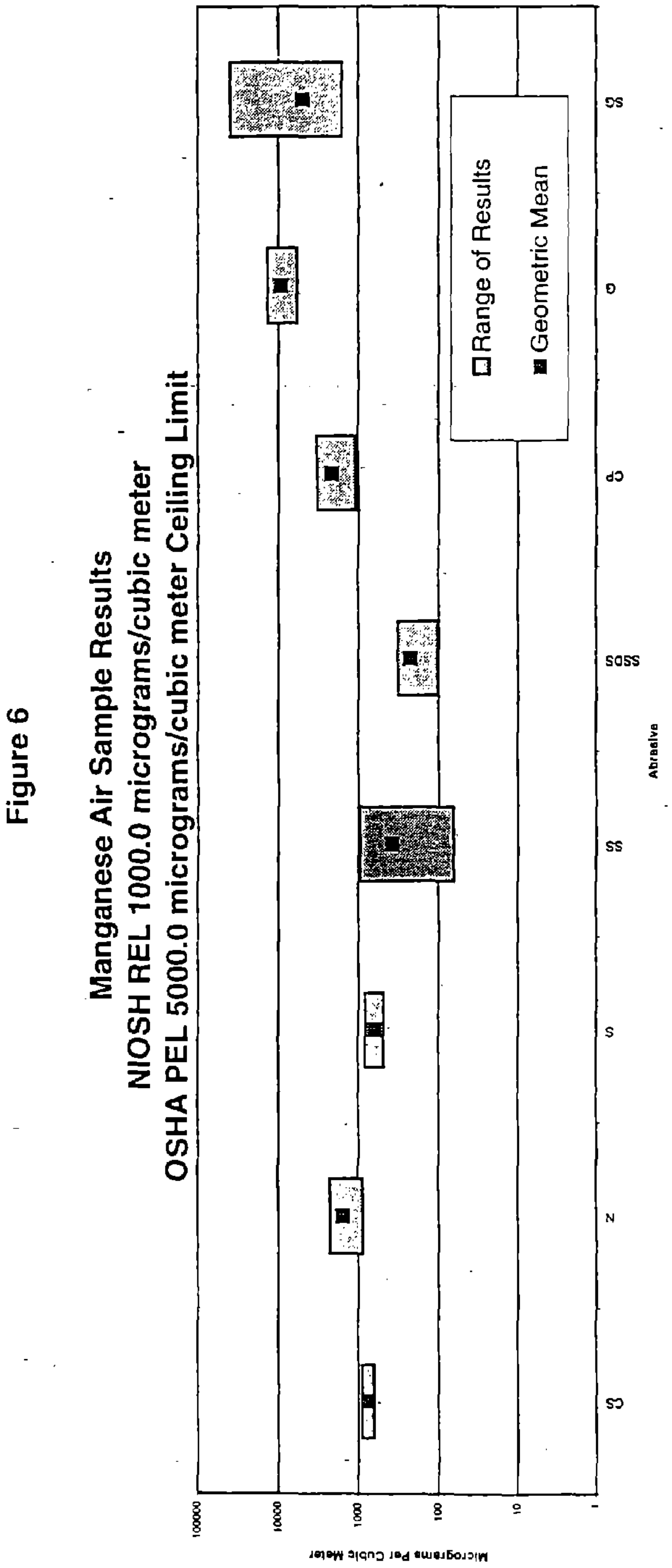


Fig_6.xls

FIGURE 7 – NICKEL AIR SAMPLE RESULTS

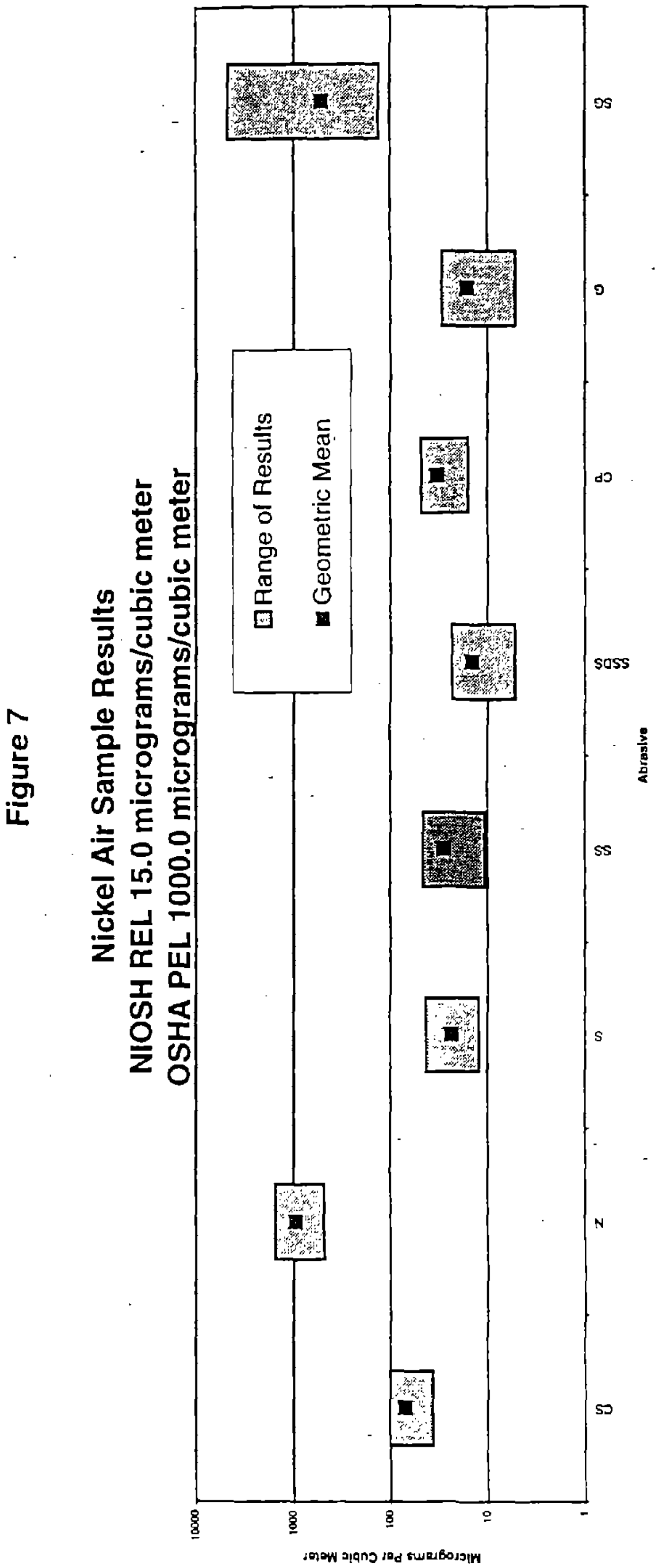


FIGURE 8 – QUARTZ AIR SAMPLE RESULTS

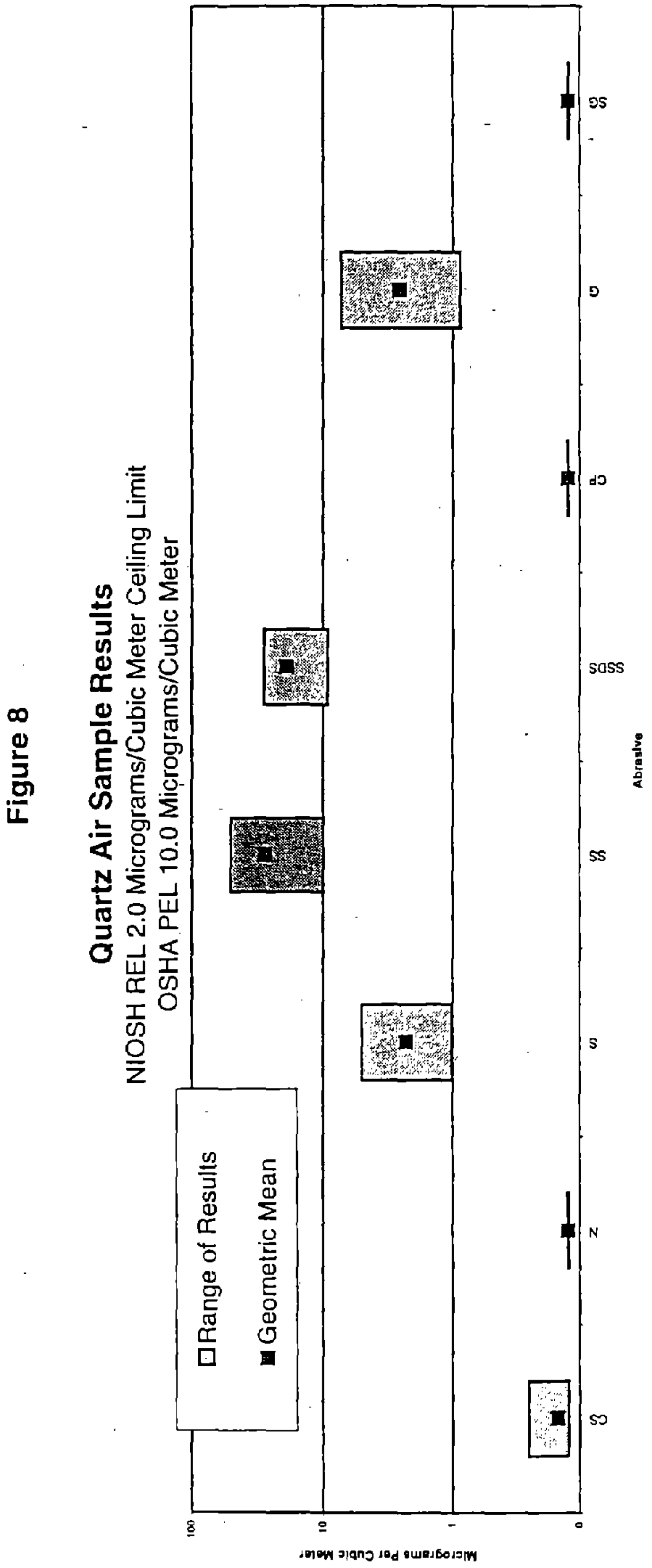


FIGURE 9 – TITANIUM AIR SAMPLE RESULTS

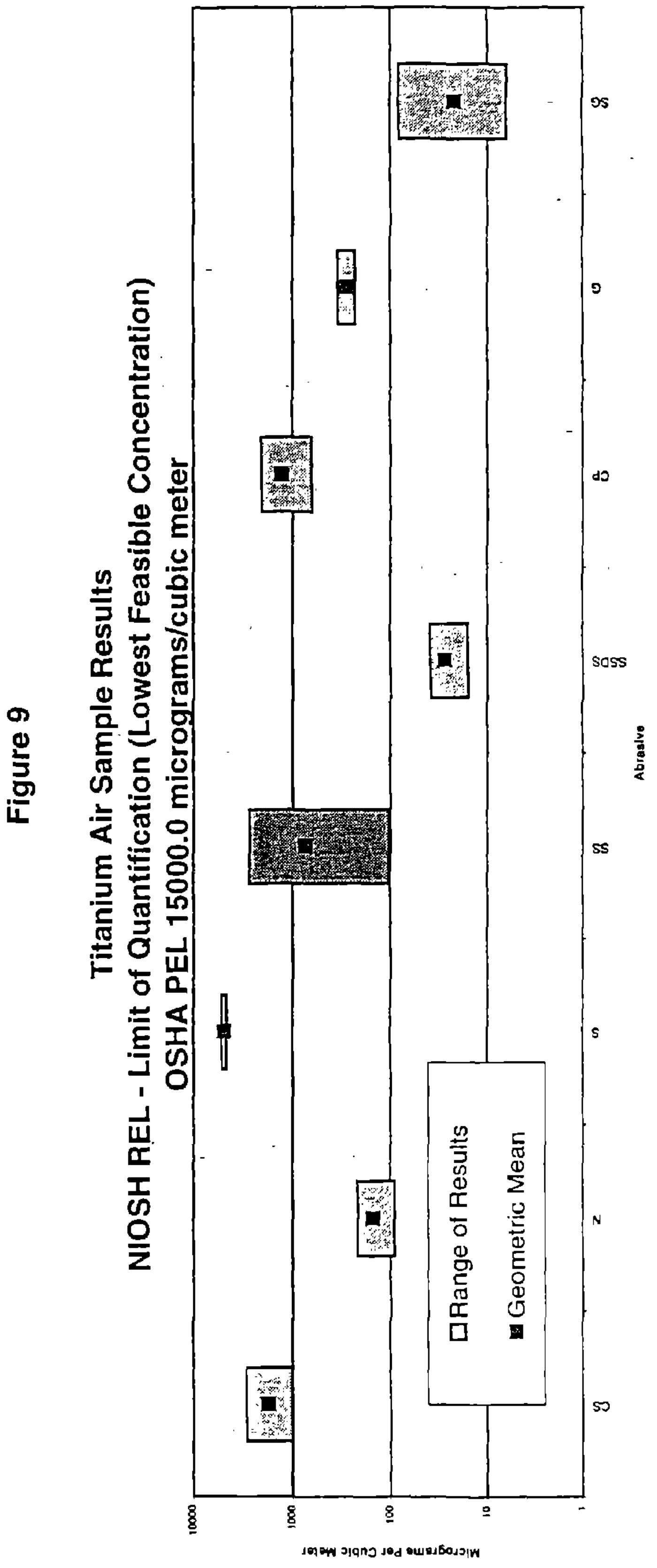


Fig_9.xls

FIGURE 10 – VANADIUM AIR SAMPLE RESULTS

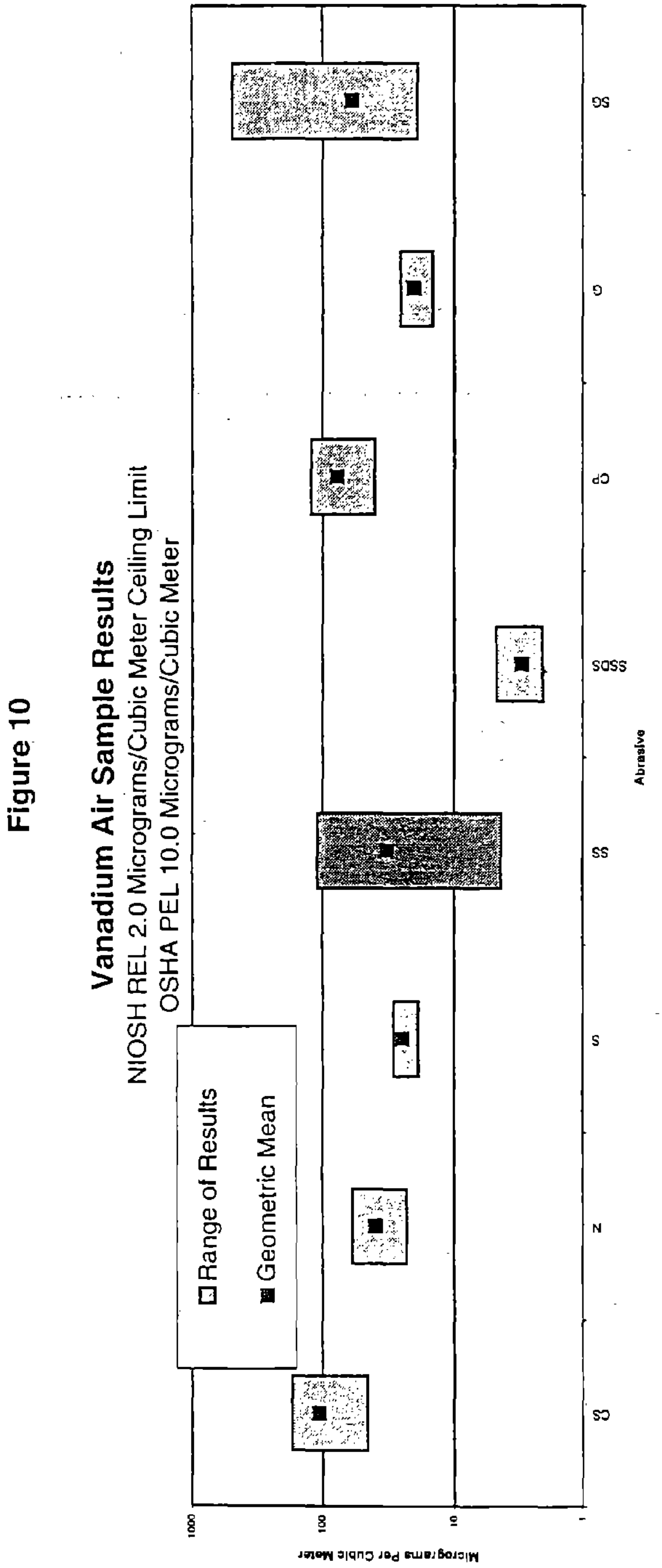


Fig_10.xls

Industrial Hygiene Discussion

Eight generic types of abrasives were evaluated for 28 metals/elements, and respirable quartz and cristobalite, through the analysis of airborne dust and bulk materials. For comparison purposes, NIOSH selected twelve health-related agents for comparative analysis, including: arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, respirable quartz, silver, titanium, vanadium, and radium-226. Table (-), found at the end of this discussion on page (-), summarizes the airborne monitoring results for each of these health-related agents by generic category of abrasive, except radium-226, which is discussed elsewhere. The following is a discussion of key observations concerning this data. It is summarized by generic type of abrasive.

Coal Slag

All four of the airborne samples of coal slag had a measured concentration above the LOD for arsenic. The geometric mean concentration of 8.558 $\mu g/m^3$ for the coal slag generic abrasive category was about 2 times higher than that of silica sand at 4.225 $\mu g/m^3$. Coal slag has the fourth highest geometric mean concentration of arsenic; steel grit, copper slag, and garnet were higher.

All four airborne samples of coal slag had a measured concentration above the LOD for beryllium. The geometric mean concentration of 3.334 $\mu g/m^3$ for the coal slag generic abrasive category was about 4 times higher than that of silica sand at 0.792 $\mu g/m^3$. Coal slag had the highest geometric mean concentration of beryllium

All four of the airborne samples of coal slag had a measured concentration above the LOD for cadmium. The geometric mean concentration of 0.496 $\mu g/m^3$ for the coal slag generic abrasive category was 2.7 times greater than that of silica sand at 0.185 $\mu g/m^3$. Coal slag had the second highest geometric mean concentration of cadmium behind garnet.

All four of the airborne samples of coal slag had a measured concentration above the LOD for chromium. The geometric mean concentration of 111.4 $\mu g/m^3$ for the coal slag generic abrasive category was over 3 times higher than that of silica sand at 36.08 $\mu g/m^3$. Coal slag had the third highest geometric mean concentration of chromium behind nickel slag and steel grit.

All four of airborne samples of coal slag had a measured concentration above the LOD for lead. The geometric mean concentration of 11.33 $\mu g/m^3$ for the coal slag generic abrasive category is 1.9 times higher than that of silica sand at 6.05 $\mu g/m^3$. Coal slag had the second highest geometric mean concentration of lead behind staurolite.

All four airborne samples of coal slag had a measured concentration above the LOD for manganese. The geometric mean concentration of 746.8 $\mu g/m^3$ for the coal slag generic abrasive category was nearly 2 times higher than that of silica sand at 383.6 $\mu g/m^3$. Garnet, steel grit, copper slag, and nickel slag had higher geometric mean concentrations while staurolite, silica sand, and silica sand with dust suppressant were lower.

All four of the airborne samples of coal slag had a measured concentration above the LOD for nickel. The geometric mean concentration of 70.6 µg/m^3 for the coal slag generic abrasive category was nearly 2.5 times higher than that of silica sand at 28.3 µg/m^3. Coal slag had the third highest geometric mean concentration of nickel; steel grit and nickel slag were higher.

One out of four coal slag airborne samples was above the LOD for respirable quartz. Coal slag's geometric mean concentration 0.148 mg/m^3 was less than 1% of silica sand at 27.96 mg/m^3. Coal slag had the lowest geometric mean concentration of respirable quartz for the generic abrasives with results above the LOD.

All four airborne samples of coal slag had a measured concentration above the LOD for titanium. Coal slag's geometric mean concentration of 1,786 µg/m^3 was about 2.4 times higher than that of silica sand at 749.6 µg/m^3. Coal slag had the second highest geometric mean concentration of titanium behind staurolite.

All four airborne samples of coal slag had a measured concentration above the LOD for vanadium. Coal slag's geometric mean concentration of 106.3 µg/m^3 was about 3 times higher than that of silica sand at 32.62 µg/m^3. Coal slag had the highest geometric mean concentration of vanadium.

Silver was not detected above the LOD for the coal slag generic abrasive category Based on the industrial hygiene results in the field study, substituting coal slag for silica sand in abrasive blasting should reduce airborne respirable quartz concentrations. However, the coal slag generic abrasive category is not without potential hazardous health-related agent concerns.

Coal slag, as a generic category of abrasives, has the highest geometric mean concentration of beryllium and vanadium, and the second highest geometric mean for cadmium, lead, and titanium. All of the airborne data from the field study must be viewed as indicative only of relative potential for the presence of health-related agents, since the field conditions were not necessarily representative of actual work site conditions. In addition, variability between individual abrasives within a generic category must also be considered prior to drawing any broad health-based conclusions.

Nickel Slag

All four of the airborne samples of nickel slag had a measured concentration above the LOD for arsenic. The geometric mean concentration of 4.306 µg/m^3 was slightly higher than that of silica sand at 4.225 µg/m^3. The geometric mean concentration of nickel slag was the third lowest; silica sand and staurolite were lower.

All four airborne samples of nickel slag had measured concentrations of beryllium above the LOD. The geometric mean concentration of 0.150 µg/m^3 was less than 20% of silica sand at 0.792 μg/m^3. Nickel slag had the third lowest geometric mean concentration of beryllium; silica sand with dust suppressant and steel grit were lower.

All four airborne samples of nickel slag had measured concentrations above the LOD for cadmium. The geometric mean concentration of 0.344 μg/m^3 is about 1.8 times higher than silica sand at 0.185 μg/m^3. Garnet, coal slag, copper slag, and steel grit had higher geometric mean concentrations of cadmium while staurolite, silica sand with dust suppressant, and silica sand were lower.

All four airborne samples of nickel slag had measured concentrations above the LOD for chromium. The geometric mean concentration of 3,513 is about 97 times higher than that of silica sand at 36.08 μg/m^3. Nickel slag had the highest geometric mean concentration of chromium.

All four airborne samples of nickel slag had measured concentrations of lead above the LOD for lead. The geometric mean concentration of 6.880 μg/m^3 was slightly higher than silica sand at 6.052 μg/m^3. Nickel slag had the third lowest geometric mean concentration of lead; copper slag and silica sand was lower.

All four airborne samples of nickel slag had measured concentrations above the LOD for manganese. The geometric mean concentration of 1,575 μg/m^3 was about 4 times higher than silica sand at 383.6 μg/m^3. Nickel slag had the fourth highest geometric mean concentration for manganese; garnet, steel grit, and copper slag were higher.

All four of the airborne samples of nickel slag had measured concentrations above the LOD for nickel. The geometric mean concentration of 948.4 μg/m^3 was nearly 34 times higher than silica sand at 28.33 μg/m^3. Nickel slag had the highest geometric mean concentration of nickel.

All four airborne samples of nickel slag had a measured concentration above the LOD for titanium. The geometric mean concentration of 150.8 μg/m^3 was about 20% of silica sand at 749.6 μg/m^3. Nickel slag had the third lowest geometric mean concentration of titanium; silica sand with dust suppressant and steel grit were lower.

All four airborne samples of nickel slag had measured concentrations above the LOD for vanadium. The geometric mean concentration of 39.56 μg/m^3 was slightly higher (1.2 times) than silica sand at 32.62 μg/m^3. Nickel slag had the fourth highest geometric mean concentration of vanadium; coal slag, steel grit, and copper slag were higher.

Respirable quartz and silver were not detected above the LOD in any of the nickel slag airborne samples. Based on the industrial hygiene results in the field study, substituting nickel slag for silica sand in abrasive blasting should reduce airborne respirable quartz concentrations. However, the nickel slag generic abrasive category is not without potential hazardous health-related agent concerns.

Nickel slag as a generic category of abrasives had the highest geometric mean concentration of chromium and nickel. All of the airborne data from the field must be viewed as indicative only of relative potential for the presence of health-related agents, since the field conditions were not necessarily representative of actual work site conditions. In addition, variability between individual abrasives within a generic category must also be considered prior to drawing any broad health-based conclusions.

Staurolite

Two out of four of the airborne samples of staurolite had a measured concentration above the LOD for arsenic. The geometric mean concentration of 1.229 $\mu g/m^3$ was approximately 30% that of silica sand at 4.225 $\mu g/m^3$. Staurolite had the lowest geometric mean concentration of arsenic.

All four of the airborne samples of staurolite had a measured concentration above the LOD for beryllium. The geometric mean concentration of 0.577 $\mu g/m^3$ was approximately 73% that of silica sand at 0.792 $\mu g/m^3$. Staurolite had the fourth highest geometric mean concentration of beryllium; coal slag, silica sand, and copper slag were higher.

All four airborne samples of staurolite had a measured concentration above the LOD for cadmium. The geometric mean concentration of 0.248 $\mu g/m^3$ was slightly higher (approximately 1.3 times) than silica sand at 0.185 $\mu g/m^3$. Staurolite had the third lowest geometric mean concentration of cadmium; silica sand and silica sand with dust suppressant were lower.

All four airborne samples of staurolite had a measured concentration above the LOD for chromium. The geometric mean concentration of 74.08 $\mu g/m^3$ was about 2 times higher than of silica sand at 36.08 $\mu g/m^3$. Staurolite was the fifth highest geometric mean for chromium; nickel slag, steel grit, coal slag, and garnet were higher.

All four of the airborne results of staurolite had measured concentrations above the LOD for lead. The geometric mean concentration of 42.82 $\mu g/m^3$ was 7 times higher than silica sand at 6.05 $\mu g/m^3$. Staurolite had the highest geometric mean concentration of lead.

All four of the airborne sample results for staurolite had measured concentrations above the LOD for manganese. The geometric mean concentration of 638.7 $\mu g/m^3$ was about 1.7 times higher than silica sand at 383.6 $\mu g/m^3$. Staurolite had the third lowest geometric mean concentration for manganese; silica sand and silica sand with dust suppressant were lower.

All four of the airborne sample results for staurolite had measured concentrations above the LOD for nickel. The geometric mean concentration of 23.94 $\mu g/m^3$ was approximately 85% that of silica sand at 28.33 $\mu g/m^3$. Staurolite had the third lowest geometric mean concentration for nickel; garnet and silica sand with dust suppressant were lower.

All four of the airborne samples of staurolite had a measured concentration above the LOD for respirable quartz. The geometric mean concentration of 2.306 mg/m^3 was 8% of that of silica sand at 27.96 mg/m^3. Of the five generic categories of abrasives with detectable concentrations of respirable quartz (silica sand, silica sand with dust suppressant, garnet, staurolite, and coal slag), staurolite had the second lowest geometric mean concentration; coal slag was lower.

All four of the airborne sample results of staurolite had a measured concentration above the LOD for titanium. The geometric mean concentration of 4,892 µg/m^3 was about 6.5 times higher than that of silica sand at 749.6 µg/m^3. Staurolite had the highest geometric mean concentration of titanium.

All four airborne samples of staurolite had measured concentrations above the LOD for vanadium. The geometric mean concentration of 24.88 µg/m^3 was 76% that of silica sand at 32.62 µg/m^3. Staurolite had the third lowest geometric mean concentration of vanadium; garnet and silica sand with dust suppressant were lower.

Silver was not detected above the LOD for the staurolite generic category of abrasives. Staurolite had the highest geometric mean concentration for lead and titanium. Based on the industrial hygiene results in the field study, substituting staurolite for silica sand in abrasive blasting should reduce airborne respirable quartz concentrations. All of the airborne data from the field study must be viewed as indicative only of relative potential for the presence of health-related agents, since the field conditions were not necessarily representative of actual work site conditions. In addition, variability between individual abrasives within a generic category must also be considered prior to drawing any broad health-based conclusions.

Silica Sand

Three out of four airborne samples of silica sand had measured concentrations above the LOD for arsenic. The geometric mean concentration was 4.225 µg/m^3. Silica sand had the second lowest geometric mean concentration of arsenic for the eight generic abrasive categories. Only staurolite was lower.

Three out of four airborne samples of silica sand had measured concentrations above the LOD for beryllium. The geometric mean concentration was 0.792 µg/m^3. This placed silica sand second highest of the eight generic abrasive categories, with coal slag abrasives having a higher geometric mean concentration.

All four of the airborne results of silica sand had measured concentrations above the LOD for cadmium. The geometric mean concentration was 0.185 µg/m^3. Silica sand had the lowest geometric mean concentration of cadmium within the eight generic abrasives.

Three out of four airborne samples of silica sand had measured concentrations above the LOD for chromium. The geometric mean concentration was 36.082 μg/m^3. This places silica sand second lowest among the eight generic abrasives. Silica sand with dust suppressant had a lower geometric mean concentration.

Three out of four airborne samples of silica sand had measured concentrations above the LOD for lead. The geometric mean concentration was 6.052 μg/m^3. Silica sand had the lowest geometric mean concentration out of the eight generic abrasives.

All four airborne samples of silica sand had measured concentrations above the LOD for manganese. The geometric mean concentration was 383.573 μg/m^3. This was the second lowest geometric mean concentration for manganese out of the eight generic abrasives. The lowest geometric concentration was silica sand with dust suppressant.

All four airborne sample results had a measured concentration above the LOD for nickel. The geometric mean concentration was 28.326 μg/m^3. This placed silica sand fifth out of eight generic abrasives. Staurolite, garnet, and silica sand with dust suppressant had lower geometric mean concentrations of nickel.

All four airborne samples of silica sand had measured concentrations above the LOD for respirable quartz. The geometric mean concentration was 27.959 mg/m^3. Silica sand had the highest geometric mean concentration of respirable quartz of all the generic categories of abrasives.

All four airborne samples of silica sand had measured concentrations above the LOD for titanium. The geometric mean concentration was 749.579 μg/m^3. This placed silica sand fourth out of eight generic abrasives. Garnet, nickel slag, steel grit, and silica sand with dust suppressant had lower geometric mean concentrations of titanium.

All four airborne samples had a measured concentration above the LOD for vanadium. The geometric mean concentration for silica sand was 32.622 μg/m^3. This placed silica sand fifth out of eight generic abrasives. Staurolite, garnet, and silica sand with dust suppressant had lower geometric mean concentrations of vanadium.

There were no detectable concentrations of silver within the silica sand generic abrasive category.

Silica Sand with Dust Suppressant

All four airborne results of silica sand with dust suppressant had measured concentrations above the LOD for arsenic. The geometric mean concentration of 6.190 μg/m^3 was about 1.5 times that of silica sand at 4.225 μg/m^3. Silica sand with dust suppressant had the fifth highest geometric mean concentration of arsenic; steel grit, copper slag, garnet, and coal slag were higher.

Three out of the four airborne results of silica sand with dust suppressant had measured concentrations above the LOD for beryllium. The geometric mean concentration of 0.094 μg/m^3 was about 12 % that of silica sand at 0.792 μg/m^3. Silica sand with dust suppressant had the second lowest geometric mean concentration of beryllium. The lowest geometric mean concentration (0.041 μg/m^3) was that of steel grit.

All four airborne samples of silica sand with dust suppressant had a measured concentration above the LOD for cadmium. The geometric mean concentration of 0.216 μg/m^3 was similar to silica sand (1.2 times higher) at 0.185 μg/m^3. Silica sand with dust suppressant had the second lowest geometric mean concentration of cadmium; silica sand was lower.

All four airborne samples of silica sand with dust suppressant had measured concentrations above the LOD for chromium. The geometric mean concentration of 33.52 μg/m^3 was approximately 93% that of silica sand at 36.08 μg/m^3. Silica sand with dust suppressant had the lowest geometric mean concentration for chromium.

All four airborne samples of silica sand with dust suppressant had measured concentrations above the LOD for lead. The geometric mean concentration of 8.563 μg/m^3 was slightly higher (1.4 times) than silica sand at 6.052 μg/m^3. Silica sand with dust suppressant had the third highest geometric mean concentration of lead; coal slag and staurolite were higher.

All four airborne sample results for silica sand with dust suppressant had measured concentrations above the limit of detection for manganese. The geometric mean concentration of 226.6 μg/m^3 was approximately 60% that of silica sand at 383.6 μg/m^3. Silica sand with dust suppressant was the lowest geometric mean concentration of manganese.

Three out of four airborne sample results for silica sand with dust suppressant had measured concentrations above the limit of detection for nickel. The geometric mean concentration of 14.58 μg/m^3 was approximately 50% that of silica sand at 28.33 μg/m^3. Silica sand with dust suppressant was the lowest geometric mean concentration of nickel.

All four airborne samples of silica sand with dust suppressant had measured concentrations above the LOD for respirable quartz. The geometric mean of 19.04 mg/m^3 was approximately 68% that of silica sand at 27.96 mg/m^3. The silica sand with dust suppressant abrasive category had the second highest geometric mean concentration of respirable quartz of all eight generic abrasive types; silica sand was higher.

Only one of 4 airborne samples of silica sand with dust suppressant had measured concentration above the LOD for silver. The geometric mean of silica sand with dust suppressant was1.045 μg/m^3, which is approximately 1.2 times that of silica sand at 0.861 mg/m^3. Silica sand with dust suppressant was the only abrasive with a sample result above the limit of detection for silver.

All four airborne samples of silica sand with dust suppressant had measured concentrations above the LOD for titanium. The geometric mean concentration of 27.789

µg/m^3 was about 4% of silica sand at 749.58 µg/m^3. Silica sand with dust suppressant had the second lowest geometric mean concentration of titanium; steel grit was lower.

All four airborne samples of silica sand with dust suppressant had measurable concentrations above the LOD for vanadium. The geometric mean concentration of 3.010 µg/m^3 was about 9% that of silica sand at 32.62 µg/m^3. Silica sand with dust suppressant had the lowest geometric mean concentration of the eight generic abrasives.

Copper Slag

All four airborne samples of copper slag had a measured concentration above the LOD for arsenic. The geometric mean concentration of 21.82 µg/m^3 for the copper slag generic abrasive category was more than 5 times higher than that of silica sand at 4.225 µg/m^3. Copper slag had the second highest geometric mean concentration of arsenic. Only steel grit with a geometric mean concentration of 22.65 µg/m^3 was higher.

All four airborne samples of copper slag had a measured concentration above the LOD for beryllium. The geometric mean concentration of 0.766 µg/m^3 for the copper slag generic abrasive category was 97% that of silica sand at 0.792 µg/m^3. Copper slag had the third highest geometric mean concentration of beryllium; only coal slag and silica sand were higher.

All four airborne samples of copper slag had a measured concentration above the LOD for cadmium. The geometric mean concentration of 0.448 µg/m^3 for the copper slag generic abrasive category was about 2.4 times higher than that of silica sand at 0.185 µg/m^3. Copper slag had the third highest geometric mean concentration of cadmium; coal slag, and garnet were higher.

All four airborne samples of copper slag had a measured concentration above the LOD for chromium. The geometric mean concentration of 73.7 µg/m^3 for the copper slag generic abrasive category was about 2 times higher than that of silica sand at 36.08 µg/m^3. Copper slag had the third lowest geometric mean concentration of chromium; silica sand and silica sand with dust suppressant were lower.

All four airborne samples of copper slag had a measured concentration above the LOD for lead. The geometric mean concentration of 6.785 µg/m^3 for the copper slag generic abrasive category was slightly higher than that of silica sand at 6.052 µg/m^3. The copper slag generic abrasive category had the second lowest geometric concentration of lead; only silica sand was lower.

All four airborne samples of copper slag had a measured concentration above the LOD for manganese. The geometric mean concentration of 2,181 µg/m^3 for the copper slag generic abrasive category was about 5.7 times higher than that of sand at 383.6 µg/m^3. Copper slag had the third highest geometric mean concentration of manganese; garnet and steel grit were higher.

All four airborne samples of copper slag had a measured concentration above the LOD for nickel. The geometric mean concentration of 33.39 µg/m^3 for the copper slag generic abrasive category was slightly higher than that of silica sand at 28.33 µg/m^3. Copper slag has the fourth highest geometric mean concentration of nickel; coal slag, steel grit, and nickel slag were higher.

All four airborne samples of copper slag had a measured concentration above the LOD for titanium. Copper slag's geometric mean concentration of 1,289 µg/m^3 was about 1.7 times higher than that of silica sand at 749.6 µg/m^3. Copper slag had the third highest geometric mean concentration of titanium; coal slag and staurolite were higher.

All four airborne samples of copper slag had a measured concentration above the LOD for vanadium. Copper slag's geometric mean concentration of 77.157 µg/m^3 was about 2.4 times higher than that of silica sand at 32.62 µg/m^3. Copper slag had the second highest geometric mean concentration of vanadium; coal slag was higher.

Respirable quartz and silver were not detected above the LOD for the copper slag generic abrasive category. Based on the industrial hygiene results in the field study, substituting copper slag for silica sand in abrasive blasting should reduce airborne respirable quartz concentrations. However, the copper slag generic abrasive category is not without potentially hazardous health-related agent concerns.

Out of the eight generic abrasive categories, copper slag has the second highest geometric mean airborne concentration of arsenic and vanadium. All of the airborne data from the field study must be viewed as indicative only of relative potential for the presence of health-related agents, since the field conditions were not necessarily representative of actual work site conditions. In addition, variability between individual abrasives within a generic category must also be considered prior to drawing any broad health-based conclusions.

Garnet

All four airborne samples of garnet had a measured concentration above the LOD for arsenic. The geometric mean concentration of 9.292 µg/m^3 was about 2.2 times that of silica sand at 4.225 µg/m^3. Garnet had the third highest geometric mean concentration of arsenic of all the generic abrasives; copper and steel grit were higher.

All four airborne samples had measured concentrations above the LOD for beryllium. The geometric mean concentrations of 0.505 µg/m^3 was slightly less than 63% that of silica sand at 0.792 µg/m^3. Garnet had the fifth highest geometric mean concentration of beryllium; staurolite, copper slag, silica sand, and coal slag were higher.

All four airborne samples of garnet had measured concentration above the LOD for cadmium. The geometric mean concentration of 1.105 µg/m^3 was nearly 6 times higher than silica sand at 0.185 µg/m^3. Garnet had the highest geometric mean concentration of cadmium.

All four airborne samples of garnet had measured concentrations above the LOD for chromium. The geometric mean concentration of 94.37 μg/m^3 was approximately 2.6 times higher than silica sand at 36.08 μg/m^3. Garnet had the fourth highest geometric mean concentration of chromium; nickel slag, steel grit, and coal slag were higher.

All four airborne samples of garnet had measured concentrations above the LOD for lead. The geometric mean concentration of 8.558 μg/m^3 was slightly higher (1.4 times) than silica sand at 6.052 μg/m^3. Garnet had the fourth highest geometric mean concentration of lead; staurolite, coal slag, and silica sand with dust suppressant were higher.

All four airborne samples of garnet had measured concentrations above the LOD for manganese. The geometric mean of 9,486 μg/m^3 was approximately 25 times higher than silica sand at 383.6 μg/m^3. Garnet had the highest geometric mean concentration of manganese.

Three out of four airborne samples of garnet had a measured concentration above the LOD for nickel. The geometric mean concentration of 16.38 μg/m^3 was about 60% that of silica at 28.33 μg/m^3. Garnet had the second lowest geometric mean concentration of nickel; only silica sand with dust suppressant was lower.

All four airborne samples of garnet had measured concentrations above the LOD for respirable quartz. The geometric mean concentration of 2.6 mg/m^3 was about approximately 9% that of silica sand at 27.96 mg/m^3. Of the eight generic abrasives, garnet had the third highest measured geometric mean concentration; silica sand and silica sand with dust suppressant were higher.

All four airborne samples of garnet had measured concentrations above the LOD for titanium. The geometric mean concentration of 284.3 μg/m^3 was less than 40% that of silica sand at 749.6 μg/m^3. Staurolite, coal slag, copper slag, and silica sand had higher geometric mean concentrations while nickel slag, steel grit, and silica sand with dust suppressant were lower.

All four airborne samples of garnet had measured concentrations above the LOD for vanadium. The geometric mean of 20.37 μg/m^3 was approximately 63% that of silica sand at 32.62 μg/m^3. Of the eight generic abrasives, garnet had the second lowest measured concentration; silica sand with dust suppressant was lower.

None of the airborne samples had measured concentrations above the LOD for silver. Based on the industrial hygiene results in the laboratory study, substituting garnet in abrasive blasting should reduce airborne respirable quartz concentrations. However, the garnet generic abrasive category is not without potential hazardous health-related agent concerns.

Garnet had the highest geometric mean concentration of cadmium and manganese. All of the airborne data from the laboratory must be viewed as indicative only of the relative potential for the presence of health-related agents, since the field conditions were not necessarily representative of actual work site conditions. In addition, variability between individual abrasives within a generic category must also be considered prior to drawing any broad health-based conclusions.

Steel Grit

All four airborne samples of steel grit had measured concentrations above the LOD for arsenic. The geometric mean concentration of 22.65 μg/m^3 was over 5 times higher than silica sand at 4.225 μg/m^3. Steel grit had the highest geometric mean concentration of arsenic.

All four airborne samples of steel grit had measured concentrations above the LOD for cadmium. The geometric mean concentration of 0.426 μg/m^3 was 2.3 times higher than silica sand at 0.185 μg/m^3. Steel grit had the fourth highest geometric mean concentration of cadmium; garnet, coal slag, and copper slag were higher.

All four airborne samples of steel grit had measured concentrations above the LOD for chromium. The geometric mean concentration of 1,025 μg/m^3 was approximately 28 times that of silica sand at 36.08 μg/m^3. Steel grit had the second highest geometric mean concentrations of chromium, while nickel slag was higher.

All four airborne samples of steel grit had measured concentrations above the LOD for lead. The geometric mean concentration of 7.137 μg/m^3 was slightly higher than silica sand at 6.052 μg/m^3. Steel grit had the fourth lowest geometric mean concentration of lead; nickel slag, copper slag and silica sand were lower.

All four airborne samples of steel grit had measured concentrations above the LOD for manganese. The geometric mean concentration of 4,942 μg/m^3 was approximately 13 times higher than silica sand at 383.6 μg/m^3. Steel grit has the second highest geometric mean concentration of manganese; garnet was higher.

All four airborne samples of steel grit had measured concentrations above the LOD for nickel. The geometric mean concentration of 523.6 μg/m^3 was approximately 18.5 times higher than silica sand at 28.3 μg/m^3. Steel grit had the second highest geometric mean concentration of nickel; nickel slag was higher.

All four airborne samples of steel grit had measured concentrations above the LOD for titanium. The geometric mean concentration of 21.7 μg/m^3 was approximately 3% that of silica sand at 749.6 μg/m^3. Steel grit had the lowest geometric mean concentration of titanium.

All four airborne samples of steel grit had a measured concentration above the LOD for vanadium. The geometric mean concentration of 59.16 μg/m^3 was approximately 1.8 times higher than silica sand at 32.62 μg/m^3. Steel grit had the third highest geometric mean concentration of vanadium; coal slag and copper slag were higher.

All of steel grit's airborne samples were less than the LOD for beryllium, respirable quartz, and silver. Based upon the industrial hygiene results in the field study, substituting steel grit for silica sand in abrasive blasting should reduce airborne respirable quartz concentrations. However, the steel grit generic abrasive category is not without potential health-related agent concerns.

Steel grit as a generic category of abrasives had the highest geometric mean concentration of arsenic, and the second highest geometric mean concentrations of chromium, manganese, and nickel. All of the airborne data from the field must be viewed as indicative only of the relative potential for the presence of health-related agents, since the field conditions were not necessarily representative of actual work site conditions. In addition, variability between individual abrasives within a generic category must also be considered prior to drawing any broad health-based conclusions.

Table 1

Summary Table: Airborne Sample Results of Health Related Elements by Generic Catagory of Abrasive

Note: Unless otherwise noted, all Minimum, Maximum, and Geometric Mean Values are in micrograms per cubic meter

Generic Abrasive	Number of Samples	Arsenic	Beryllium	Cadmium	Chromium	Lead	Manganese	Nickel	Respirable Quartz (mg/m^3)	Silver	Titanium	Vanadium
CS	4	7.182 - 10.54 8.588 4	0.86 - 5.87 3.334 4	0.275 - 1.032 0.496 4	62.37 - 162.4 111.369 4	9.93 - 12.04 11.332 4	633.7 - 903.2 746.851 4	36.6 - 101.5 70.559 4	0.12 - 0.25 0.148 1	0.84 - 0.9 0.861 0	1011 - 2933 1786.259 4	45.16 - 171.5 106.305 4
N	4	2.099 - 6.114 4.306 4	0.08 - 0.23 0.150 4	0.231 - 0.569 0.344 4	1931 - 5435 3513.072 4	5.04 - 8.38 6.880 4	881.6 - 2264 1575.632 4	483 - 1540 948.446 4	0.12 - 0.125 0.123 0	0.74 - 0.905 0.842 0	90.26 - 217.4 150.787 4	23.09 - 58.88 39.562 4
S	4	0.615 - 1.446 1.229 2	0.33 - 0.8 0.577 4	0.205 - 0.307 0.248 4	54.26 - 98.18 74.084 4	31.3 - 57.86 42.818 4	480 - 818.2 638.728 4	12.3 - 42.96 23.944 4	1.01 - 5.03 2.306 4	0.82 - 0.835 0.825 0	4591 - 5166 4891.980 4	18.78 - 28.93 24.884 4
SS	4	0.645 - 11.28 4.225 3	0.108 - 4.83 0.792 3	0.065 - 0.316 0.185 4	5.375 - 94.53 36.082 3	1.075 - 14.21 6.052 3	64.52 - 947.5 383.573 4	10.8 - 46.21 28.326 4	9.91 - 50.52 27.959 4	0.84 - 0.9 0.861 0	103.2 - 2731 749.579 4	4.3 - 109.2 32.622 4
SSDS	4	4.196 - 7.937 6.190 4	0.042 - 0.14 0.094 3	0.105 - 0.511 0.216 4	14.69 - 46.81 33.523 4	4.62 - 11.24 8.563 4	102.8 - 325.6 226.562 4	5.25 - 23.55 14.580 3	9.18 - 28.2 19.104 4	0.82 - 2.04 1.045 1	15.74 - 38.82 27.788 4	2.04 - 4.71 3.010 4
CP	4	10.92 - 33.13 21.817 4	0.38 - 1.24 0.766 4	0.119 - 3.73 0.448 4	39.7 - 101.5 73.668 4	3.18 - 10.14 6.785 4	1092 - 3313 2181.686 4	15.9 - 47.62 33.394 4	0.12 - 0.124 0.123 0	0.8 - 0.835 0.824 0	635.2 - 2070 1289.302 4	39.7 - 122.2 77.157 4
G	4	5.605 - 11.89 9.292 4	0.39 - 0.64 0.505 4	0.685 - 1.507 1.105 4	56.05 - 131.6 94.373 4	5.19 - 11.67 8.558 4	5813 - 13585 9486.913 4	5.19 - 29.72 16.376 3	0.87 - 7.28 2.600 4	0.82 - 0.85 0.835 0	228.4 - 339.6 284.261 4	14.53 - 25.47 20.372 4
SG	4	6.834 - 185.8 22.654 4	0.041 - 0.042 0.041 0	0.084 - 12.25 0.426 4	310.6 - 8576 1025.304 4	1.92 - 24.5 7.137 4	1595 - 38798 4942.877 4	130 - 4697 523.563 4	0.12 - 0.123 0.123 0	0.82 - 0.835 0.827 0	6.26 - 81.68 21.701 4	19.05 - 490.1 59.158 4

<--- **Range Min. - Max. Values**

<--- Geometric Mean

<--- Samples > Limit of Detection

Treated Versus Untreated Abrasives

Table 2 presents a comparison of the geometric mean concentrations for each of the 11 health-related agents for silica sand abrasive treated with dust suppressant and an untreated silica sand abrasive. While the data is presented as a paired set, the abrasives are not from the same supplier. Therefore, any variability noted may be due more to the variation between silica sand abrasives than the effect of the dust suppressant. Nonetheless, a review of the data shows that the geometric mean concentration for four of the health-related agents (arsenic, cadmium, lead and silver) increased for the silica sand with dust suppressant abrasive, while it decreased for the remaining seven health-related agents.

TABLE 2

Comparison of Geometric Mean Concentrations of Health-Related Agents for Untreated and Dust Suppressant Treated Abrasives

Note: Unless noted, all concentrations in micrograms per gram

Pair Abrasive	Arsenic	Beryllium	Cadmium	Chromium	Lead	Manganese	Nickel	Respirable Quartz (mg/m^3)	Silver	Titanium	Vanadium
SS	4.23	0.79	0.18	36.1	6.05	383.6	28.3	28.0	0.86	749.6	32.6
SSDS	6.19	0.09	0.22	33.5	8.56	226.6	14.6	19.1	1.04	27.8	3.0

Bulk Sample Discussion

Figures 11 to 21 on pages 77 to 87 and Table 3 on page 88 show the concentrations for the virgin bulk levels of eleven hazardous health-related agents for each of the 8 abrasive products tested. These are the same hazardous health-related agents that were used for comparative analysis of the airborne concentrations. The concentrations are indicated by a small square.

For abrasive having results below the limit of detection for the given health-related agent, the concentration was calculated by using LOD/2, which is the method used to estimate the average concentration in the presence of non-detectable values described by Hornung and Reed.[H&R20]

Figures 11 to 21 and Table 3 provide some indication of the source of the airborne concentrations described previously in the industrial hygiene results and discussion sections. The metal content in the steel surface, which was blasted, is unknown.

Radiation

Eight different abrasive blasting materials were analyzed for content of radioactive materials using two independent methods, direct gamma measurements for virgin (unused) and spent (used) bulk samples and radiochemical separation of radium with alpha spectrometry measurements for airborne samples. Gamma spectrometry involves lacing a sample of the material on a high resolution germanium detector installed in a low background shield to detect the presence of photons from gamma-emitting radionuclides in the sample. The specific radiochemical separation of radium involves a rigorous chemical dissolution of a small amount of sample, usually less than 1 gm, followed by precipitation and filtration to isolate radium from the solution for alpha counting.

The abrasive blasting materials were collected during a field study conducted outdoors on a barge using a portable containment structure. The bulk samples of abrasive blasting included material obtained from the bag before blasting (unused) and material that was collected from the floor of the portable containment structure after blasting. Although the physical particle size distribution of the abrasive blasting material will likely change after it is used, there is no evidence that blasting should effect the inherent radioactive content of the abrasive unless the surface being blasted is, itself, contaminated.

Because of the prevalence of radioactive contamination in reclaimed materials, it is prudent to survey blasting slags for radioactive contamination. Gamma spectrometry is the traditional method that is used to survey bulk materials for photon emitting radioactive contaminants such as 137Cs and 60Co. These contaminants are easy to detect, even in samples of very small mass, because the photons emitted from the contaminants have a very high yield. The photon yield from naturally occurring radioactive materials is substantially lower making it necessary to analyze samples having greater mass.

The naturally occurring radioactive materials expected to be found in the blasting abrasives include 238U and its decay products, 232Th and its decay products, and 40K. Each of these long-lived radionuclides is found in varying concentrations in all natural matrix materials since they are ubiquitous throughout the earth. It is common practice to evaluate natural matrix samples for radioactivity content using gamma spectrometry since 238U and 232Th and 40K have gamma-emitting radioactive decay products that can easily be detected if the sample size is sufficiently large. Unfortunately, 238U and 232Th are, themselves, not gamma emitters so analysis by gamma spectrometry can be misleading if the measurement procedure is not optimized for detecting low abundant photons from their respective progeny.

Analysis of radium in natural matrix samples is best performed by separating the radium from the sample matrix so that the alpha particles from the decay of 226Ra and 224Ra can be reliably detected. The primary decay mode of radium is by alpha emission, although the decay progeny emit copious quantities of photons. Radium also emits a 185 keV photon with very low abundance (i.e., ~ 4%). Unfortunately, analysis of radium by gamma spectrometry is seriously confounded by photons from 235U that is also present in natural matrix samples. Therefore, the most sensitive and reliable method for analyzing the content of radium in a natural matrix sample is by radiochemical separation and alpha spectrometry. Unfortunately, the radiochemical method limits the sample size to less than 1 g.

The sensitivity of gamma spectrometry and radium alpha spectrometry varies substantially from sample to sample. The laboratory reported values for "detection limits" and measurement uncertainty for most of the sample results. The detection limit and measurement uncertainty for the radiochemical analyses are explicitly determined for each sample using a 133Ba tracer added to each sample before processing. Therefore, the results reported for 226Ra are very reliable. Unfortunately, due to small sample size and background measurement variations, the gamma spectrometry results are inherently very unreliable. The same criteria that were developed for analysis of Phase I Laboratory Study gamma spectrometry results were used to analyze the data associated with the Phase II Field Study. The three criteria for identifying positive results are reproduced below:

(1) The reported result for an isotope in a sample must exceed the range of detection limits reported for that isotope in all samples. Variation in detector background is the greatest uncertainty since the sample size is so small. In most cases, the concentration of naturally occurring radioactive material in a 10 g sample will be significantly less than the amount that can be reliably detected by gamma spectrometry. Therefore, a result for an isotope that is truly greater than background must exceed the range of detection limits reported for all the samples measured in a batch.

(2) The reported result for a sample must exceed three times the reported uncertainty. The uncertainty reported for each isotope in the sample represents only one standard deviation of Poisson counting statistics and does not include variation in background. In order for a sample to be significantly greater than background, the result must exceed the 99% confidence limit defined by the Poisson distribution.

(3) If the reported isotope is a member of a chain, it's parent should also be present, especially if the progeny has a short half-life. This is especially important for the short-lived radon progeny (which are present in the air and will confound the sample measurement) since they must be supported by a longer-lived parent in the sample.

Results

226Ra by Radiochemical Separation and Alpha Spectrometry: Airborne Samples

The NIOSH contract laboratory Standard Operating Procedure (SOP) WN-IN-314 "The Determination of Radium-226 in Solids by Alpha Spectrometry[7]" was implemented for radiochemical analysis of radium and follows the recognized method for conducting these measurements. Although the detection limit was reported for each sample result, the laboratory did not report the measurement uncertainty, so the reliability of the measurement results cannot be evaluated.

The radium content of the total and respirable dusts of staurolite abrasive were greater than the reported detection limit. The quantity of 226Ra detected in the staurolite abrasive is similar to the expected quantity of 226Ra normally found in soil. There is no reason to believe that any of the other respirable or total abrasive dust samples contained radium in excess of the detection limit, even though the radium content for certain samples of respirable or total dusts exceeded the detection limit. This is an indication that there is still considerable uncertainty in these results since there is no reason to believe that the content of radium in the abrasive would be partitioned differently between the respirable and total dust fractions. The laboratory should report the measurement uncertainty for each sample along with the detection limit so that a more reliable evaluation of the results could be developed.

Gamma Spectrometry Analysis Results: Virgin and Used Bulk Samples

Gamma spectrometry measurements have been performed using virgin and used bulk samples of abrasive blasting materials to determine the content of several gamma-emitting isotopes. These measurements were analyzed by following the NIOSH contract laboratory (SOP) WR-EP-325 "Determination of Gamma Emitting Isotopes.[8]" Evaluation of the gamma spectrometry data leads to inconclusive findings because the size of the sample used in each measurement was too small. The small sample size, combined with the low content of naturally occurring radioactive materials in these samples, leads to highly uncertain results.

The raw and spent samples of garnet and copper slags were both significantly positive for 238U, although it is unclear from the laboratory procedure how uranium, which decays by alpha emission, is detected using gamma spectrometry. On the other hand, it is not reasonable to expect that the raw samples of coal slag, which were positive for uranium, would be different in uranium content than the spent coal slag, which was not positive for uranium.

Lead-210 was found in many samples and could be indicative of the presence of radium. Both samples of raw and spent steel grit abrasive were positive for 210Pb. However, the photon energy of 210Pb is very low (47 keV) and its yield is also very low (~4%) which makes detection very difficult unless the detector is specially designed for low energy photons. Because the sample mass was so small, the reliability of the 210Pb results is quite uncertain. This conclusion is further supported by the finding that the

210Pb content of raw and blasted abrasives were inconsistent, since there is no reason to believe that the blasting process would preferentially remove the nuclide. On the other hand, because a considerable volume of compressed air is used in the blasting process, one might conclude that radon and its progeny from the air could be added to the blasted abrasive, although the gamma spectrometry results do not support this finding.

No evidence was present in the data to indicate that any of the samples exhibited elevated concentrations of technologically-enhanced radioactive materials such as 137Cs or 60Co. Unlike the naturally occurring radioactive materials, the photon yield of the technologically-enhanced radioactive contaminants is high and easily detected, even in small 10 g samples.

Discussion

Analysis of naturally occurring radioactive materials in natural matrix samples is confounded by the presence of uranium, thorium, and potassium in the background of the measurement. Likewise, room air contains varying amounts of radon and its short-lived progeny, which are also present as confounders in the background and the sample measurement. Therefore, it is necessary to include estimates of the total propagated uncertainty with all measurement results so that the data can be adequately evaluated. Likewise, since the detection efficiency increases with sample size, it is necessary to use a sample of sufficient mass so that the total amount of activity expected in the sample will exceed the limit of detection for the analytical method. The laboratory did not use sufficient sample mass to produce gamma spectroscopy measurements with sufficient reliability to produce conclusive results.

A non-negligible source of contamination for spent blasting abrasives is the air compressor that is used during the blasting process. Radon in the air will be concentrated by the air compressor. Since radon is very soluble in oil and other organic fluids, the compressor will also act as a radon reservoir and may actually contaminate the abrasive with 210Pb, the longest lived decay product of 222Rn.

Further evaluation of this data must be preceded by an evaluation of the computer method used by the NIOSH contract laboratory for analyzing gamma spectra. Likewise, the laboratory must report the total propagated uncertainty for all of their results as well as the detection limits so that a more reliable analysis of the data can be performed.

Figure 11
Arsenic Virgin Bulk Sample Results

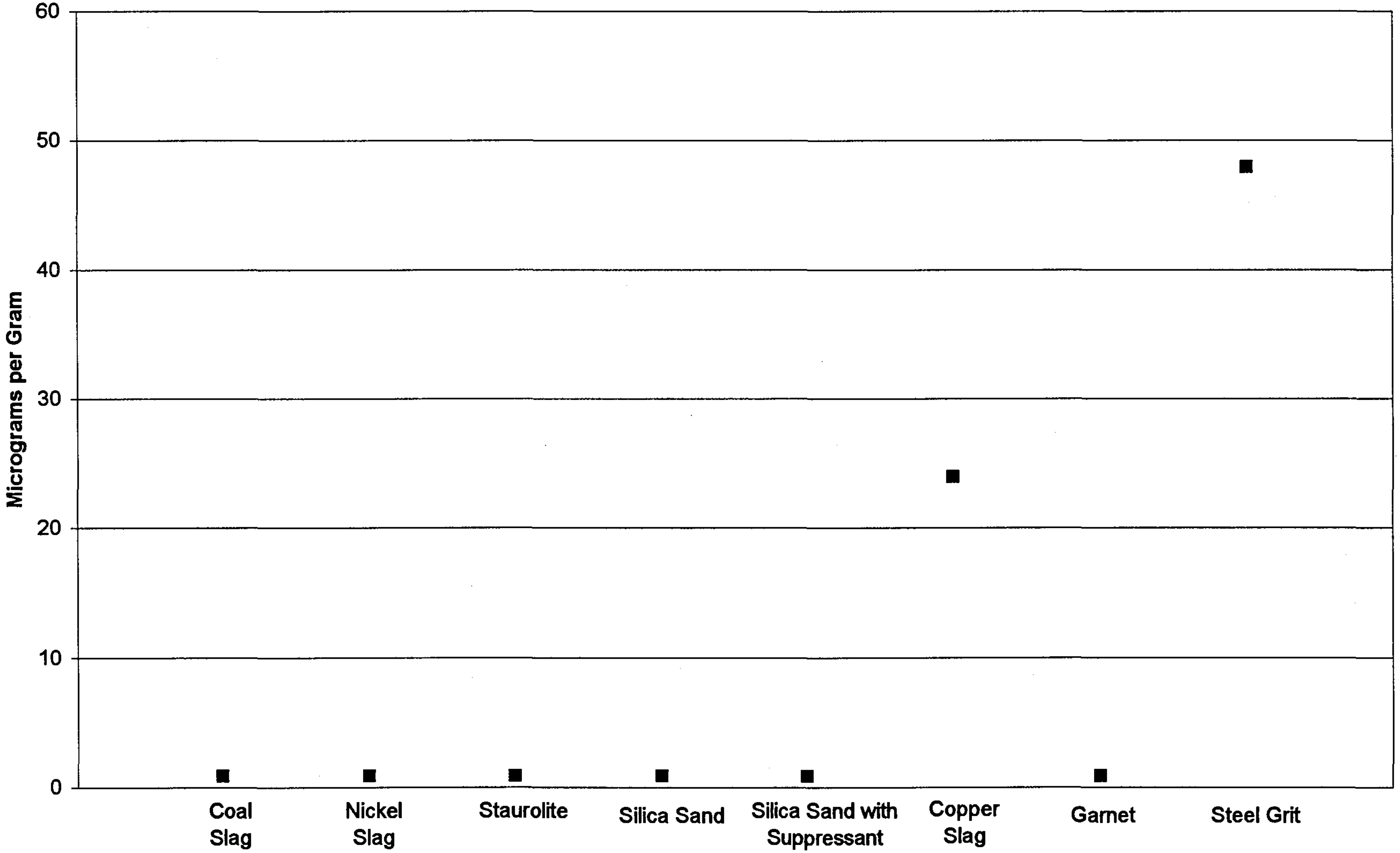


FIGURE 12 – BERYLLIUM VIRGIN BULK SAMPLE RESULTS

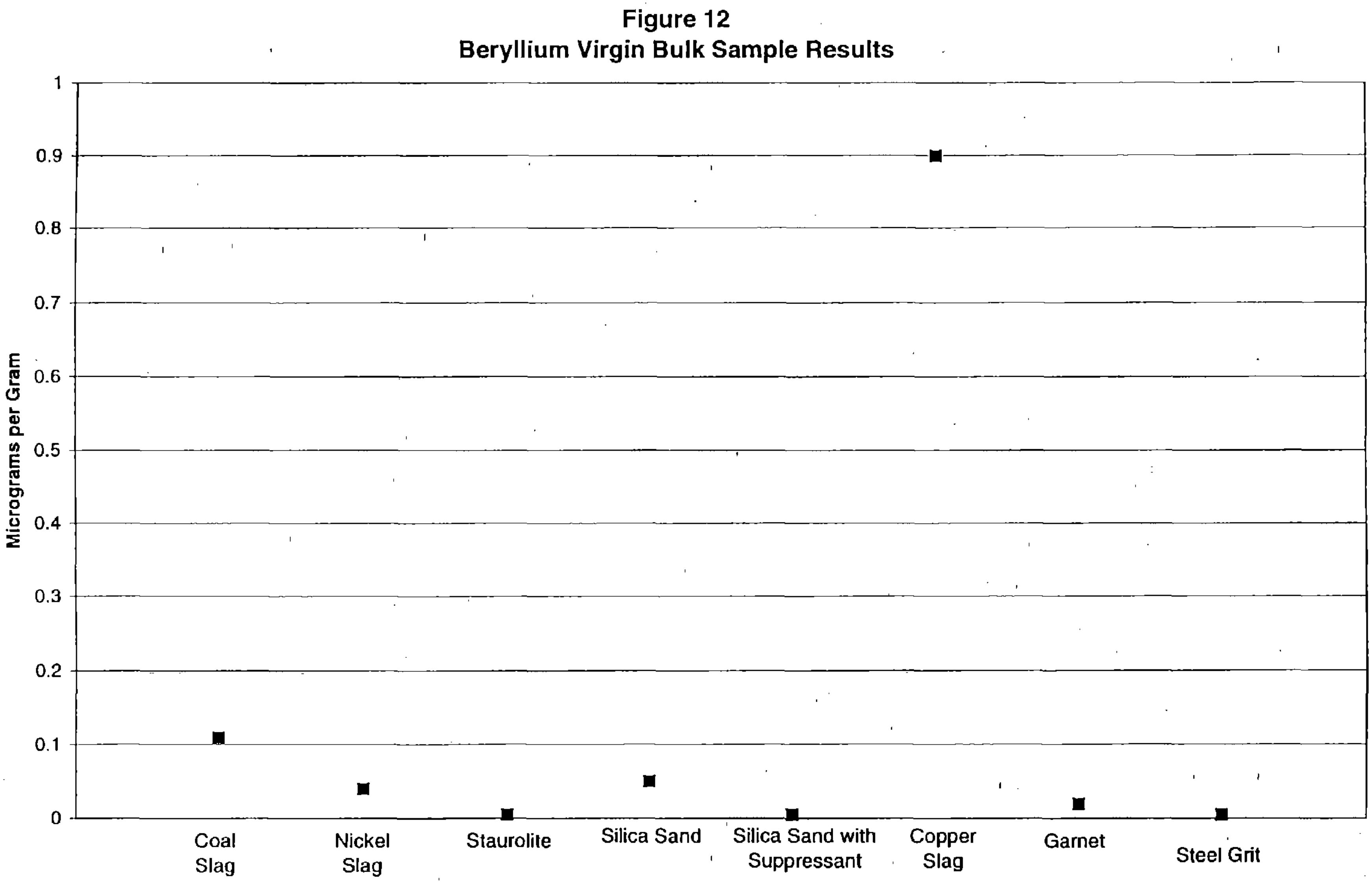


Figure 12
Beryllium Virgin Bulk Sample Results

fig12_22.xls / Fig 12

FIGURE 13 – CADMIUM VIRGIN BULK SAMPLE RESULTS

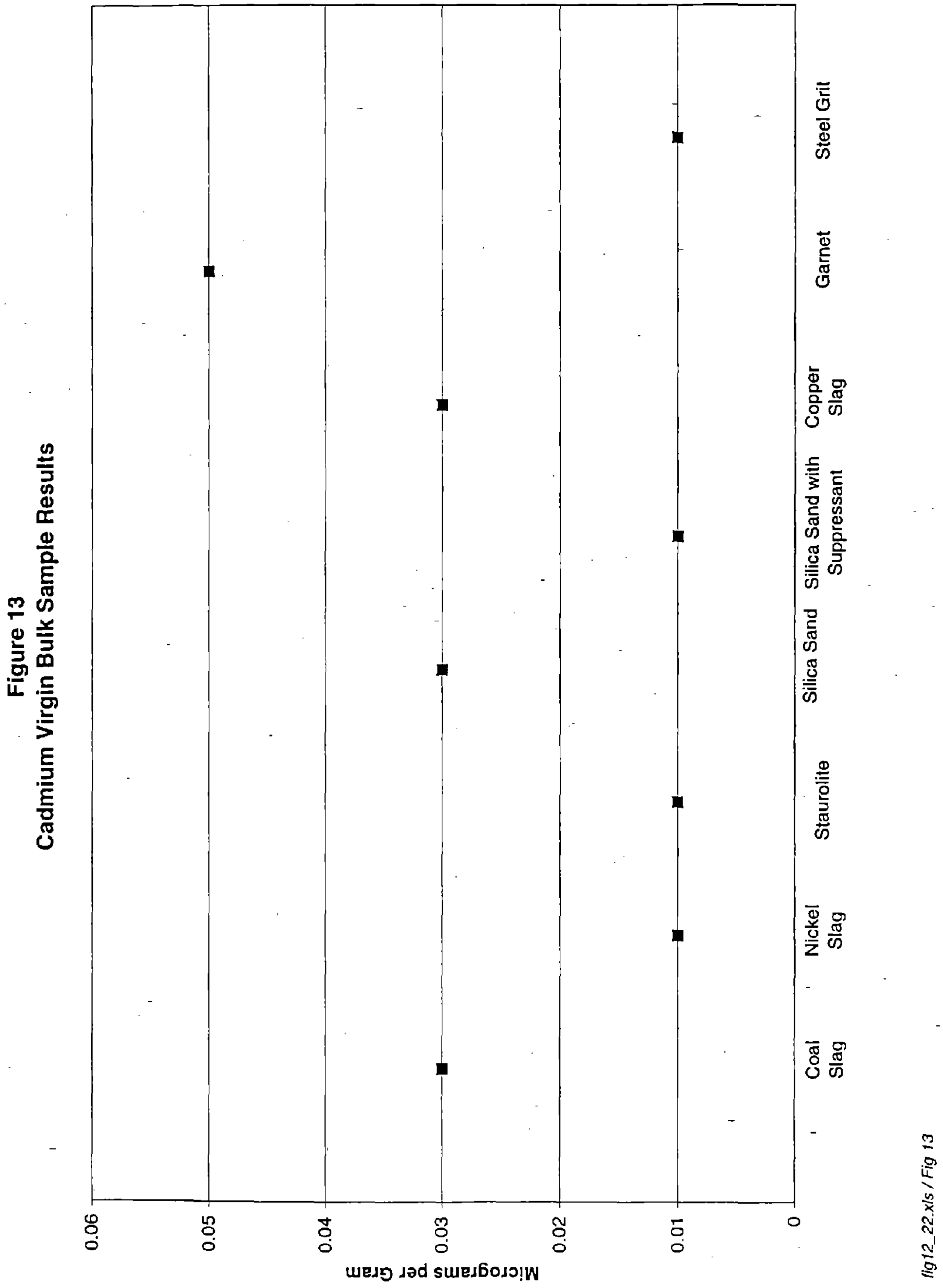


FIGURE 14 – CHROMIUM VIRGIN BULK SAMPLE RESULTS

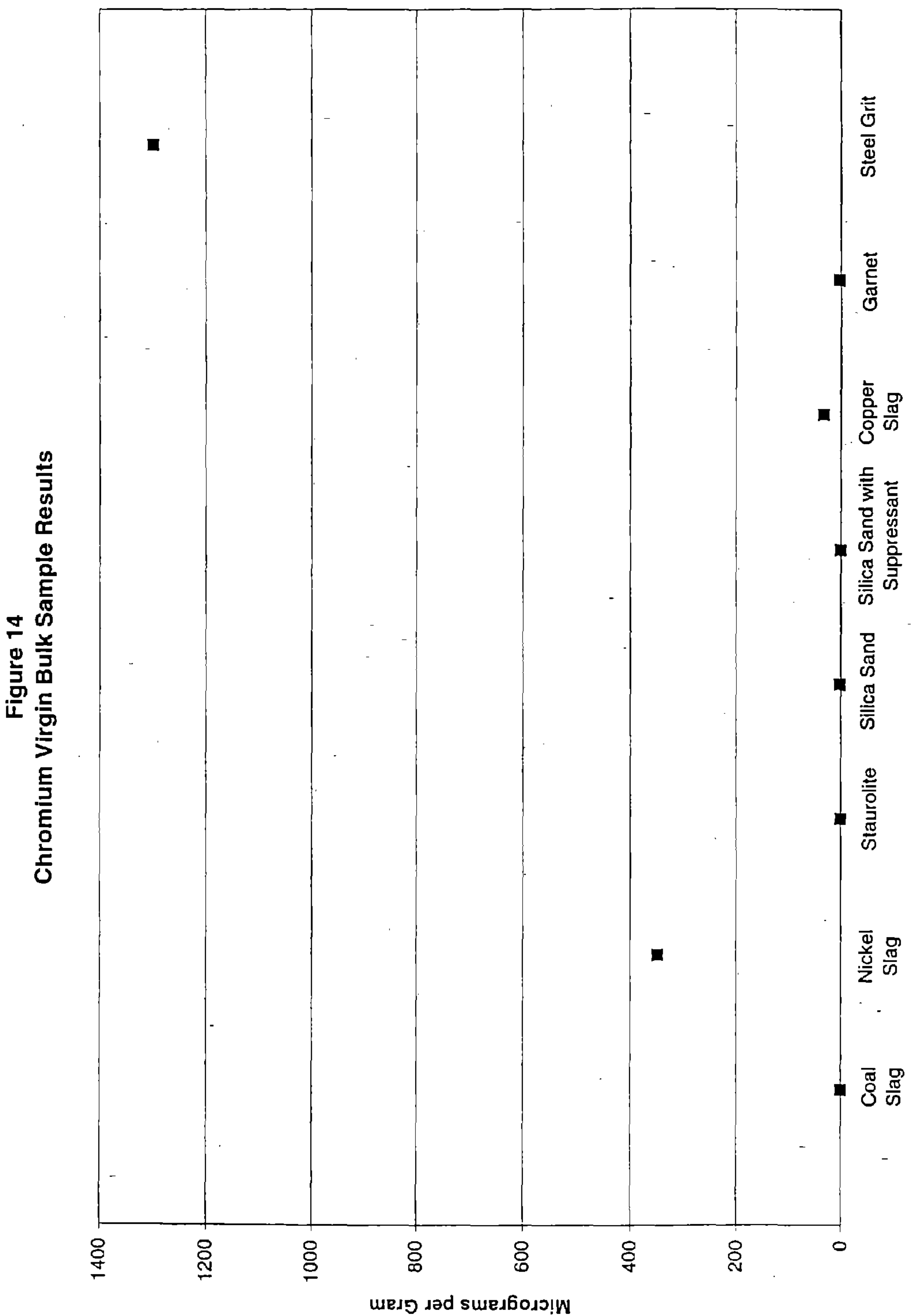


fig12_22.xls / Fig 14

FIGURE 15 – LEAD VIRGIN BULK SAMPLE RESULTS

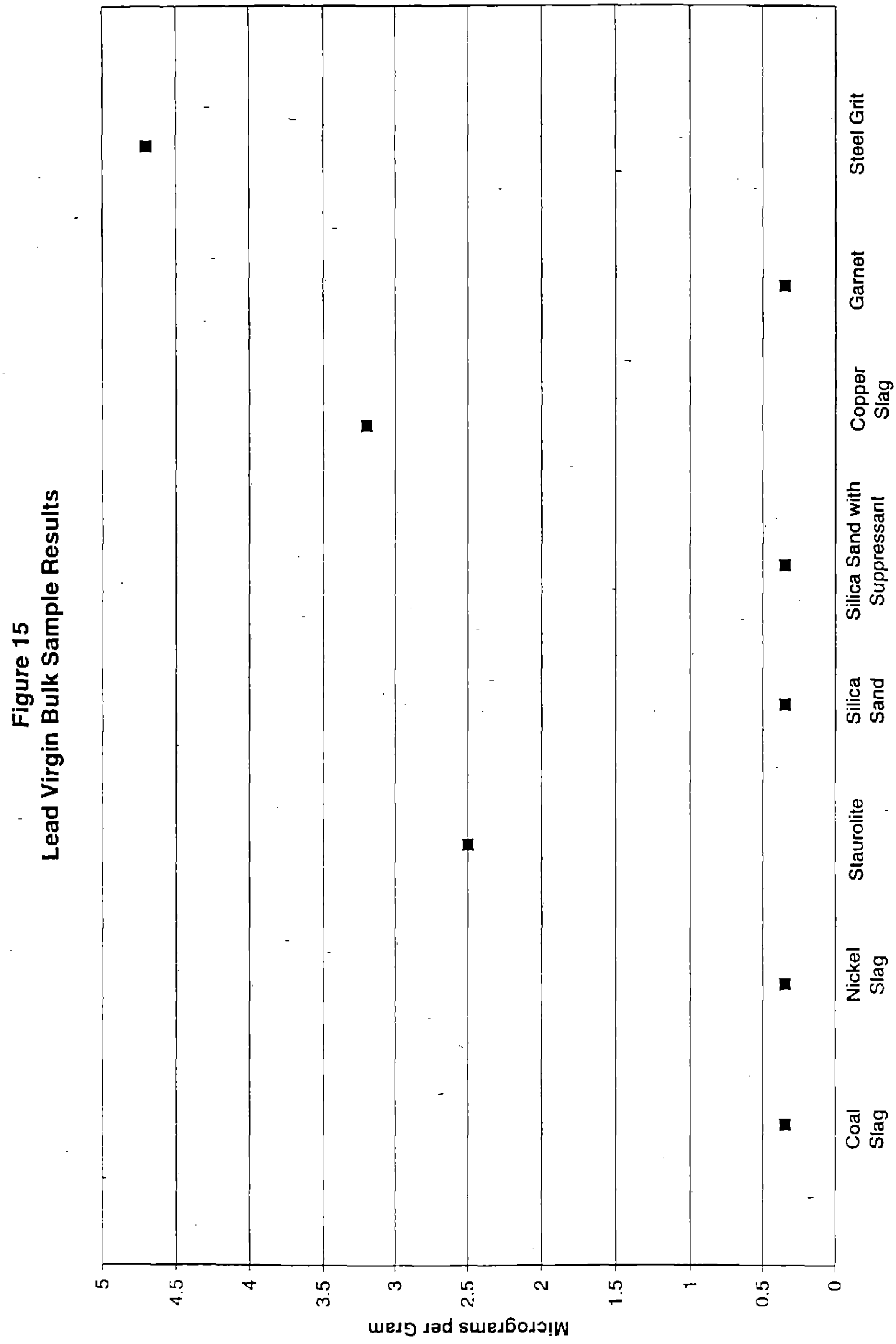


fig12_22.xls / Fig 15

FIGURE 16 – MANGANESE VIRGIN BULK SAMPLE RESULTS

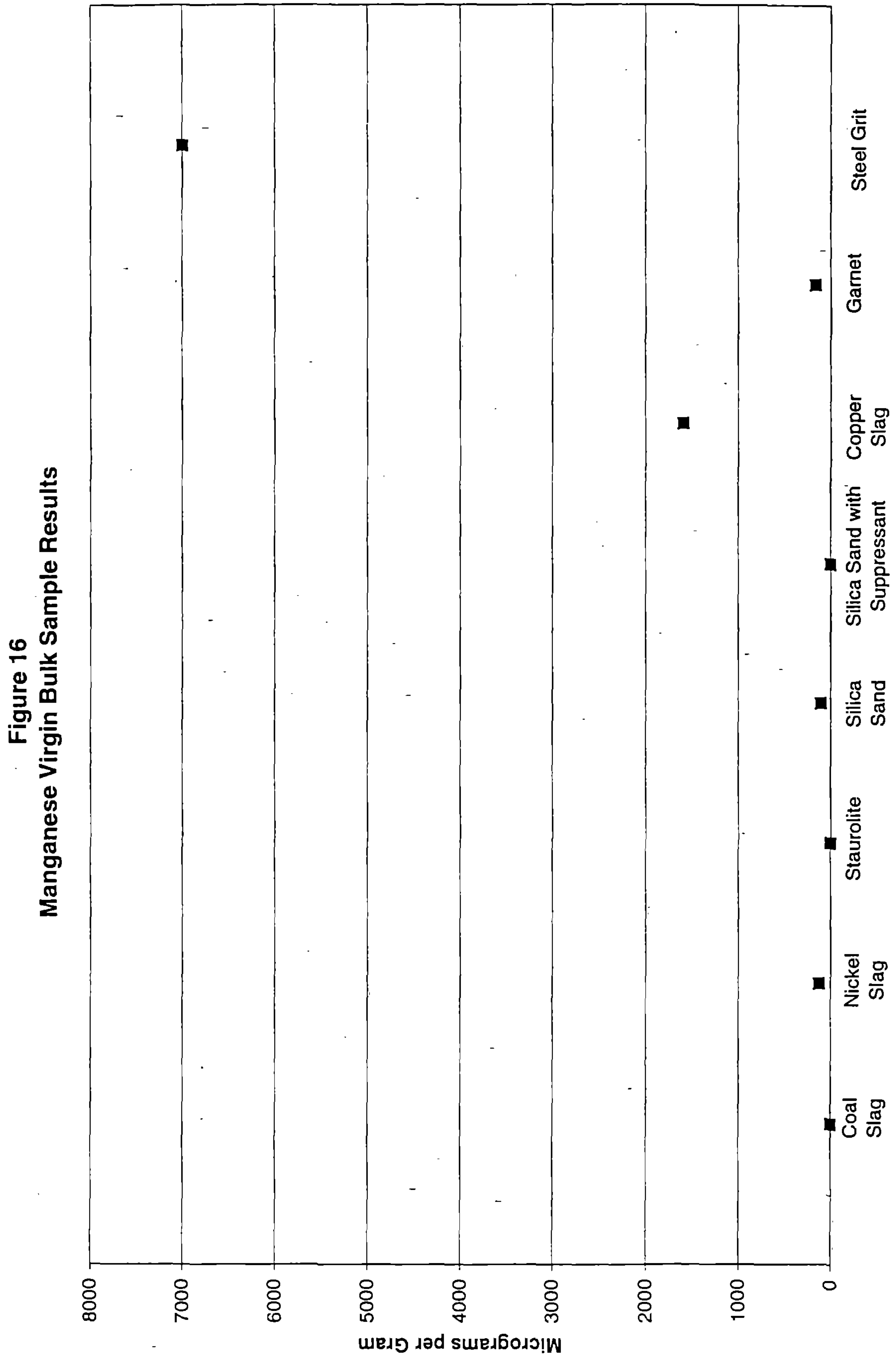


fig12_22.xls / Fig 16

FIGURE 17 – NICKEL VIRGIN BULK SAMPLE RESULTS

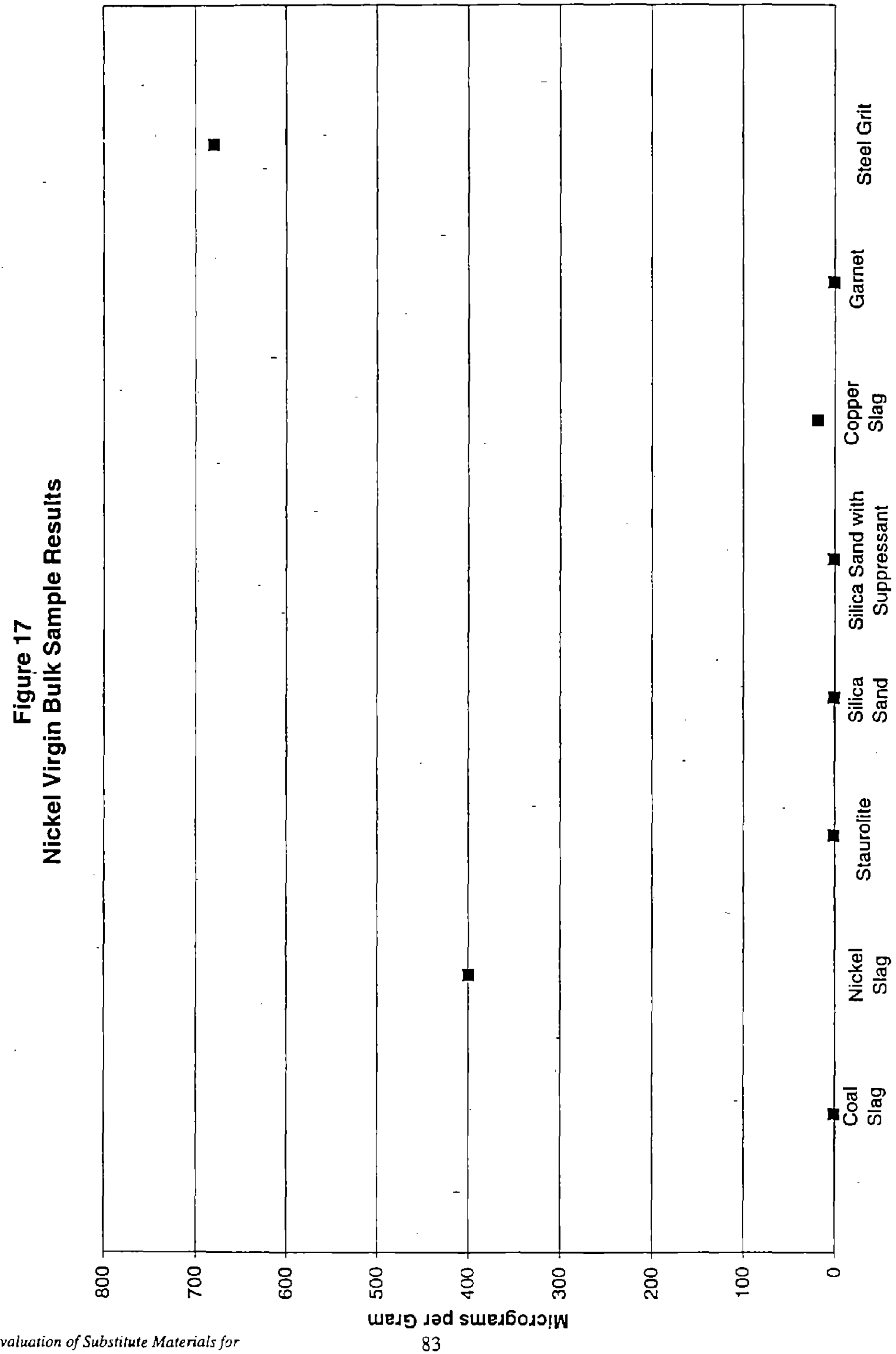


fig12_22.xls / Fig 17

FIGURE 18 – SILVER VIRGIN BULK SAMPLE RESULTS

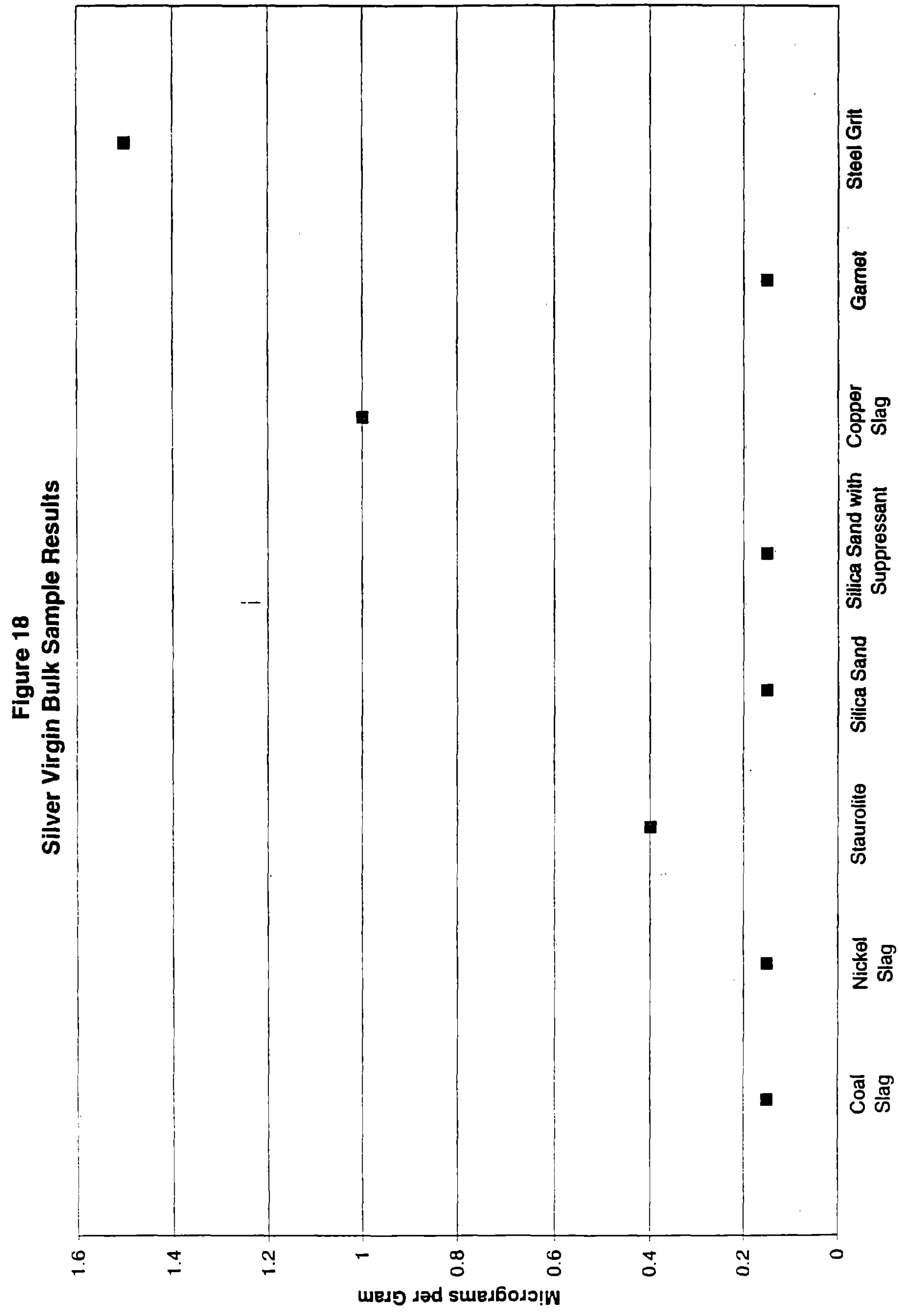


Fig12_22.xls / Fig 18

FIGURE 19 – TITANIUM VIRGIN BULK SAMPLE RESULTS

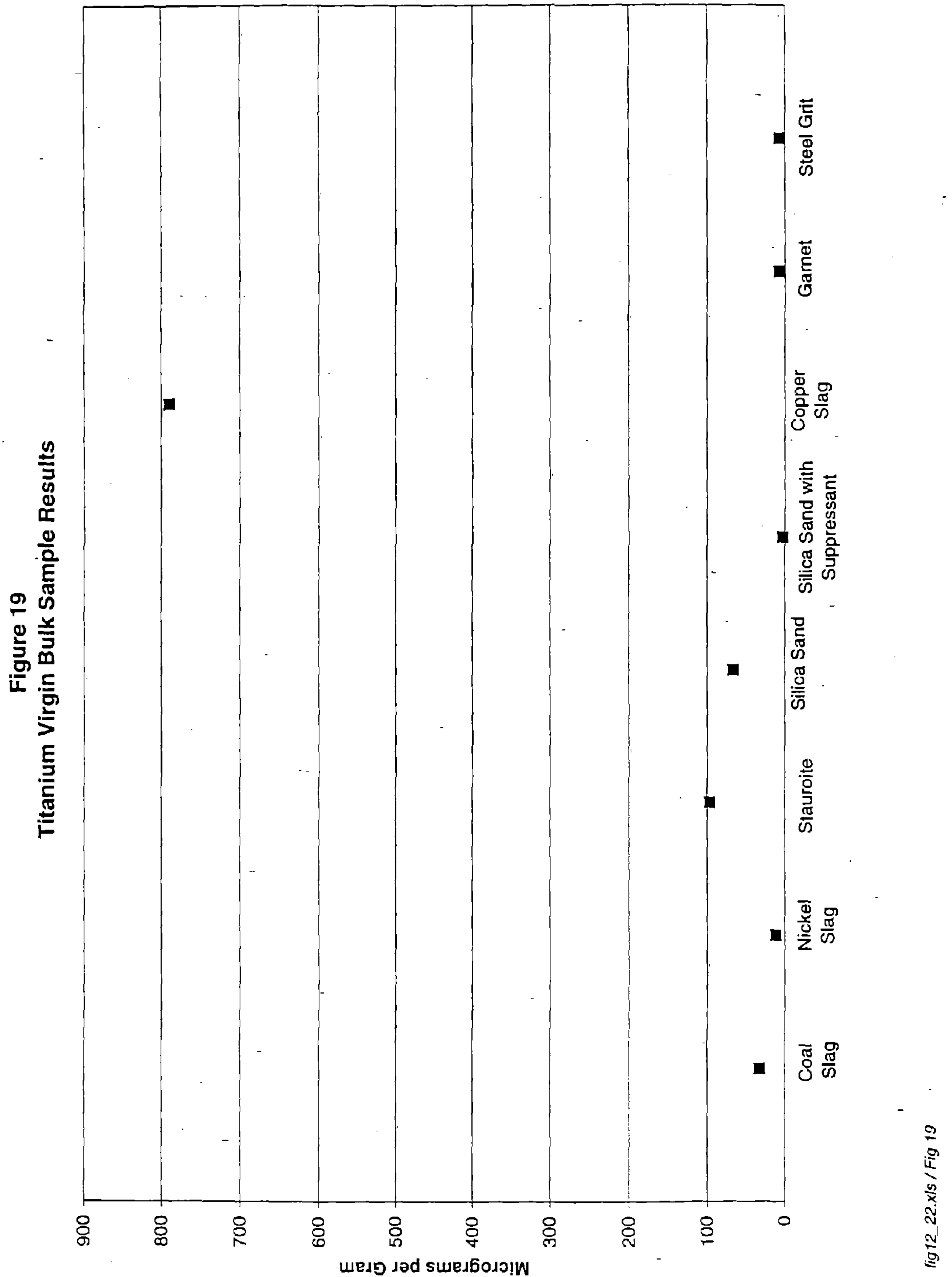


FIGURE 20 – VANADIUM VIRGIN BULK SAMPLE RESULTS

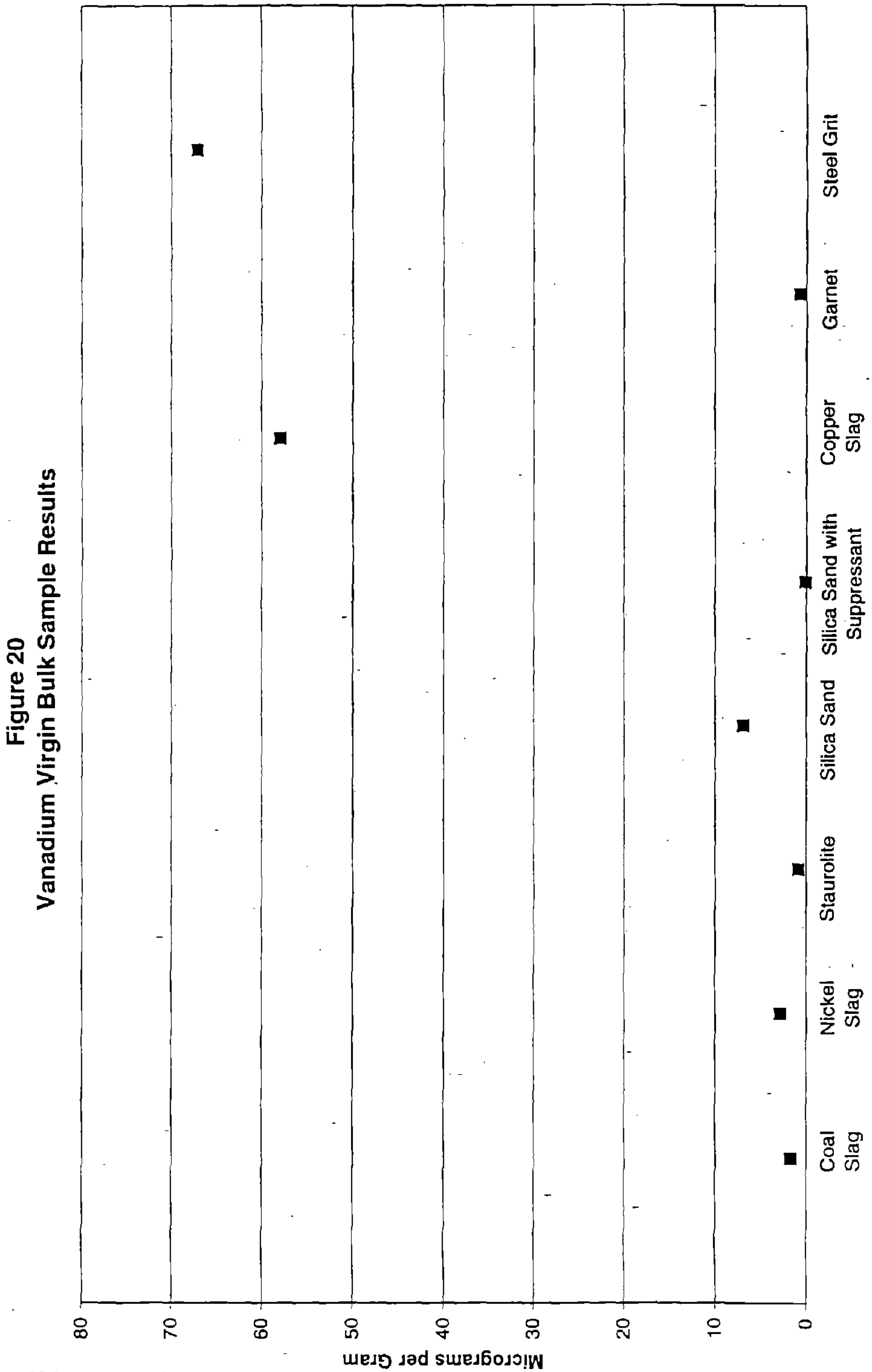


Figure 20
Vanadium Virgin Bulk Sample Results

fig12_22.xls / Fig 20

FIGURE 21 – QUARTZ VIRGIN BULK SAMPLE RESULTS

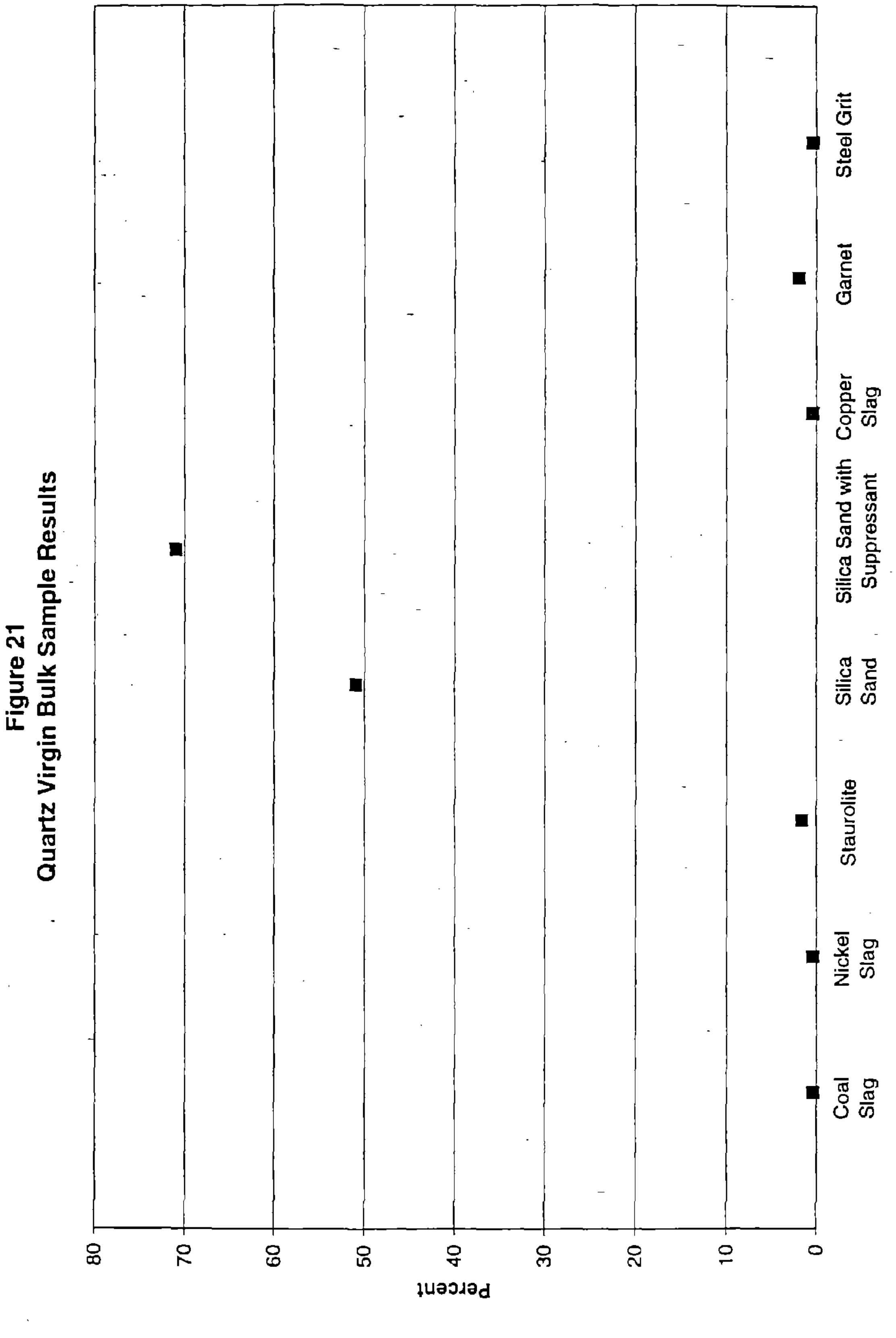


fig12_22.xls / Fig 21

Table 3

Summary Table: Bulk Sample Results of Health Related Elements by Generic Category of Abrasive
Note: Unless noted, all concentrations in micrograms per gram

Abrasive	Arsenic	Beryllium	Cadmium	Chromium	Lead	Manganese	Nickel	Quartz (%)	Silver	Titanium	Vanadium
CS	0.45 0	0.11 1	0.03 1	1 0	0.35 0	2.8 1	1 0	0.4 0	0.15 0	33 1	1.8 1
N	0.45 0	0.04 1	0.01 0	350 1	0.35 0	130 1	400 1	0.4 0	0.15 0	12 1	2.9 1
S	0.45 0	0.005 0	0.01 0	1 0	2.5 1	5.3 1	1 0	1.6 1	0.4 1	97 1	0.9 1
SS	0.45 0	0.05 1	0.03 1	3 1	0.35 0	110 1	1 0	51 1	0.15 0	67 1	6.9 1
SSDS	0.45 0	0.005 0	0.01 0	1 0	0.35 0	0.17 1	1 0	71 1	0.15 0	3.4 1	0.15 0
CP	24 1	0.9 1	0.03 1	33 1	3.2 1	1600 1	19 1	0.4 0	1 1	790 1	58 1
G	0.45 0	0.02 1	0.05 1	3 1	0.35 0	170 1	1 0	1.9 1	0.15 0	7.9 1	0.7 1
SG	48 1	0.005 0	0.01 0	1300 1	4.7 1	7000 1	680 1	0.4 0	1.5 0	7.5 1	67 1

<---- Values
<---- Samples > LOD
Limit of Detection

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Conclusions from the study are provided separately below for performance and industrial hygiene issues. The abrasives are grouped below based on similar performance characteristics relative to silica sand.

Abrasive Performance Issues

The eight abrasives were evaluated for cleaning rate, consumption rate, surface profile, breakdown, and embedment. It is important to recognize that the Phase 1 Study demonstrated that the performance characteristics within a given generic category class of abrasive was variable. Individual abrasives within a generic category showed both "good" and "poor" performance. For Phase 2, only one abrasive from each generic category was selected for evaluation. As a result, conclusions regarding the entire category of abrasives based on the specific abrasive evaluated are inappropriate. Each unique abrasive needs to be evaluated individually. Further, it must be recognized that by establishing the optimum operating conditions for each abrasive (nozzle orifice size, metering valve setting, nozzle-to-workpiece distance, etc.), the relative performance of the abrasives will be affected. The results presented in this Phase 2 report are representative of the specific pre-established operating conditions which were tightly controlled.

Based on the study parameters, the staurolite abrasive evaluated exhibited performance characteristics (cleaning rate, consumption rate, breakdown and embedment) that were superior to the silica sand abrasive evaluated. However, staurolite was the most expensive abrasive to use ($1.02/square foot versus $0.72/sqaure foot for silica sand). Each of the other abrasives evaluated exhibited a range of properties that were comparable to, better, or worse than silica sand. The coal slag abrasive exhibited both improved cleaning and consumption rates, but more embedment than silica sand. The cost of use was comparable ($0.69/square foot versus $0.72/square foot). Garnet also exhibited improved cleaning and consumption rates but at an increased cost ($0.89/square foot versus $0.72/square foot). Steel grit exhibited lesser cleaning rates under the test, but significantly improved breakdown rates. The cost of use was comparable to garnet. The copper slag abrasive evaluated exhibited reduced cleaning rates over silica sand and a poorer breakdown rate. The cost of use was higher ($0.82/square foot versus $0.72/square foot). Nickel slag exhibited reduced cleaning rates, but less embedment. The cost of use was higher ($0.96/square foot versus $0.72/square foot). Conclusions regarding the effect of dust suppressant can not be made because the treated and untreated silica sands were different products.

It should be noted that if the abrasive must be treated as a hazardous waste, or it is used to remove a hazardous paint which causes the entire waste stream to be hazardous, the cost of use changes dramatically. If the resulting waste stream required disposal as a hazardous waste, the costs would range from $0.91/square foot to $1.67/square foot (versus $0.69/square foot to $1.02/square foot for non-hazardous disposal) with silica sand costing $1.37/square foot. Steel grit, in this case, is the most cost effective at $0.91/square foot.

Industrial Hygiene Related Issues

While the study evaluated 30 potential contaminants, this analysis focused on eleven health-related agents selected by NIOSH including: arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, respirable quartz, silver, titanium, and vanadium. The airborne sampling data should be viewed as an indicator of the potential for worker exposure to the health-related agents, since the conditions of the field study may not be representative of actual worksite conditions. More importantly, variability between individual abrasives within a generic abrasive category must be considered prior to drawing any broad conclusions regarding airborne concentrations of hazardous health-related agents. The attributes of the specific abrasive rather than the generic class of abrasive must be considered when making any health based comparisons.

Based on the industrial hygiene results collected in the field study, silica sand abrasives exhibited the highest levels of respirable quartz. The relative airborne concentrations of the other 10 health-related agents in silica sand varied. Substituting any of the alternative abrasives for silica sand should significantly reduce airborne respirable quartz concentrations for abrasive blasting. This respirable quartz reduction could serve as a major step in preventing the occurrence of silicosis in abrasive blasting. However, all of the alternative abrasives had at least four hazardous health-related agents which resulted in a higher geometric mean concentration of the agent than that of silica sand, as described below.

Coal slag had a greater geometric mean airborne concentration than those of silica sand for all the hazardous health-related agents, except respirable quartz. Out of the eight generic abrasive categories, coal slag had the highest geometric mean airborne concentrations of beryllium and vanadium, and the second highest geometric mean concentration of cadmium, lead, and titanium.

Nickel slag had greater geometric mean airborne concentrations than that of silica sand for seven of the hazardous health-related agents, except beryllium, respirable quartz, and titanium. Nickel slag had the highest geometric mean concentration of chromium and nickel.

Staurolite had greater geometric mean airborne concentrations than that of silica sand for six of the health-related agents. Staurolite had the highest geometric mean concentrations of lead and titanium.

Copper slag had greater geometric mean airborne concentrations than that of silica sand for eight hazardous health-related agents. Copper slag had the second highest geometric mean airborne concentration of arsenic and vanadium, and the third highest geometric mean concentrations of beryllium, cadmium, manganese, and titanium.

Garnet had higher geometric mean concentrations than that of silica sand for five hazardous health-related agents, including arsenic, cadmium, chromium, lead, and manganese. Garnet had the highest geometric mean concentration of manganese and the third highest geometric mean concentrations of arsenic and respirable quartz.

Steel grit had higher geometric mean concentrations than that of silica sand for seven hazardous health-related agents. Steel grit had the highest geometric mean concentration of arsenic, and the second highest geometric mean concentrations of chromium, manganese, and nickel.

No comparison of the effect of dust suppressant to reduce dust generation can be made, as the underlying silica sand abrasives were from different suppliers. Therefore, apparent differences may be due to the inherent variability within generic abrasive categories as opposed to the effect of the dust suppressant.

In summary, no single abrasive category had reduced levels of all health-related agents, although all the substitutes offer advantages over silica sand with regard to respirable quartz. All of the alternative abrasive categories have higher levels of at least four of the other health-related agents, as compared to silica sand.

Recommendations

Based upon the above conclusions, consideration should be given to the following recommendations:

1. When staurolite, coal slag, nickel slag, copper slag, garnet and/or steel grit abrasives are used as alternatives to silica sand, select specific products from within the generic category which limit worker exposure to multiple toxic contaminants and which optimize desired performance characteristics. As indicated throughout this study, Phase 1 demonstrated that the attributes of the individual products within a generic classification varied widely. Only one abrasive from each category was selected for this Phase 2 study.

2. Given the potential exposures to multiple contaminants from both the abrasive, as well as a painted steel surface, worker protection programs should be expanded to address all potential metals (e.g., as opposed to the current focus on worker lead protection programs). Perhaps a comprehensive vertical health standard for industrial maintenance painting operations addressing the use of abrasives, or classes of generic abrasives, should be developed. The standard would automatically invoke the necessary levels of protection and work practices without the need to uniquely evaluate each abrasive for all possible metals.

In addition to the fundamental recommendations described above, this study identified the need for additional research. The recommended studies should be used to:

3. Evaluate the potential for correlations between the concentration of health-related agents in all virgin abrasives, and the resulting airborne concentrations, for use as a selection criteria.

4. Improve the quality of data regarding cleaning rate, consumption rate, and cost. The protocol should be modified to allow selection of blast nozzle size, meter valve setting, and nozzle pressure for each individual abrasive, set experimentally in conjunction with the suppliers. While such variations limit the strict reproducibility of the study and introduce subjective design criteria, these detractions will result in improved cleaning rate, consumption rate, and cost data.

REFERENCES

---

[1] "SSPC-SP 10/NACE No. 2 Near-White Blast Cleaning" SSPC Publication No. 95-02. The Society for Protective Coatings, (formerly Steel Structures Painting Council), 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4656. (412) 281-2331; fax (412) 281-9982.

[2] "Standard Test Method for Indicating Oil or Water in Compressed Air" *Annual Book of Standards*, ASTM D4285-83. American Society for Testing and Materials, 100 Harbor Drive, West Conshohocken, PA 19248-2959.

[3] "SSPC VIS1-89" Visual Standard for Abrasive Blast Cleaned Steel, (Standard Reference Photographs), Guide and Standard, SSPC: The Society for Protective Coatings, (formerly Steel Structures Painting Council) 40 24th Street, 6th Floor, Pittsburgh, PA 15222-4656, (412) 281-2331; fax (412) 281-9982.

[4] "Standard Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel." *Annual Book of Standards*, Method C of ASTM D4417-93, Vol. 6.02, 1994. American Society for Testing and Materials, 100 Harbor Drive, West Conshohocken, PA 19248-2959. (610) 832-9500; fax (610) 832-9555.

[5] "Standard Test Method for Sieve or Screen Analysis of Fine and Coarse Aggregates." *Annual Book of Standards, ASTM* C136-92 Vol. 4.02 Concrete and Aggregates, pp 79-82 1993. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187. (215) 299-5400; fax (215) 977-9679.

[6] "OSHA Lead in Construction Training Course," May 1, 1997, KTA-Tator, Inc., 115 Technology Drive, Pittsburgh, PA 15275.

[7] "NIOSH Manual of Analytical Methods," Fourth Edition, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, August 1994
    Silica, Crystalline, Respirable; Method 7500, Issue 2
    Elements (ICP); Method 7300, Issue 2
    Particulate Not Otherwise Regulated, Respirable; Method 0600, Issue 2

[8] NIOSH Standard Operating Procedure (SOP) WR-IN-314 "The Determination of Radium-226 in Solids by Alpha Spectrometry." Revision No. 1, effective May 7, 1993. DataChem Laboratories, Inc., Salt Lake City, UT 84123-2547.

[9] NIOSH Standard Operating Procedure (SOP) WR-IN-325 "Determination of Gamma Emitting Isotopes." Revision No. 2, effective August 11, 1995. DataChem Laboratories, Inc., Salt Lake City, UT 84123-2547.

[10] "Occupational Safety and Health Administration (OSHA) Technical Manual" United States Department of Labor, Occupational Safety and Health Administration, OSHA

Instruction TED 1.15, September 22, 1995, Office of Science and Technology Assessment

Chapter 1: Personal Sampling for Air Contaminants
Section C: Sampling Techniques
Technique 3: Respirable Dust

[11] "Achieving Productivity from Abrasive Blast Cleaning Systems," *Journal of Protective Coatings & Linings*, Volume No. 9, September 1989, pp 31-36.

[12] "Users Guide to Selection of Blasting Abrasives," National Shipbuilding Research Program (NSRP); NSRP Program Manager, Halter Marine Group, Inc., P.O. Box 3029, Gulfport, MS 39505.

[13] EPA Office of Solid Waste. "Test Methods for Evaluating Solid Waste. Physical and Chemical Methods." Toxicity Characteristics Leaching Procedure (TCLP Method 1311) 2nd ed. Washington, DC: Environmental Protection Agency, 1982; SW-846. Updated June 13, 1997 (62 FR 32452).

[14] *The AED Green Book*, 49th Edition, 1998 Rental Rates & Specifications for Construction Equipment, pp. 49, 71. PRIMEDIA Information, Inc., Machinery Information Division, 1735 Technology Drive, Suite 410, San Jose, California 95110-1313.

[15] The Tool Shed. 2705 East Washington Street, Indianapolis, IN 46201. (317) 467-2525. Equipment Rental Rate Catalog: pp. 7. Alpha VB 1200 Blast & Recovery System.

[16] Blast Abrasives & Equipment. 3rd Edition. pp 12. Rental Rates. Blast N' Vac w/Hopper No HEPA Filter. 888-444-2705. http://www.blastabrasives.com.
e-mail: blast@indyweb.net.

[17] "The Salary Calculator", Home Buyer's Fair, Inc., Suite 3, 10304 North Hayden Road, Scottsdale, AZ 85258. Online. Internet. Available:
http://www2.homefair.com/calc/salcalc.html?NETSCAPE_LIVEWIRE.scr=homefair

[18] Transportation Research Board, *Synthesis of Highway Practice 251, Lead-Based Paint Removal for Steel Highway Bridges*, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418, 1997.

[19] Richard W. Hornung and Laurence D. Reed, "Estimation of Average Concentration in the Presence of Nondetectable Values," *Appl. Occup. EnvironHYG5(1)*, January 1990, pp 46-51.

---

[20] Richard W. Hornung and Laurence D. Reed, "Estimation of Average Concentration in the Presence of Nondetectable Values," *Appl. Occup. EnvironHYG 5(1)*, January 1990, pp 46-51.

APPENDIX 1

PHASE 2
STUDY DESIGN/PROTOCOL

Based on an understanding of the project objectives, KTA/SET Environmental (KTA/SET) has developed a study protocol for the Phase 2 "field" portion of the project. The protocol is based on the stated research objectives, the pilot industrial hygiene study conducted by NIOSH and KTA/SET during February 1996, the Phase 1 "laboratory" study, and KTA/SET experience in conducting abrasive blast cleaning studies.

The project requires stringent controls over many variables. Exhaustive quality assurance/control measures will be maintained throughout this phase in order to obtain valid meaningful data. Because of these requirements, the study will be under the direct supervision of Daniel P. Adley, a Certified Industrial Hygienist (CIH). The principal investigator will be Kenneth A. Trimber.

Protection of human operators will be a top priority. Operators will be provided with proper training and personal protective equipment to ensure their safety and health. Implementation of project specific training on the hazards associated with the various abrasive blast cleaning media, use of properly maintained ventilation systems during the field phase, observation of work practices including personal hygiene, and adequate respiratory protection (Bullard Series 88 Type CE supplied air respirator with an assigned protection factor of 1,000) will help ensure the safety of human operators. This protection will be complimented by a medical surveillance program designed to assess worker health status prior to and following Phase 2 of the project.

PHASE 2 (FIELD STUDY) PROTOCOL

1. Blast Cleaning Facilities

1.1. KTA/SET will use a customized containment and ventilation system to conduct Phase 2 of the study. The containment will be appropriately sized to recreate (as feasible) the KTA 12' x 8' x 8' walk-in blast room used for the Phase 1 work. Once the field site is selected, a KTA/SET containment/ventilation design engineer will conduct a site visit and subsequently design a containment and ventilation system. The containment system will be constructed by KTA/SET personnel, based on drawings submitted to and approved by NIOSH.

1.2. The blast cleaning equipment will include a production Clemco six cubic foot gravity feed abrasive hopper equipped with an abrasive metering valve and a 15 foot length of reinforced air/abrasive hose. A new section of hose will be assembled prior to the initiation of Phase 2. The hose will be flushed, washed, and dried inside and out prior to use with each new abrasive. A Boride brand No. 7 (7/16" orifice) nozzle will be used for the field study. The nozzle orifice size will be monitored throughout Phase 2 using a Clemco nozzle orifice gage. The nozzle will be replaced if the orifice diameter increases by one size (to 8/16" or when uneven wear is observed). The metering valve setting will vary, depending upon each abrasive media. The metering valve setting will be established by the operator prior to each abrasive trial. This procedure will be conducted on the day prior to the actual blast trial using a small quantity of abrasive. All IH monitoring samples and post blast abrasive media samples will be obtained prior to establishing the metering valve setting for the following day's trial.

1.3. The volume of air supply (cubic feet per minute) will be maintained throughout the project by employing a 375 CFM air compressor. The air supply will be examined for oil and water contamination in accordance with ASTM D4285 (blotter test) prior to each abrasive study.

1.4. The blast operator will be equipped with a Bullard Series 88 Type CE supplied air respirator (blast helmet), which has an assigned protection factor (APF) of 1,000. The breathing air will be filtered through an Industrial Scientific Model PL-100 3 stage breathing air purification unit, which also monitors for carbon monoxide.

1.5. Blast cleaning air pressure will be maintained at 90-100 psi at the blast nozzle and will be held constant for each abrasive. Actual blast cleaning air pressure will be measured using a hypodermic needle pressure gage and the results documented for each abrasive.

1.6. Phase 2 of the blast cleaning study will be performed on the side of a barge which is in temporary dry dock. The surface will be homogeneous, so that the results of the study for each abrasive are comparable. The actual surfaces to be prepared are subject to approval by NIOSH prior to project initiation. An area of approximately 70 square feet will be demarcated for each abrasive material. Upon completion of blast cleaning, the containment will be thoroughly cleaned, then moved to a new section of the barge side wall and prepared for the next abrasive material.

1.7. The nozzle-to-work piece distance will be held at a consistent distance (18 inches) throughout the study. A ¼" diameter rod will be mounted on the blast nozzle and so configured to touch the surface without affecting the abrasive/air pathway. The operator will use this rod to maintain the nozzle-to-substrate distance. The operator will be instructed to keep the nozzle perpendicular to the substrate, producing the greatest amount of abrasive ricochet, simulating a worst-case airborne dust condition.

1.8. The containment will be ventilated throughout the study. Cross draft ventilation will be used. Target air flow will be 50 to 75 feet per minute (fpm) for each abrasive trial. Actual cross-sectional air flow will be measured and recorded prior to each abrasive trial using a rotating vane anemometer.

1.9. Environmental conditions within the containment will be recorded prior to each abrasive trial. Environmental conditions will be assessed using a 24-hour recording hygrometer (probe stationed inside the containment), and a digital thermocouple-equipped surface temperature thermometer. Barometric pressure will also be recorded.

1.10. A Lunardini abrasive media vacuuming system will be used to collect the abrasive debris and to vacuum all containment surfaces after each abrasive trial.

2. Abrasive Media

2.1 The generic types of abrasives and number of each to be studied are as follows:

Abrasive Type	No. of Abrasives
01 Silica Sand	1
02 Silica Sand w/Dust Suppressant	1
03 Coal Slag	1
04 Copper Slag	1
05 Nickel Slag	1
06 Garnet	1
07 Staurolite	1
08 Steel Grit	1

3. Substrate Material

3.1 The substrate material for Phase 2 will be comprised of the side of a barge in temporary dry dock. The surfaces for blast cleaning will be steel, with corrosion products present. Attempts will be made to locate eight (8) areas which are similar in appearance and condition. The existing substrate conditions will be documented and photographed. SSPC Visual Standard No. 1 (VIS 1-89) will be employed as appropriate.

4. Health Screenings and Training of Human Subjects (Blast Operators)

4.1 Prior to initiating the blast cleaning portion of the Phase 2 study, human subjects will receive the following health screening. Items 4.1.2, 4.1.3 and 4.1.5 will be reassessed after the Phase 2 work is completed.

4.1.1 Pulmonary Function Test (if not current)

4.1.2 Blood Test for Lead, Zinc Protoporphryn (ZPP), and cadmium

4.1.3 Urinalysis for Cadmium

4.1.4 Qualitative Respirator Fit Testing (if not current)

4.1.5 Blood chemistry profiles and complete blood count with differential.

4.2 Prior to initiating the field study, human subjects will receive training in the following areas:

4.2.1 Health Hazards of Lead, Chromium, Cadmium, Arsenic, Beryllium, Iron Oxide, and Silica

4.2.2 Proper Use of Respirators

4.2.3 Hygiene Practices

4.2.4 Review of Project Testing Protocol – Roles/Responsibilities

5. Protocol for Abrasive Trials

5.1. Assessment of Containment Conditions

5.1.1. Environmental conditions within the containment will be assessed prior to each abrasive evaluation. The conditions that will be monitored include air temperature, relative humidity, dew point, surface temperature, and barometric pressure. Data will be acquired using a thermocouple equipped digital surface temperature thermometer, a barometer, and a 24-hour recording hygrometer (remote probe stationed inside the containment).

5.1.2. The containment will be ventilated throughout the study. Cross draft ventilation will be used. A cross-sectional assessment of air flow will be conducted and documented prior to abrasive evaluations using an Alnor Rotating Vane Anemometer. Target ventilation will be 50 to 75 feet per minute.

5.2. Testing Protocol for Each Abrasive Media

5.2.1. Upon receipt of each abrasive shipment, the manufacturer, supplier, trade name, size and grade will be recorded in a log book. Each abrasive media will be assigned a unique number representing the KTA/SET project number, phase number, and abrasive number (e.g., J97119-P2-01).

5.2.2. An area approximately 14 feet long by 5 feet high (~70 square feet) will be demarcated for each abrasive.

5.2.3. A one hundred pound sample of abrasive, as received, will be riffled to ensure homogeneity, then a one-pound sample will be collected from the homogenous mix for submittal to NIOSH for analysis.

5.2.4. A second 100 gram sample will be collected from the riffled quantity and a sieve analysis conducted in accordance with ASTM C 136 "Standard Test method for Sieve or Screen Analysis of Fine and Coarse Aggregates".

5.2.4.1 The grit will be tamped and shaken through a series of sieves (screen numbers 10, 12, 16, 20, 30, 40, 50, 60, 70, 100, 140, 200, 270 and a pan at the bottom) for seven minutes using an automated shaker. The abrasive collected on each screen will be emptied into numbered and tared sample cups. The underside of each screen will be cleaned with a brass brush to loosen trapped particles, which will also be collected into the appropriate sample cups. The contents of each sample cup will be weighed and documented.

5.2.5. The abrasive media will be loaded into a 6 cubic foot Clemco abrasive hopper equipped with a specialized metering valve. A sufficient quantity of media will be loaded to attain a continuous 30 - 45 minute blast sequence or to clean the available square footage, whichever occurs first.

5.2.6. The air pressure utilization (in psi) at the nozzle will be maintained at 90-100 psi and will be measured and recorded using a hypodermic needle pressure gage prior to each abrasive trial.

5.2.7. Prior to initiating blast cleaning operations, operator and area sampling pumps will be calibrated and the filter media loaded onto the sample holders, or onto the operator (as required). See Industrial Hygiene Protocol (Section 6.0).

5.2.8. The operator will continuously blast clean the designated area , until the abrasive supply is exhausted.

5.2.9. Upon completion of the sampling durations described in Section 6.0, the operator and area sampling pumps will be turned off and the time of day recorded. The sampling media will be removed from the operator and containment when the blast cleaning is completed, and immediately sealed to prevent contamination.

5.2.10. The quantity of time required to blast clean the designated area will be recorded. The actual square footage cleaned will be measured and recorded, along with the total elapsed time.

5.2.11. The area cleaned will be photographed.

5.3. Collection of Blast Cleaning Data

5.3.1. Surfaces will be inspected to verify the required SSPC SP10/NACE No. 2 "Near-White Metal" blast condition has been achieved. SSPC VIS1-89 pictorial standards for assessing surface cleanliness will be used.

5.3.2. Surface profile will be measured in accordance with ASTM D 4417-93 "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel", Method C. X-Coarse Testex replica tape and a spring micrometer will be used. Fourteen (14) measurements will be obtained and documented from the unpitted areas of the structure.

5.3.3. Abrasive embedment will be assessed in 35 random locations using a 10x illuminated magnifier and a 1/2" x 1/2" grid containing 100 squares. The number of squares containing embedded material will be quantified in each of the areas, and a total percentage of embedment calculated and documented.

5.3.4. The abrasive remaining in the blast hose and abrasive hopper (if appropriate) will be collected and weighed to calculate the total consumption rate of the abrasive media (by comparison with original weight used to fill the hopper).

5.3.5. A representative 100 pound sample of the spent abrasive and debris will be collected from the containment floor and riffled (to ensure homogeneity), then a one-pound sample will be collected from the homogenous mix for submittal to NIOSH for analysis.

5.3.6 A 100 gram sample of the riffled spent abrasive and debris will be used for sieve analysis in accordance with ASTM C 136 "Standard Test method for Sieve or Screen Analysis of Fine and Coarse Aggregates". The sample will be tamped and shaken through a series of sieves (screen numbers 10, 12, 16, 20, 30, 40, 50, 60, 70, 100, 140, 200, 270 and a pan at the bottom) for seven minutes using an automated shaker. The material collected on each screen will be emptied into tared, numbered sample cups. The underside of each screen will be cleaned with a brass brush to loosen trapped particles, which will also be collected into the appropriate sample cups. The contents of each sample cup will be weighed and documented.

5.4. Cleaning Procedure Between Abrasive Trials

5.4.1. The abrasive hopper, blast hose and nozzle will be cleaned by exhausting clean, dry compressed air through the system for approximately one minute with the ventilation system in operation. The blast hose will be rinsed with fresh water and dried with compressed air. Two blast hoses will be used and alternated to allow thorough drying prior to use.

5.4.2. The walls, floor, and ceiling of the containment will be thoroughly vacuumed between abrasive media trials. The worker will also decontaminate the blast helmet, coveralls, gloves and boots after each abrasive trial using a vacuum and damp wiping as required. Blasting capes will be alternated and cleaned daily.

5.4.3. An industrial hygiene technician, under the direction of a Certified Industrial Hygienist (CIH), will witness all cleaning procedures and inspect the containment after each cleaning to ensure prevention of sample cross contamination. Additional cleaning with damp cloths will be used, as necessary. The IH Technician will visually verify the cleanliness of all equipment.

5.5. Photographic/Videographic Documentation

5.5.1. 35mm slide photography and 8mm videography will be employed throughout the testing protocol to record typical operations.

6. Industrial Hygiene Monitoring Protocol

5.6. Industrial Hygiene monitoring will be conducted prior to project initiation (background), and during each abrasive trial. Monitoring will entail collection of airborne samples for :

5.6.1. Respirable Crystalline Silica

5.6.2. Respirable Radiochemical Activity

5.6.3. Total Airborne Radiochemical Activity

5.6.4. Total Airborne Elements

5.7. Prior to each abrasive trial, sampling pumps will be calibrated using a Gilian Gilibrator-2 primary calibration precision flow bubble meter equipped with a standard flow cell (20cc-6 lpm). Calibration will be conducted through the representative filter media. The actual flow rates for each pump will be documented on the pump calibration report (attached).

5.8. Verification of flow rates will be conducted upon completion of each abrasive trial. Post trial pump flow rates will be measured and documented on the pump flow verification form (attached).

5.9. Filter media will be positioned in sample holders in four locations within the containment, and include :

  5.9.1. Make-up Air Side of Containment (fixed location)

  5.9.2. Operator Area (fixed location)

  5.9.3. Exhaust (ventilation) Area of Containment (fixed location)

  5.9.4. On the operator, within the breathing zone

5.10. Sample bank holders will be mounted 12" from the containment side walls (make-up, operator area and exhaust), at breathing zone height (5-6'). Samples will have a 6" clearance from each other.

5.11. Filter media positioned in the operator's breathing zone will be mounted in a hemisphere 6-9" from the nose/mouth, forward of the shoulders in a downward direction, outside of respiratory protection.

5.12. Sampling for Respirable Dust and Respirable Crystalline Silica

  5.12.1. Respirable crystalline silica samples will be collected in each of the three areas in the containment and within the breathing zone of the operator using MSA 10mm nylon cyclones equipped with 37mm, 0.5 micron pore pre-weighed PVC filter media, at a flow rate of 1.7 liters per minute. Sampling for crystalline silica will commence after three minutes of blast time has elapsed, to facilitate equilibrium within the containment. Twenty four (24) minute samples will be obtained.

  5.12.2. Samples will be analyzed for respirable dust and silica. Analysis for respirable crystalline silica will be conducted in accordance with NIOSH method 7500 (x-ray diffraction); analysis for respirable dust will be conducted by NIOSH laboratories in accordance with NIOSH Method 0600.

5.13. Sampling for Respirable Radiochemical Activity

  5.13.1. Respirable radiochemical activity samples will be collected in each of three areas in the containment using MSA 10mm nylon cyclones equipped with 37mm, 0.5 micron pore pre-weighed PVC filter media, at a flow rate of 1.7 liters per minute.

  5.13.2. Sampling for respirable radiochemical activity will commence after three minutes of blast time has elapsed, to facilitate equilibrium within the containment. Twenty four (24) minute samples will be obtained.

5.13.3. Analysis for respirable radiochemical activity will be conducted by NIOSH laboratories.

5.14. Sampling for Total Radiochemical Activity

5.14.1. Total radiochemical activity samples will be collected in each of three areas in the containment using pre-weighed 37mm, 0.5 micron pore PVC filter media at a flow rate of 4.0 liters per minute.

5.14.2. Sampling for total radiochemical activity will commence after 3 minutes of blast time has elapsed, to facilitate equilibrium within the containment. Twenty-four (24) minute samples will be obtained.

5.14.3. Analysis for total radiochemical activity will be conducted by NIOSH laboratories.

5.15. Sampling for Elements

5.15.1. Elemental samples will be collected in each of the three areas in the blast room and within the breathing zone of the operator using sampling pumps equipped with 37mm, 0.8 micron pore mixed cellulose ester membrane filter media. Sampling will be conducted at a flow rate of 2.0 liters per minute.

5.15.2. Sampling for elements will commence after three minutes of blast time has elapsed, to facilitate equilibrium within the containment. Twenty-four (24) minute samples will be collected.

5.15.3. Analysis for elements will be conducted by NIOSH laboratories in accordance with NIOSH Method 7300.

5.16. Background Monitoring

5.16.1. Prior to initiating Phase 2, background monitoring will be conducted for seven (7) hours. Airborne samples for respirable dust, respirable crystalline silica, respirable radiochemical activity, total radio-chemical activity and elements will be collected in each of three areas within the containment, with the ventilation system in operation. The air flow (in fpm) will be measured and documented for the background study. Flow rates will be similar to those targeted during actual blast cleaning operations.

7. Report Format

7.1 Upon completion of all testing procedures and receipt of analytical data from the NIOSH laboratory, a written report will be prepared. The report will be formatted as follows:

- 7.1.1 Introduction
- 7.1.2 Executive Summary
- 7.1.3 Description of Abrasive Media Test Procedures
- 7.1.4 Description of Industrial Hygiene Monitoring Procedures
- 7.1.5 Results of Abrasive Media Testing
- 7.1.6 Results of Industrial Hygiene Analysis
- 7.1.7 Calculation of Operating Costs based on Economical Factors
- 7.1.8 Statistical Analysis of Operator and Area Exposure Monitoring Data
- 7.1.9 Quality Assurance/Quality Control Procedures Implemented to Ensure Validity of Testing
- 7.1.10 Testing Errors, Deficiencies or Deviations Encountered
- 7.1.11 Conclusions and Recommendations
- 7.1.12 Photographic Documentation

APPENDIX 2

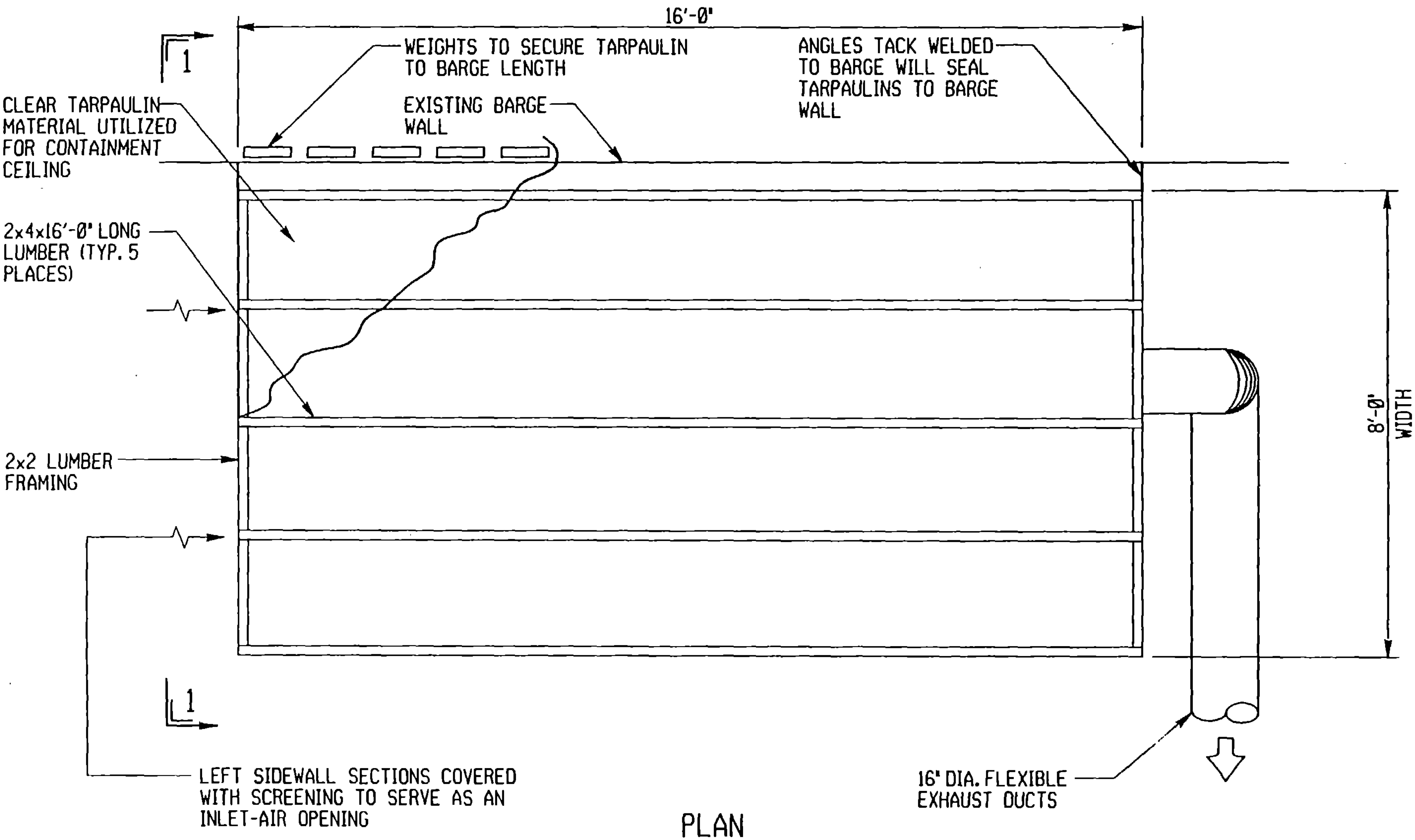
APPENDIX 2
Productivity Data

Abrasive Type	Log Number	Nozzle Size	Nozzle Pressure	Choke Valve Setting	Metering Valve Setting
CS	J97119-03	7/16"	95 psi	70°	1/2"
N	J97119-P2-05	7/16"	95 psi	90°	3/8"
S	J97119-07	7/16"	95 psi	90°	5/16"
SS	J97119-01	7/16"	95 psi	90°	5/16"
SSDS	J97119-02	7/16"	95 psi	90°	5/16"
CP	J97119-P2-04	7/16"	95 psi	90°	7/16"
G	J97119-P2-06	7/16"	95 psi	90°	5/16"
SG	J97119-P2-08	7/16"	95 psi	90°	3/8"

Runcond.xls / Prod_data

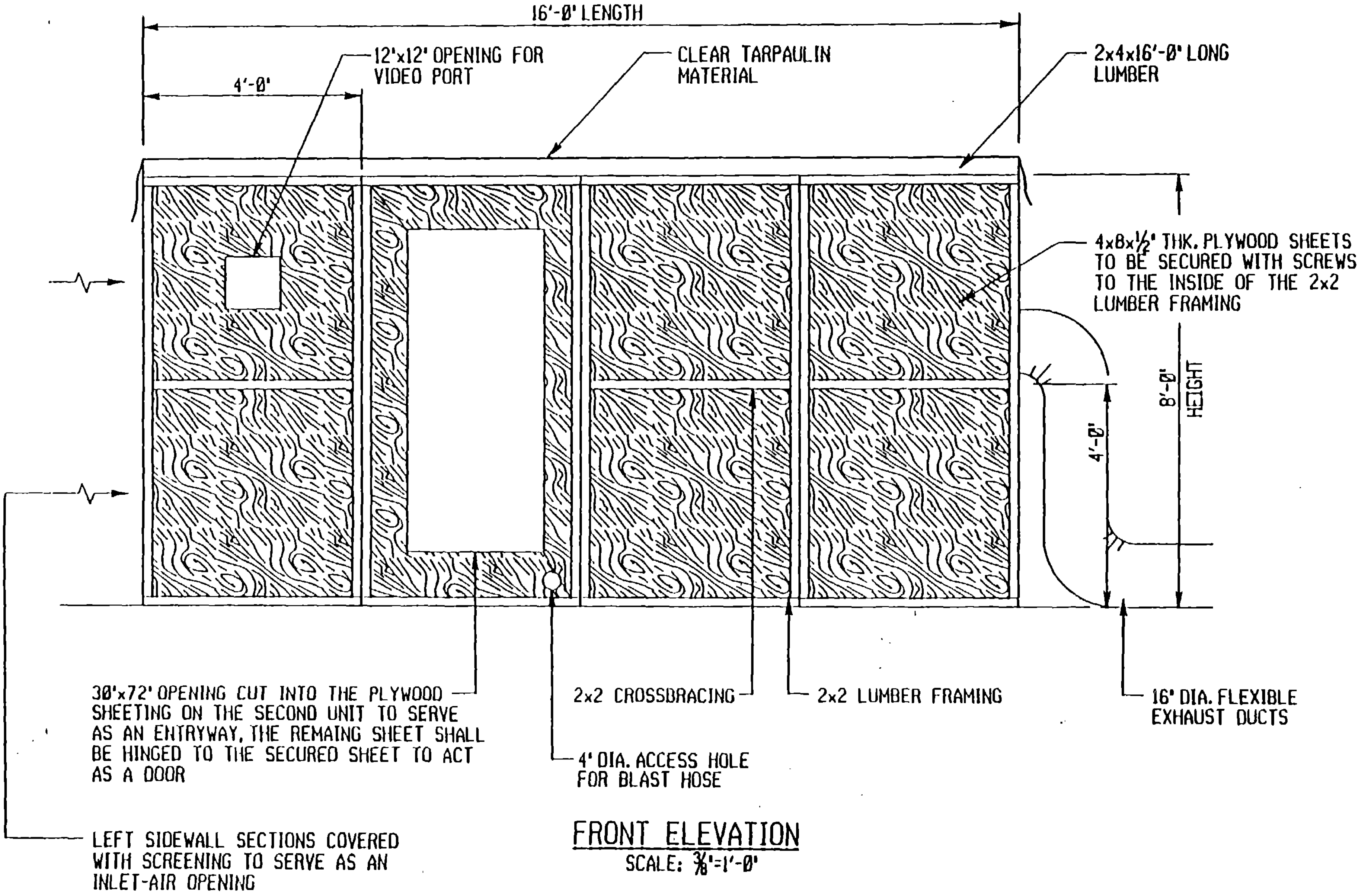
APPENDIX 2
Blast Run Conditions

Abrasive Type	Log Number	Blast Date	Blast Time	Ambient Conditions					Ventilation
				Air Temp °F	RH %	DP °F	ST °F	Bar Pre	Air Flow (FPM)
CS	J97119-03	9/16/97	12:55 PM	78	60	63	88	30.00	41.67
N	J97119-P2-05	9/24/97	9:40 AM	55	70	45	63	29.26	41.42
S	J97119-07	9/19/97	8:43 AM	60	83	55	71	29.18	23.92
SS	J97119-01	9/17/97	9:57 AM	69	76	61	72	29.80	41.08
SSDS	J97119-02	9/18/97	10:00 AM	68	80	62	75	30.09	36.25
CP	J97119-P2-04	9/23/97	10:15 AM	60	78	53	66	29.21	44.92
G	J97119-P2-06	9/22/97	9:45 AM	55	70	45	63	29.38	27.25
SG	J97119-P2-08	9/25/97	9:44 AM	58	83	53	66	29.00	35.08



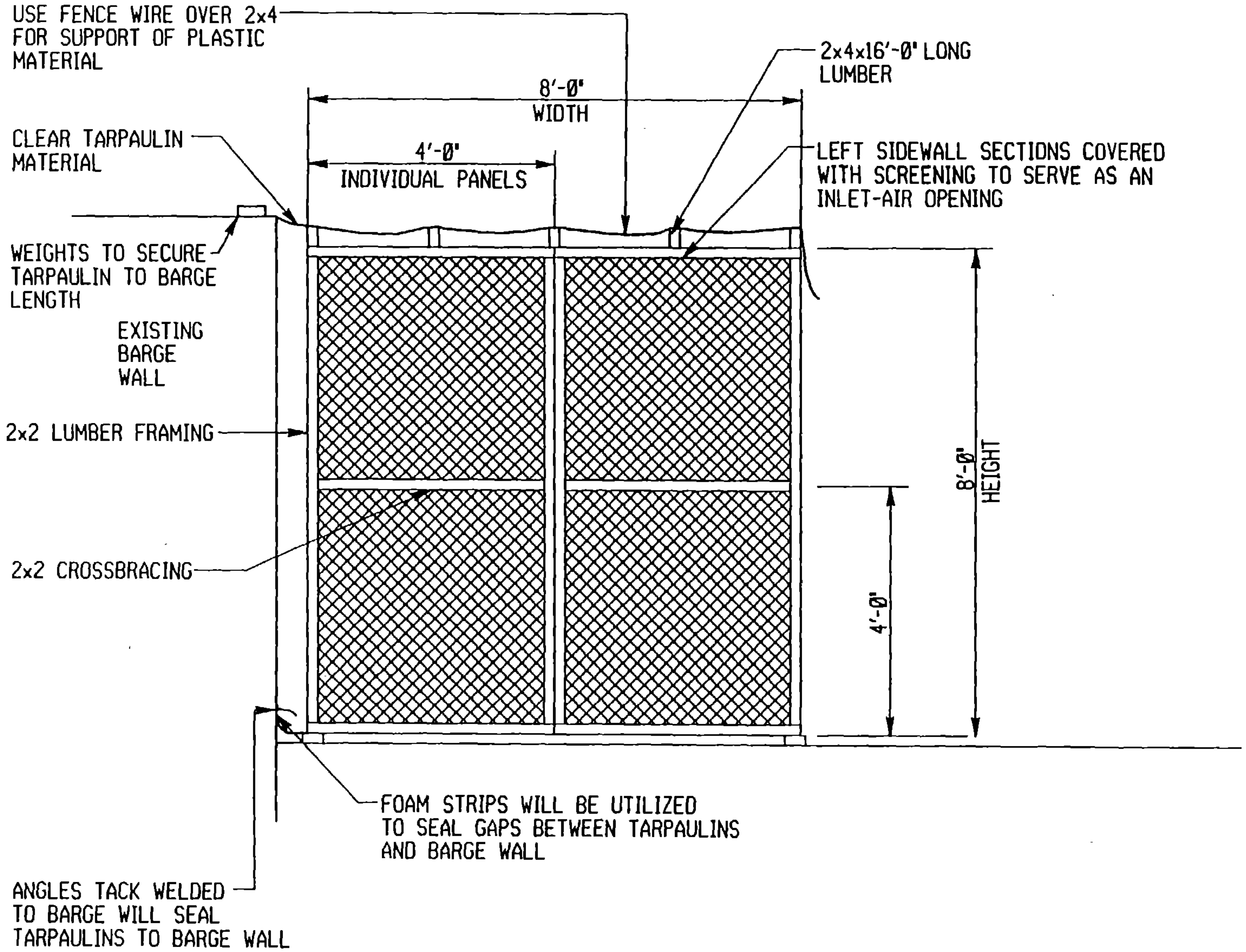
PLAN

SCALE: 3/8"=1'-0"



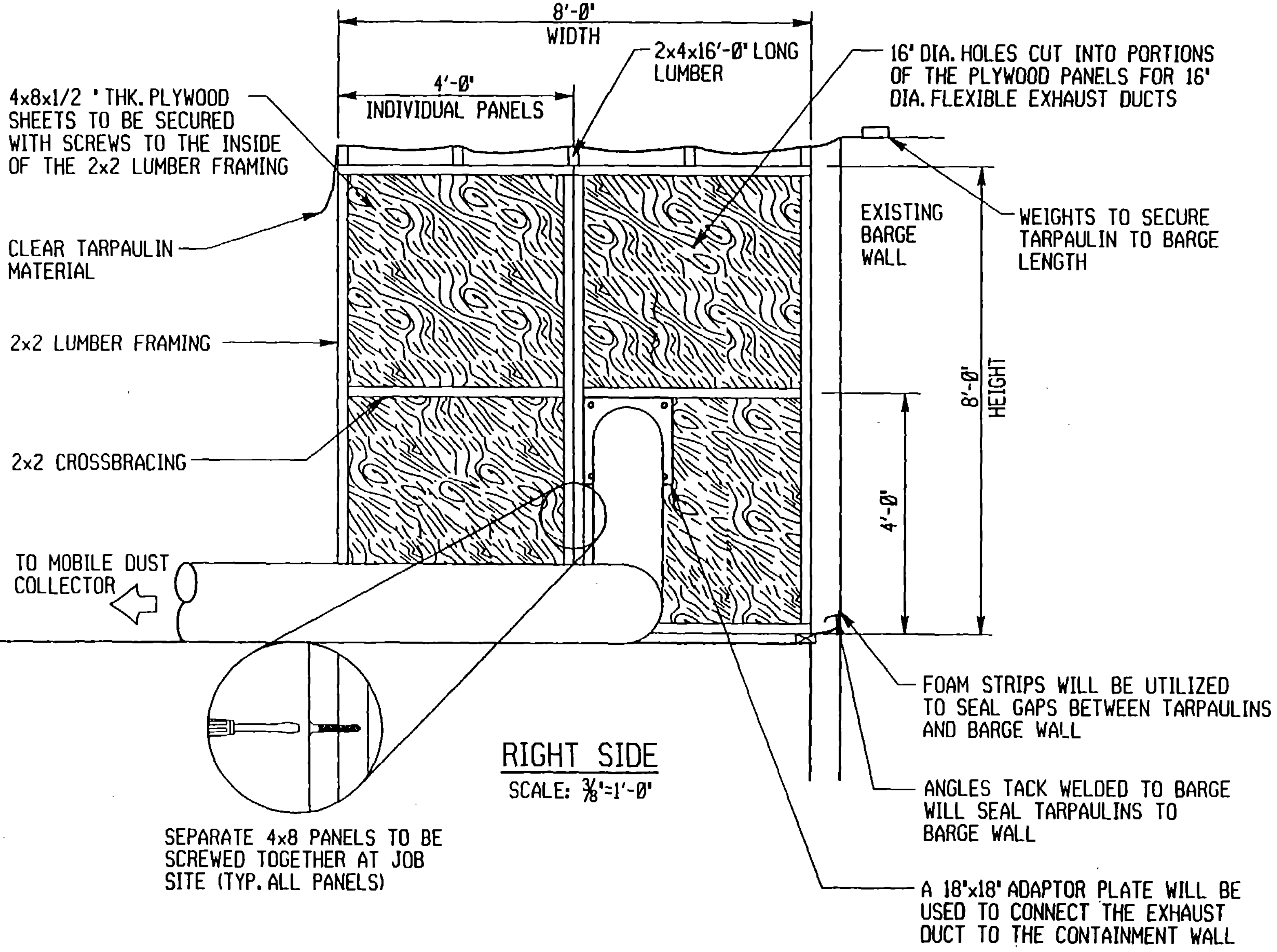
FRONT ELEVATION

SCALE: ⅜'=1'-0'



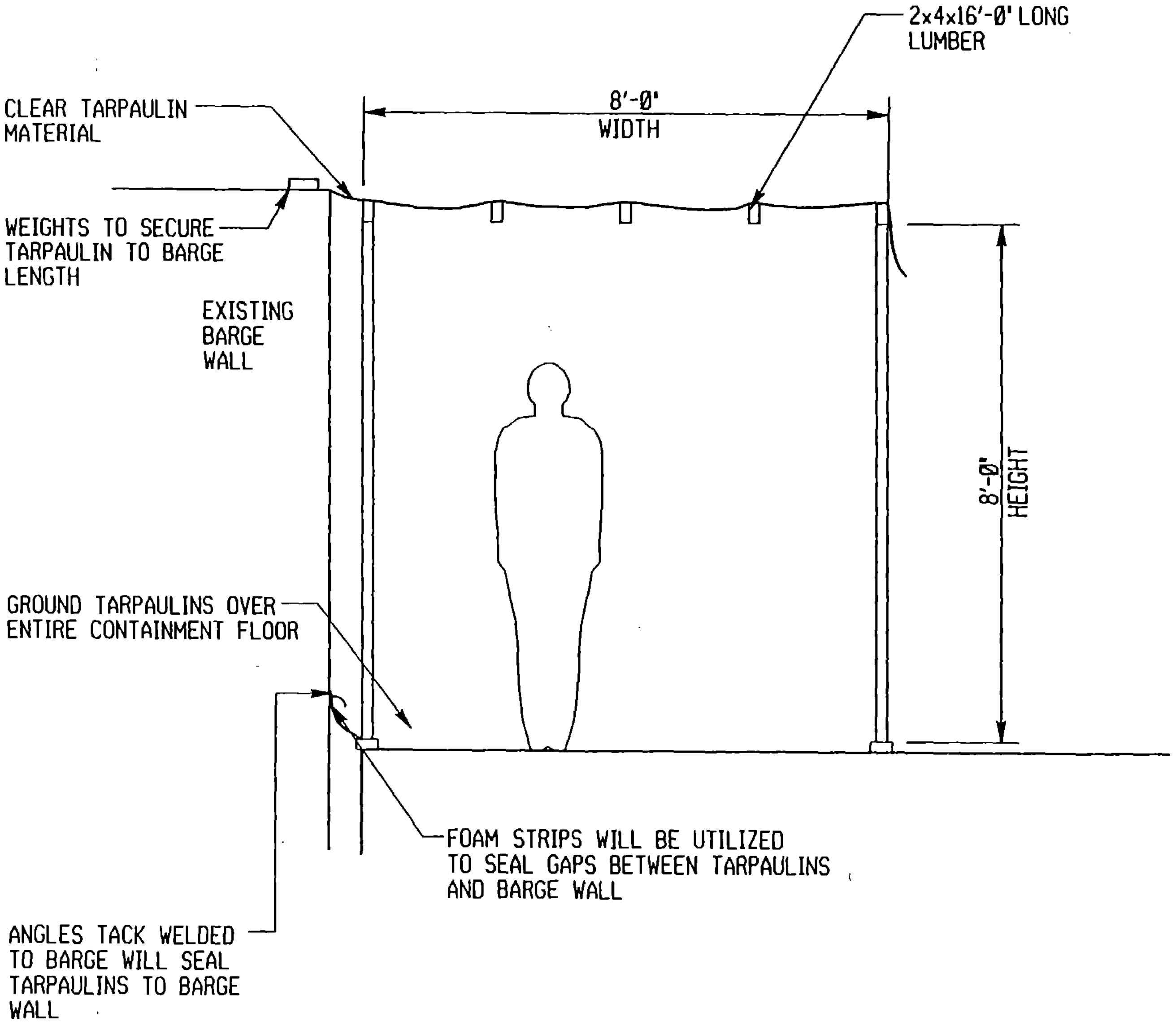
LEFT SIDE

SCALE: 3/8"=1'-0"



RIGHT SIDE

SCALE: 3/8"=1'-0"



SECTION 1-1

SCALE: 3/8"=1'-0"

APPENDIX 3

Exhibit 1

KTA-TATOR, Inc.
Protective Coating Consultants
115 Technology Drive
Pittsburgh, PA
412-788-1300

NIOSH
Project

Facility:		**Blast Cleaning Inspection Report**	Time	Air T °F	RH %	DP °F	ST °F	Bar Pre
Date:	IR #: J95331-01							
KTA/SET Job Number J95331								

Generic Abrasive	Trade Name
Abrasive Log Number	Size Designation Grade
Abrasive Mfg.	Supplier
Pre Blast Checkboxes:	

Abrasive Riffle ☐	100g Sieve Analysis ASTM C-136 ☐	Sample Envelope Microhardness ITL ☐
1 lb Sample NIOSH ☐	300ml Sample ASTM D-4940 KTA Lab ☐	1 lb Sample KTA ☐

Item No:		Surface Preparation		Surface Profile (mils)			Embedment					Steel Sample
Panel No:		Spec	Act	Spec	Act	Act	Area 1	Area 2	Area 3	Area 4	Area 5	Area #
1		SP-10		2-3								
2		SP-10		2-3								
3		SP-10		2-3								
4		SP-10		2-3								
5		SP-10		2-3								
6		SP-10		2-3								
7		SP-10		2-3								
8		SP-10		2-3								
9		SP-10		2-3								

Consumption and Cleaning Rate			**Total Blast Time**
Initial Amount of Abrasive	**Spec**	**Act.**	**Choke Valve Setting**
Abrasive left (hose and pot)			**Metering Valve Setting**
Square Feet Cleaned			

S. P. QUALITY ITEMS		CAL OK	Instrument	SERIAL NUMBER
Hose/Nozzle Number Used	1 2	☐	HYGROMETER	
Nozzle Orifice Gauge	Size: 3 4 5 6	☐	SURFACE THERMOMETER	
ASTM D-4285 Blotter Test Results	P F	☐	TESTEX TAPE Used XC C	N/A
Nozzle Pressure	psi	☐	SPRING MICROMETER	
Hose Flushed and dried	Y N	☐	NOZZLE ORIFICE GAGE	
		☐	BAROMETER	

Post Blast Checkboxes:

Abrasive Riffle ☐	1 lb Sample NIOSH ☐	100g Sieve Analysis ASTM C-136 ☐

Technician	Signature	Project Supervisor	Signature
Date	Print	Date	Print

KTA Tator Blast Cleaning Inspection Report Form				**QPF-WDC345R.1**	
Rev. 1	Org. By: MFM	App. by:	Page 1 of 1	Issued 4-15-96	File #

Exhibit 2

KTA Sieve Analysis Report Form	MATF 100R.2
Revision No. 2	Issued 3/12/96

KTA-Tator, Inc.

MATS Group
Sieve Analysis

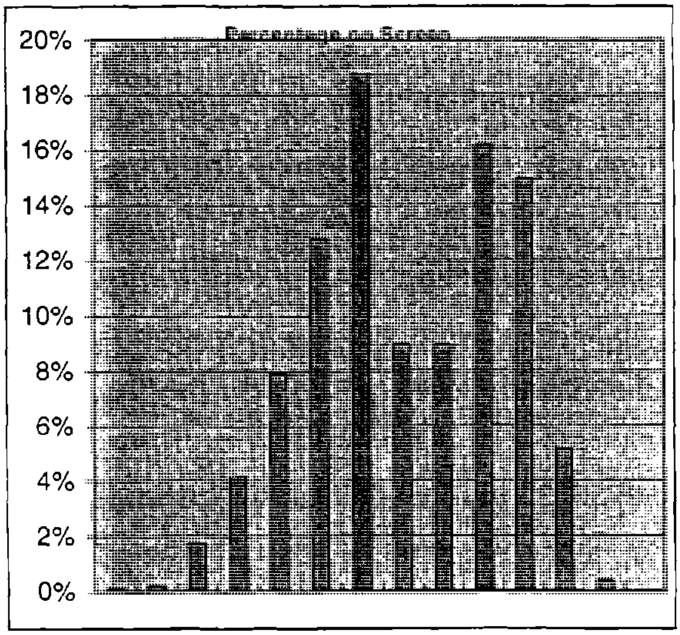
Sample Number ____________________ Date ____________________
Weight of Sample ____________________ Technician ____________________
Sample Description ____________________ Job ____________________
____

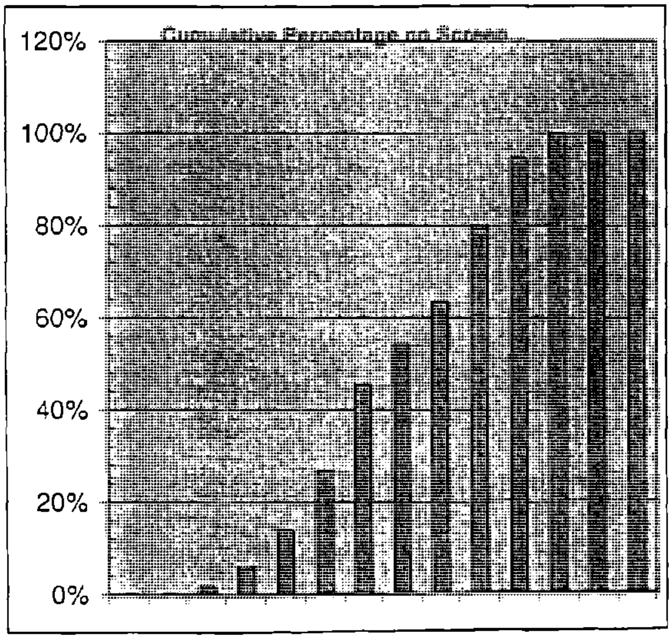
Sieve #	Wt. Cup and Grit	Cup	Grit	% of Total	Cum % of Total	S.O.S.** in mm	Particle Size Avg
10	12.7	12.6	0.1	0.10%	0.10%	2.000	0.20
12	13.1	12.9	0.2	0.20%	0.20%	1.700	0.34
16	15.2	13.5	1.7	1.71%	1.91%	1.180	2.01
20	16.8	12.7	4.1	4.13%	6.04%	0.850	3.49
30	20.6	12.8	7.8	7.85%	13.90%	0.600	4.68
40	25.4	12.7	12.7	12.79%	26.69%	0.425	5.40
50	31.5	12.9	18.6	18.73%	45.42%	0.300	5.58
60	21.7	12.8	8.9	8.96%	54.38%	0.250	2.23
70	21.8	12.9	8.9	8.96%	63.34%	0.210	1.87
100	28.9	12.9	16	16.11%	79.46%	0.150	2.40
140	27.7	12.9	14.8	14.90%	94.36%	0.110	1.63
200	17.5	12.4	5.1	5.14%	99.50%	0.075	0.38
270	13.1	12.7	0.4	0.40%	99.90%	0.053	0.02
Pan*	12.8	12.8	0	0.00%	99.90%	0.038	0.00
Total			99.3	100.00%		Sum =	30.21

* Approximated as a #400 Sieve

** S.O.S. is Screen Opening Size

Average particle size = Sum / Total Wt. (in mm) = 0.30





1255.xls Sieve Test Results

Exhibit 3

KTA/SET ENVIRONMENTAL

115 Technology Drive
Pittsburgh, PA
412-788-1300

Project: CDC/NIOSH; Phase 2	**Pump Calibration Report**	Facility: Consolidated Coal Co., Elizabeth, PA

Date:	Time:	Generic Abr. Type:
KTA/SET Project Number: J95119		Trade Name:
Abrasive Log Number:		Supplier:
Abrasive Mfg.:		Size:
		Grade:

Calibration Equipment:

Gilibrator Precision Flow Bubble Meter SN:

Gilibrator Standard Flow Cell SN:

Calibration Conducted By: ____________________(print) ______________________(signature)

Comments:

Location: Make-up Air Sample Bank

Pump ID	Hose No.	Media	Target (l/min)	Actual Flow (l/min)					Ave Flow (l/min)
				1	2	3	4	5	
A	1	PVC (Resp. Dust)	1.7						
B	2	PVC (Resp. R.A.)	1.7						
C	3	PVC (Total R.A.)	4.0						
D	4	0.8 µ m MCE	2.0						

KTA/SET Pump Calibration Report Form					
Rev. 2	Org. By: WDC	App. By:	Page 1 of 2	Issued 7-1-96	

Exhibit 3
(con't)

KTA/SET ENVIRONMENTAL

115 Technology Drive
Pittsburgh, PA
412-788-1300

Location: Operator Air Sample Bank

Pump ID	Hose No.	Media	Target (l/min)	Actual Flow (l/min)					Ave Flow (l/min)
				1	2	3	4	5	
E	5	PVC (Resp.)	1.7						
F	6	PVC (R.A.)	1.7						
G	7	PVC (Total R.A.)	4.0						
H	8	0.8 µ m MCE	2.0						

Location: Exhaust Sample Bank

Pump ID	Hose No.	Media	Target (l/min)	Actual Flow (l/min)					Ave Flow (l/min)
				1	2	3	4	5	
I	9	PVC (Resp.)	1.7						
J	10	PVC (Resp. R.A.)	1.7						
K	11	PVC (Total R.A.)	4.0						
L	12	0.8 µ m MCE	2.0						

Location: Make-up Air Sample Bank

Pump ID	Hose No.	Media	Target (l/min)	Actual Flow (l/min)					Ave Flow (l/min)
				1	2	3	4	5	
M	13	PVC (Resp. Dust)	1.7						
N	14	0.8 µ m MCE	2.0						

KTA/SET Pump Calibration Report Form					
Rev. 2	Org. By: WDC	App. By:	Page 2 of 2	Issued 7-1-96	

Exhibit 4

KTA/SET ENVIRONMENTAL
MECHANICAL VENTILATION EVALUATION FORM

Project: CDC/NIOSH, Phase 2
Equipment:
Air Measurement Instrument:

Evaluator:
Inspection Date:
KTA/SET No.: J97119

A. LOCATION DIAGRAM

AIR VELOCITY MEASUREMENTS
INSIDE BLAST ROOM

1	2	3	4
5	6	7	8
9	10	11	12

Measurements are made at the center of the blast room, across the cross-sectional area perpendicular ot the air flow.

MEASUREMENT RESULTS

1 ____________ 7 ____________
2 ____________ 8 ____________
3 ____________ 9 ____________
4 ____________ 10 ____________
5 ____________ 11 ____________
6 ____________ 12 ____________

Average Air Velocity (AAV) = ________ FPM

Exhibit 5

KTA/SET ENVIRONMENTAL

115 Technology Drive
Pittsburgh, PA
412-788-1300

Project: CDC/NIOSH; PHASE 2	**Industrial Hygiene Report**	Facility: Consolidated Coal Co., Elizabeth, PA

Date:	Time:	Generic Abr. Type:	
KTA/SET Project Number: J97119		Trade Name:	
Abrasive Log Number:		Supplier:	
Abrasive Mfg.:		Size:	
Worker Properly Protected (✓)		Grade:	

Ventilation Assessment Complete (✓)			**Ventilation Form Complete (✓)**		

Cleaning Verification (✓)				
Hopper		Walls		
Hose		Ceiling		
Nozzle		Floor		
Reclaimer		Worker		
Chain of Custody – Air – Complete (✓)				

Comments:

Technician	Project Supervisor
Print	Print
Signature	Signature
Date	Date

KTA/SET Industrial Hygiene Report Form					
Rev. 2	Org. By: WDC	App. By:	Page 1 of 2	Issued 7-1-96	

Exhibit 5
(con't)

AIR SAMPLING DATA

Location: Make-up Air Sample Bank

Pump ID	Hose No.	Sample No.	Media	Time On	Time Off	Elapsed Time	Volume
A	1		0.5 μ m PVC				
B	2		0.5 μ m PVC				
C	3		0.5 μ m PVC				
D	4		0.8 μ m MCE				

Location: Make-up Air Sample Bank

Pump ID	Hose No.	Sample No.	Media	Time On	Time Off	Elapsed Time	Volume
E	4		0.5 μ m PVC				
F	5		0.5 μ m PVC				
G	6		0.5 μ m PVC				
H	7		0.8 μ m MCE				

Location: Make-up Air Sample Bank

Pump ID	Hose No.	Sample No.	Media	Time On	Time Off	Elapsed Time	Volume
I	8		0.5 μ m PVC				
J	9		0.5 μ m PVC				
K	10		0.5 μ m PVC				
L	11		0.8 μ m MCE				

Location: Operator Breathing Zone

Pump ID	Hose No.	Sample No.	Media	Time On	Time Off	Elapsed Time	Volume
M	13		0.5 μ m PVC				
N	14		0.8 μ m MCE				

Exhibit 6

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
Division of Respiratory Disease Studies
1095 Willowdale Road
Morgantown, WV 26505-2888
(304) 285-5754

SAMPLE SUBMITTAL FORM

NIOSH Investigator: Mark F. Greskevitch
Date: July 1, 1996
Sampling Site: KTA/SET ENVIRONMENTAL, INC. ENCLOSED BLASTING BOOTH in PITTSBURGH, PA
Project No: DRDS 96-057
Industrial Process: SIC 1700 CONSTRUCTION
Collection Date: 06-07-96
Air Temp (°C): N/A
Shipment Date: 06-27-96

Sequence Number	Analysis Requested	Sample Characteristics (Type*, Manuf., Lot No.)
8395	Elemental: ICP-AES (7300) and Graphite furnace method for 4 elements listed in comments	Airborne samples for elemental analysis, see attached MSDS sheets of abrasive used and spec sheets for steel blasted upon

* Specify: Solid Sorbent Tube (eg. Charcoal), Filter Type, Impinger Solution, Bulk Sample, Blood, Urine, Tissue, Other

Laboratory Sample Number	Field Sample Number	Air Vol. (liters)

Exhibit 7

CHAIN OF CUSTODY RECORD - AIR SAMPLING FORM

SHEET ____ OF ____

1. PROJECT NUMBER: J95331

2. DATE:

3. PROJECT NAME/LOCATION: NIOSH/CDC - PITTSBURGH, PA

4. NAME OF SAMPLER

Print

Signature

Name

Company KTA/SET Environmental

City Pittsburgh

State PA

Zip Code 15275

6. **SAMPLE NUMBERS**

7. SAMPLES RELINQUISHED BY			8. SAMPLES RECEIVED BY		
NAME	DATE	TIME (note am/pm)	NAME	DATE	TIME (note am/pm)

KTA/SET ENVIRONMENTAL

115 TECHNOLOGY DRIVE
PITTSBURGH, PA 15275

PHONE: (412) 788-1300
FAX: (412) 788-1306

CHAINOC.DOC

Exhibit 8

KTA/SET ENVIRONMENTAL

115 Technology Drive
Pittsburgh, PA
412-788-1300

Project: CDC/NIOSH; Phase 2	**Pump Flow Verification Report**	Facility: Consolidated Coal Co., Elizabeth, PA

Date:	Time:	Generic Abr. Type:
KTA/SET Project Number: J97119		Trade Name:
Abrasive Log Number:		Supplier:
Abrasive Mfg.:		Size:
		Grade:

Verification Equipment:

Gilibrator Precision Flow Bubble Meter	SN:
Gilibrator Standard Flow Cell	SN:

Calibration Conducted By: ______________________(print) ______________________(signature)

Comments:

Location: Make-up Air Sample Bank

Pump ID	Hose No.	Media	Target (l/min)	Actual Flow (l/min)					Ave Flow (l/min)
				1	2	3	4	5	
A	1	PVC (Resp.)	1.7						
B	2	PVC (Resp. R.A.)	1.7						
C	3	PVC (Total R.A.)	4.0						
D	4	0.8 µ m MCE	2.0						

Exhibit 8
(con't)

Location: Operator Area Sample Bank

Pump ID	Hose No.	Media	Target (l/min)	Actual Flow (l/min)					Ave Flow (l/min)
				1	2	3	4	5	
E	5	PVC (Resp.)	1.7						
F	6	PVC (Resp. R.A.)	1.7						
G	7	PVC (Total R.A.)	4.0						
H	8	0.8 µ m MCE	2.0						

Location: Exhaust Sample Bank

Pump ID	Hose No.	Media	Target (l/min)	Actual Flow (l/min)					Ave Flow (l/min)
				1	2	3	4	5	
I	9	PVC (Resp.)	1.7						
J	10	PVC (Resp. R.A.)	1.7						
K	11	PVC (Total R.A.)	4.0						
L	12	0.8 µ m MCE	2.0						

Location: Operator Breathing Zone

Pump ID	Hose No.	Media	Target (l/min)	Actual Flow (l/min)					Ave Flow (l/min)
				1	2	3	4	5	
M	13	PVC (Resp. Dust)	1.7						
N	14	0.8 µ m MCE							

KTA/SET Pump Flow Verification Report Form					
Rev. 2	Org. By: WDC	App. By:	Page 2 of 2	Issued 7-1-96	

APPENDIX 4

Exhibit 1

KTA Tator, Inc.

PATIENT INFORMATION:

VITAL SIGNS:

TESTS:

WORKPLACE CLEARANCE

Full use of Negative Pressure Respirator

PHYSICIAN COMMENTS:

SPECIMEN # | TYPE | PRIMARY LAB | REPORT STATUS

Exhibit 2

LabCorp™

ADDITIONAL INFORMATION

CLINICAL INFORMATION

XTA NO UA PER ACCT

PHYSICIAN ID. | PATIENT ID.

NAME | SEX | AGE (YR MOS)

ACCOUNT

ATE OF SPECIMEN | DATE ENTERED | DATE REPORTED

TEST	RESULT	LIMITS	TEST SITE ON BACK
LEAD STANDARD PROFILE			
Lead, Blood			
Protoporphyrin (FEP)			
Zinc Protoporphyrin			
C+CBC+DIFF+UA			
CHEMISTRIES			
Glucose			
Acid			
Creatinine, Serum			
BUN/Creatinine Ratio			
Sodium, Serum			
Potassium, Serum			
Chloride, Serum			
Calcium			
Phosphorus			
Protein, Total			
Albumin, Serum			
Globulin, Total			
A/G Ratio			
Bilirubin, Total			
Alkaline Phosphatase			
LDH			
SGOT (AST)			
SGPT (ALT)			
GGT			
Iron, Total			
LIPIDS			
Cholesterol, Total			
Triglycerides			
HDL Cholesterol			
VLDL Cholesterol Cal			
LDL Cholesterol Calc			
Chol/HDL Ratio			
Estimated CHD Risk			
(The CHD Risk is based on the			
T.Chol/HDL Ratio. Other factors			

RESULTS ARE FLAGGED IN ACCORDANCE WITH AGE DEPENDENT REFERENCE RANGES

REPORT

SPECIMEN # | TYPE | PRIMARY LAB | REPORT STATUS

Exhibit 2 (cont.)

LabCorp™

ADDITIONAL INFORMATION

CLINICAL INFORMATION

PHYSICIAN ID.

PATIENT ID.

NAME | SEX | AGE (YR/MOS.)

ACCOUNT

PT. ADD.

DATE OF SPECIMEN | DATE ENTERED | DATE REPORTED

TEST	RESULT	LIMITS	TEST SITE ON BACK

CBC, PLATELET CT, AND DIFF
White Blood Count
Red Blood Count
Hemoglobin
Hematocrit
MCV
MCH
MCHC
Platelets
Polys
Lymphs
Monocytes
Eos
s
s (Absolute)
phs (Absolute)
Monocytes(Absolute)
Eos (Absolute Value)
Baso(Absolute)

URINALYSIS GROSS EXAM
Specific Gravity
No urine specimen received.

LAB: CB LABCORP HOLDINGS DIRECTOR: RICHARD MCVAY MD
6370 WILCOX ROAD DUBLIN, OH 43016-1296

DIRECTOR: RICHARD MCVAY MD
IF YOU HAVE ANY QUESTIONS CONTACT - BRANCH: 412-937-1001 LAB: 800-321-3862
LAST PAGE OF REPORT

RESULTS ARE FLAGGED IN ACCORDANCE WITH AGE DEPENDENT REFERENCE RANGES

REPORT

APPENDIX A

TABLE A1
ABRASIVE CLEANING AND CONSUMPTION RATES

Generic Abrasive Type	Time (min)	SF Cleaned	Metering Valve Settings	Cleaning Rate (FT^2/Hour)	Consumption Rate (Lbs./Hour)	Consumption Rate (Lbs./FT^2)
CS-06	22.7	54.5	#5 (1/2")	144	1032	7.2
N-01	31.55	54.4	#3 (3/8")	104	947	9.2
S-02	24.87	58.2	#2 (5/16")	140	1137	8.1
SS-04	25.00	53.0	#2 (5/16")	127	1077	8.5
SSDS-03	21.80	53.0	#2 (5/16")	146	1284	8.8
CP-2A	33.00	56.3	#4 (7/16")	102	870	8.5
G-3A	19.92	57.4	(#2) (5/16")	173	1383	8.0
SG-2A	41.55	57.1	#3 (3/8")	83	1287	15.6

Table_A1.XLS/ A1 Abras. C&C

TABLE A2
SURFACE PROFILE

Run Number	Surface Profile Measurements (mils)*														Average Surface Profile (mils)
CS-06	4.4	4.5	4.5	4.1	3.6	3.9	4.0	4.3	4.3	4.1	4.2	4.0	4.5	4.5	4.2
N-01	4.3	3.3	4.2	4.3	4.0	4.0	4.0	4.3	3.5	4.0	4.0	4.2	4.5	4.5	4.1
S-02	4.1	4.3	4.3	4.5	4.3	4.0	4.2	4.2	2.1	3.1	4.2	4.2	3.6	3.5	3.9
SS-04	4.5	4.3	4.5	3.9	4.5	4.0	4.0	4.4	3.9	4.2	4.4	4.1	4.5	4.5	4.3
SSDS-03	4.0	3.8	4.2	4.1	4.2	3.8	4.3	4.3	3.2	3.6	3.8	4.0	4.3	4.3	4.0
CP-2A	4.4	4.5	4.5	4.4	4.3	4.5	4.5	4.5	4.5	4.2	4.2	4.4	4.5	4.0	4.4
G-3A	4.0	4.2	4.5	4.5	4.2	4.5	4.5	4.5	4.5	4.5	4.2	4.5	4.3	4.5	4.4
SG-2A	4.2	4.1	4.3	4.0	4.2	4.5	4.2	4.5	4.3	4.5	4.5	4.4	4.4	4.4	4.3

* Measurements equal to 4.5 mils represent a minimum of 4.5 mils. Higher measurements cannot be obtained using Testex Tape.

TABLE A3
BREAKDOWN RATE

Abrasive Type	Pre-Blast Particle Size (mm x 100)	Post-Blast Particle Size (mm x 100)	Average Particle Size is Reduced by X%	Average Particle Size is X% of Original
CS-06	51	21	58.82	41.18
N-01	52	22	57.69	42.31
S-02	17	12	29.41	70.59
SS-04	48	22	54.17	45.83
SSDS-03	39	23	41.03	58.97
CP-2A	79	27	65.82	34.18
G-3A	38	19	50.00	50.00
SG-2A	51	49	3.92	96.08

TABLE A4
EMBEDMENT RESULTS

Embedment Results (%)	Measurement Number	Abrasive Type							
		CS-06	N-01	S-02	SS-04	SSDS-03	CP-2A	G-3A	SG-2A
Area No. 1	1	15	7	5	7	2	14	25	9
	2	20	3	3	7	4	17	4	12
	3	21	4	2	8	4	13	12	9
	4	10	4	1	4	3	6	5	6
	5	13	3	1	3	1	9	0	4
Area No. 2	1	16	5	6	5	2	10	8	7
	2	21	3	4	6	3	12	6	9
	3	22	5	3	5	3	14	5	4
	4	9	2	3	5	0	9	3	6
	5	8	1	1	8	2	11	4	7
Area No. 3	1	27	3	4	3	4	19	3	7
	2	25	2	1	5	1	14	5	27
	3	29	1	0	3	3	12	3	8
	4	12	1	0	6	1	9	2	13
	5	14	1	1	8	0	12	3	9
Area No. 4	1	30	0	3	1	4	14	22	30
	2	19	3	1	1	0	11	17	13
	3	25	3	2	1	4	13	4	9
	4	17	2	1	1	1	10	1	10
	5	8	7	2	3	1	9	0	7
Area No. 5	1	21	2	0	3	5	12	2	21
	2	20	6	0	7	2	12	13	21
	3	19	2	1	1	3	11	3	15
	4	13	1	0	2	0	10	1	5
	5	9	1	0	6	0	9	2	8
Area No. 6	1	16	2	3	6	0	13	2	14
	2	17	2	2	3	2	12	3	26
	3	25	2	0	4	2	11	3	9
	4	11	1	0	16	0	6	1	6
	5	9	3	0	4	0	9	1	7
Area No. 7	1	15	3	2	3	0	10	5	21
	2	15	6	1	2	1	7	2	15
	3	12	0	0	6	3	11	1	5
	4	11	2	1	2	1	6	2	7
	5	7	1	1	3	0	9	2	4
Average Embedment (%)		16.6	2.7	1.6	4.5	1.8	11.0	5.0	11.1

APPENDIX B

APPENDIX B
GLOSSARY

Station No. 1 – Make-up air area of blast room
Station No. 2 – Operator area of blast room
Station No. 3 – Exhaust area of blast room

LOD – Limit of Detection
LOQ – Limit of Quantification
ND – Nondetectable (the element could not be detected above the given LOD)

Aluminum

Aluminum, in the form of a fine powder with particles less than 5 microns in size and exposures of concentrations greater than 5000 $\mu g/m^3$, has reportedly caused fibrosis of the lung. The NIOSH REL and OSHA PEL for aluminum are 10,000 and 15,000 micrograms/cubic meter of air, respectively.

Air Sample Results - Aluminum

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Aluminum			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	91	> LOQ 3.0	1956.99	> LOQ 64.52
97035	2	47.34	SS	1	630	> LOQ 3.0	13307.98	> LOQ 63.37
97029	3	44.33	SS	1	700	> LOQ 3.0	15791.37	> LOQ 67.68
97034	OBZ	47.60	SS	1	3300	> LOQ 6.0	69321.91	> LOQ 126.04
97022	1	47.66	SSDS	2	48	> LOQ 3.0	1007.05	> LOQ 62.94
97032	2	46.72	SSDS	2	140	> LOQ 3.0	2996.83	> LOQ 64.22
97025	3	49.14	SSDS	2	160	> LOQ 3.0	3256.00	> LOQ 61.05
97006	OBZ	48.95	SSDS	2	140	> LOQ 3.0	2860.18	> LOQ 61.29
97024	1	46.50	CS	3	630.00	> LOQ 3.0	13548.39	> LOQ 64.52
97020	2	47.34	CS	3	4300	> LOQ 6.0	90832.28	> LOQ 126.74
97015	3	44.33	CS	3	5300	> LOQ 10	119563.26	> LOQ 225.59
97037	OBZ	47.60	CS	3	4000	> LOQ 6.0	84026.55	> LOQ 126.04
97014	1	50.38	CP	4	560	> LOQ 3.0	11116.40	> LOQ 59.55
97011	2	47.98	CP	4	1300	> LOQ 3.0	27096.88	> LOQ 62.53
97031	3	47.92	CP	4	1300	> LOQ 3.0	27130.81	> LOQ 62.61
97019	OBZ	48.30	CP	4	1800	> LOQ 3.0	37267.08	> LOQ 62.11
97030	1	47.64	N	5	180	> LOQ 3.0	3778.34	> LOQ 62.97
97009	2	44.16	N	5	450	> LOQ 3.0	10190.22	> LOQ 67.93
97021	3	44.52	N	5	320	> LOQ 3.0	7187.78	> LOQ 67.39
97036	OBZ	54.48	N	5	420	> LOQ 3.0	7709.25	> LOQ 55.07
97018	1	48.17	G	6	2100	> LOQ 3.0	43597.41	> LOQ 62.28
97005	2	47.51	G	6	3200	> LOQ 6.0	67357.08	> LOQ 126.29
97017	3	47.11	G	6	4700	> LOQ 10.0	99762.27	> LOQ 212.26
97007	OBZ	48.76	G	6	400	> LOQ 6.0	8204.12	> LOQ 123.06
97008	1	47.92	S	7	210	> LOQ 3.0	4382.67	> LOQ 62.61
97023	2	48.40	S	7	410	> LOQ 3.0	8471.77	> LOQ 61.99
97013	3	48.89	S	7	430	> LOQ 3.0	8795.61	> LOQ 61.36
97016	OBZ	48.71	S	7	270	> LOQ 3.0	5543.24	> LOQ 61.59
97001	1	47.89	SG	8	9.5	> LOQ 3.0	198.36	> LOQ 62.64
97003	2	48.29	SG	8	32	> LOQ 3.0	662.69	> LOQ 62.13
97028	3	48.32	SG	8	40	> LOQ 3.0	827.75	> LOQ 62.08
97038	OBZ	48.97	SG	8	150	> LOQ 10.0	3062.97	> LOQ 204.20

LOD = Limit of Detection
LOQ = Limit of Quantification
ND = Nondetectable

Bulk Elemental Analysis - Aluminum

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Aluminum		Sample		
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	1200.00	>LOQ 10.0	J97119P203 PB	1600.00	>LOQ 10.0
N	J97119P205 VB	860.00	>LOQ 10.0	J97119P205 PB	970.00	>LOQ 10.0
S	J97119P207 VB	260.00	>LOQ 10.0	J97119P207 PB	390.00	>LOQ 10.0
SS	J97119P201 VB	1000.00	>LOQ 10.0	J97119P201 PB	870.00	>LOQ 10.0
SSDS	J97119P202 VB	50.00	>LOQ 10.0	J97119P202 PB	57.00	>LOQ 10.0
CP	J97119P204 VB	21000.00	>LOQ 50.0	J97119P204 PB	27000.00	>LOQ 50.0
G	J97119P206 VB	1400.00	>LOQ 10.0	J97119P206 PB	940.00	>LOQ 10.0
SG	J97119P208 VB	380.00	>LOQ 10.0	J97119P208 PB	430.00	>LOQ 10.0

Comparison of Airborne Concentrations to Bulk Concentrations - Aluminum

NIOSH REL 10000 micrograms/cubic meter
OSHA PEL 15000 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Aluminum**	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**µg/g**	**Notes**
CS	13548.39	90832.28	119563.26	84026.55	1200.00	>LOQ 10.0
N	3778.34	10190.22	7187.78	7709.25	860.00	>LOQ 10.0
S	4382.67	8471.77	8795.61	5543.24	260.00	>LOQ 10.0
SS	1956.99	13307.98	15791.37	69321.91	1000.00	>LOQ 10.0
SSDS	1007.05	2996.83	3256.00	2860.18	50.00	>LOQ 10.0
CP	11116.40	27096.88	27130.81	37267.08	21000.00	>LOQ 50.0
G	43597.41	67357.08	99762.27	8204.12	1400.00	>LOQ 10.0
SG	198.36	662.69	827.75	3062.97	380.00	>LOQ 10.0

Arsenic

Inhalation, ingestion, or dermal exposure of workers to inorganic arsenic has reportedly caused peripheral nerve inflammation (neuritis) and degeneration (neuropathy), reduced peripheral circulation, anemia, increased mortality due to cardiovascular failure, and cancer of the skin, lungs, and lymphatic system. The OSHA PEL for arsenic is 10 micrograms/cubic meter of air.

Arsenic is considered an occupational carcinogen by NIOSH. The NIOSH policy regarding occupational carcinogens has changed from a recommend exposure limit (REL) of "lower feasible concentration". The new NIOSH policy for carcinogens is described in the following paragraph (This policy applies to all workplace hazards, including carcinogens):

For the past 20 plus years, NIOSH has subscribed to a carcinogen policy that was published in 1976 by Edward J. Fairchild, II, Associate Director for Cincinnati Operations, which called for "no detectable exposure levels for proven carcinogenic substances [New York Academy of Sciences Annals 1976]." This was in response to a generic OSHA rulemaking on carcinogens.

Because of advances in science and in approaches to risk assessment and risk management, NIOSH has in more recent years adopted a more inclusive policy. NIOSH RELs will be based on risk evaluations using human or animal health effects data, and on an assessment of what levels can be feasibly achieved by engineering controls and measured by analytical techniques. To the extent feasible, NIOSH will protect not only a no-effect exposure, but also exposure levels at which there may be residual risks.

The effect of this new policy for potential occupational carcinogens will be the development, whenever possible, of quantitative RELs that are based on human and/or animal data, as well as on the consideration of technological feasibility for controlling workplace exposures to the REL. Under the old policy for potential occupational carcinogens, RELs for most carcinogens were non-quantitative values labeled "lowest feasible concentration (LFC)." In 1989, NIOSH adopted several quantitative RELs for carcinogens from OSHA's PEL update. NIOSH will also recommend the complete range of respirators (as determined by the NIOSH Respirator Decision Logic) for carcinogens with quantitative RELs. In this way, respirators will be consistently recommended regardless of whether a substance is a carcinogen or a non-carcinogen.

Air Sample Results - Arsenic

Sample	Station	Volume	Abrasive	Run	Arsenic			
No.	No.	(l/filter)	Type		Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 0.06	ND	< LOD 1.29
97035	2	47.34	SS	1	0.47	> LOQ 0.2	9.928	> LOQ 4.22
97029	3	44.33	SS	1	0.5	> LOQ 0.2	11.280	> LOQ 4.51
97034	OBZ	47.60	SS	1	0.21	> LOQ 0.2	4.411	> LOQ 4.20
97022	1	47.66	SSDS	2	0.2	< LOQ 0.2	4.196	< LOQ 4.20
97032	2	46.72	SSDS	2	0.28	> LOQ 0.2	5.994	> LOQ 4.28
97025	3	49.14	SSDS	2	0.39	> LOQ 0.2	7.937	> LOQ 4.07
97006	OBZ	48.95	SSDS	2	0.36	> LOQ 0.2	7.355	> LOQ 4.09
97024	1	46.50	CS	3	0.49	> LOQ 0.2	10.538	> LOQ 4.30
97020	2	47.34	CS	3	0.34	> LOQ 0.2	7.182	> LOQ 4.22
97015	3	44.33	CS	3	0.41	> LOQ 0.2	9.249	> LOQ 4.51
97037	OBZ	47.60	CS	3	0.37	> LOQ 0.2	7.772	> LOQ 4.20
97014	1	50.38	CP	4	0.55	> LOQ 0.2	10.918	> LOQ 3.97
97011	2	47.98	CP	4	1.2	> LOQ 0.2	25.013	> LOQ 4.17
97031	3	47.92	CP	4	1.2	> LOQ 0.2	25.044	> LOQ 4.17
97019	OBZ	48.30	CP	4	1.6	> LOQ 0.2	33.126	> LOQ 4.14
97030	1	47.64	N	5	0.1	< LOQ 0.2	2.099	< LOQ 4.20
97009	2	44.16	N	5	0.27	> LOQ 0.2	6.114	> LOQ 4.53
97021	3	44.52	N	5	0.25	> LOQ 0.2	5.615	> LOQ 4.49
97036	OBZ	54.48	N	5	0.26	> LOQ 0.2	4.772	> LOQ 3.67
97018	1	48.17	G	6	0.27	> LOQ 0.2	5.605	> LOQ 4.15
97005	2	47.51	G	6	0.48	> LOQ 0.2	10.104	> LOQ 4.21
97017	3	47.11	G	6	0.56	> LOQ 0.2	11.887	> LOQ 4.25
97007	OBZ	48.76	G	6	0.54	> LOQ 0.2	11.076	> LOQ 4.10
97008	1	47.92	S	7	ND	< LOD 0.2	ND	< LOD 4.17
97023	2	48.40	S	7	0.07	< LOQ 0.2	1.446	< LOQ 4.13
97013	3	48.89	S	7	0.07	< LOQ 0.2	1.432	< LOQ 4.09
97016	OBZ	48.71	S	7	ND	< LOD 0.06	ND	< LOD 1.23
97001	1	47.89	SG	8	0.4	> LOQ 0.2	8.352	> LOQ 4.18
97003	2	48.29	SG	8	0.33	> LOQ 0.2	6.834	> LOQ 4.14
97028	3	48.32	SG	8	1.2	> LOQ 0.2	24.832	> LOQ 4.14
97038	OBZ	48.97	SG	8	9.1	> LOQ 1.0	185.820	> LOQ 20.42

Bulk Elemental Analysis - Arsenic

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Arsenic		Sample	Arsenic	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	<LOD 0.9	J97119P203 PB	0.60	< LOQ 2.0
N	J97119P205 VB	ND	<LOD 0.9	J97119P205 PB	ND	< LOD 0.3
S	J97119P207 VB	ND	<LOD 0.9	J97119P207 PB	ND	< LOD 0.3
SS	J97119P201 VB	ND	<LOD 0.9	J97119P201 PB	0.80	< LOQ 0.9
SSDS	J97119P202 VB	ND	<LOD 0.9	J97119P202 PB	0.50	< LOQ 0.9
CP	J97119P204 VB	24.00	>LOQ 9.0	J97119P204 PB	23.00	>LOQ 9.0
G	J97119P206 VB	ND	<LOD 0.9	J97119P206 PB	ND	< LOD 0.5
SG	J97119P208 VB	48.00	>LOQ 9.0	J97119P208 PB	48.00	>LOQ 9.0

Comparison of Airborne Concentrations to Bulk Concentrations - Arsenic

NIOSH REL 2.0 micrograms/cubic meter Ceiling Limit
OSHA PEL 10.0 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Arsenic**	
Type	**$\mu g/m^3$**	**$\mu g/m^3$**	**$\mu g/m^3$**	**$\mu g/m^3$**	**µg/g**	**Notes**
CS	10.54	7.18	9.25	7.77	ND	<LOD 0.9
N	2.10	6.11	5.62	4.77	ND	<LOD 0.9
S	ND	1.45	1.43	ND	ND	<LOD 0.9
SS	ND	9.93	11.28	4.41	ND	<LOD 0.9
SSDS	4.20	5.99	7.94	7.36	ND	<LOD 0.9
CP	10.92	25.01	25.04	33.13	24.00	>LOQ 9.0
G	5.61	10.10	11.89	11.08	ND	<LOD 0.9
SG	8.35	6.83	24.83	185.82	48.00	>LOQ 9.0

Barium

The toxicity of barium depends upon the solubility of its compounds. Soluble barium compounds may cause local irritation of the nose, eyes, throat, bronchial tubes, and skin. The NIOSH REL and OSHA PEL for barium are both 500 micrograms/cubic meter of air.

Air Sample Results - Barium

Sample	Station	Volume	Abrasive	Run	Barium			
No.	No.	(l/filter)	Type		Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	0.790	> LOQ 0.2	16.99	> LOQ 4.30
97035	2	47.34	SS	1	3.600	> LOQ 0.2	76.05	> LOQ 4.22
97029	3	44.33	SS	1	4.000	> LOQ 0.2	90.24	> LOQ 4.51
97034	OBZ	47.60	SS	1	12.000	> LOQ 0.2	252.08	> LOQ 4.20
97022	1	47.66	SSDS	2	0.300	> LOQ 0.2	6.29	> LOQ 4.20
97032	2	46.72	SSDS	2	0.620	> LOQ 0.2	13.27	> LOQ 4.28
97025	3	49.14	SSDS	2	0.760	> LOQ 0.2	15.47	> LOQ 4.07
97006	OBZ	48.95	SSDS	2	0.790	> LOQ 0.2	16.14	> LOQ 4.09
97024	1	46.50	CS	3	3.5	> LOQ 0.2	75.27	> LOQ 4.30
97020	2	47.34	CS	3	15.000	> LOQ 0.2	316.86	> LOQ 4.22
97015	3	44.33	CS	3	18.000	> LOQ 0.2	406.06	> LOQ 4.51
97037	OBZ	47.60	CS	3	14.000	> LOQ 0.2	294.09	> LOQ 4.20
97014	1	50.38	CP	4	5.700	> LOQ 0.2	113.15	> LOQ 3.97
97011	2	47.98	CP	4	13.000	> LOQ 0.2	270.97	> LOQ4.17
97031	3	47.92	CP	4	13.000	> LOQ 0.2	271.31	> LOQ4.17
97019	OBZ	48.30	CP	4	18.000	> LOQ 0.2	372.67	> LOQ 4.14
97030	1	47.64	N	5	1.100	> LOQ 0.2	23.09	> LOQ 4.20
97009	2	44.16	N	5	2.300	> LOQ 0.2	52.08	> LOQ 4.53
97021	3	44.52	N	5	1.900	> LOQ 0.2	42.68	> LOQ 4.49
97036	OBZ	54.48	N	5	2.200	> LOQ 0.2	40.38	> LOQ 3.67
97018	1	48.17	G	6	0.560	> LOQ 0.2	11.63	> LOQ 4.15
97005	2	47.51	G	6	1.000	> LOQ 0.2	21.05	> LOQ 4.21
97017	3	47.11	G	6	1.300	> LOQ 0.2	27.59	> LOQ 4.25
97007	OBZ	48.76	G	6	1.200	> LOQ 0.2	24.61	> LOQ 4.10
97008	1	47.92	S	7	1.400	> LOQ 0.2	29.22	> LOQ 4.17
97023	2	48.40	S	7	2.600	> LOQ 0.2	53.72	> LOQ 4.13
97013	3	48.89	S	7	2.700	> LOQ 0.2	55.23	> LOQ 4.09
97016	OBZ	48.71	S	7	1.800	> LOQ 0.2	36.95	> LOQ 4.11
97001	1	47.89	SG	8	0.100	< LOQ 0.2	2.09	< LOQ 4.18
97003	2	48.29	SG	8	0.410	> LOQ 0.2	8.49	> LOQ 4.14
97028	3	48.32	SG	8	0.460	> LOQ 0.2	9.52	> LOQ 4.14
97038	OBZ	48.97	SG	8	1.200	> LOQ 0.2	24.50	> LOQ 4.08

Bulk Elemental Analysis - Barium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Barium		Sample	Barium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	4.50	>LOQ 0.7	J97119P203 PB	6.10	>LOQ 0.7
N	J97119P205 VB	4.20	>LOQ 0.7	J97119P205 PB	4.80	>LOQ 0.7
S	J97119P207 VB	3.00	>LOQ 0.7	J97119P207 PB	3.40	>LOQ 0.7
SS	J97119P201 VB	5.30	>LOQ 0.7	J97119P201 PB	5.60	>LOQ 0.7
SSDS	J97119P202 VB	ND	<LOD 0.2	J97119P202 PB	1.10	>LOQ 0.7
CP	J97119P204 VB	190.00	>LOQ 0.7	J97119P204 PB	230.00	>LOQ 0.7
G	J97119P206 VB	0.50	<LOQ 0.7	J97119P206 PB	0.72	>LOQ 0.7
SG	J97119P208 VB	2.80	>LOQ 0.7	J97119P208 PB	3.40	>LOQ 0.7

Comparison of Airborne Concentrations to Bulk Concentrations - Barium

NIOSH REL 500.0 micrograms/cubic meter
OSHA PEL 500.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Barium**	
Type	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/g**	**Notes**
CS	75.27	316.86	406.06	294.09	4.50	>LOQ 0.7
N	23.09	52.08	42.68	40.38	4.20	>LOQ 0.7
S	29.22	53.72	55.23	36.95	3.00	>LOQ 0.7
SS	16.99	76.05	90.24	252.08	5.30	>LOQ 0.7
SSDS	6.29	13.27	15.47	16.14	ND	<LOD 0.2
CP	113.15	270.97	271.31	372.67	190.00	>LOQ 0.7
G	11.63	21.05	27.59	24.61	0.50	<LOQ 0.7
SG	2.09	8.49	9.52	24.50	2.80	>LOQ 0.7

Beryllium

Inhalation of beryllium may result in rhinitis, tracheobronchitis, pneumonitis, and death due to pulmonary edema or heart failure. Beryllium has been associated with damage to the kidney, liver, spleen and heart, and an increased incidence of lung cancer. The NIOSH REL and OSHA PEL for beryllium are 0.50 and 2.0 micrograms/cubic meter of air, respectively.

Beryllium is considered an occupational carcinogen by NIOSH. The NIOSH policy regarding occupational carcinogens has changed from a recommend exposure limit (REL) of "lower feasible concentration". The new NIOSH policy for carcinogens is described in the following paragraph (This policy applies to all workplace hazards, including carcinogens):

For the past 20 plus years, NIOSH has subscribed to a carcinogen policy that was published in 1976 by Edward J. Fairchild, II, Associate Director for Cincinnati Operations, which called for "no detectable exposure levels for proven carcinogenic substances [New York Academy of Sciences Annals 1976]." This was in response to a generic OSHA rulemaking on carcinogens.

Because of advances in science and in approaches to risk assessment and risk management, NIOSH has in more recent years adopted a more inclusive policy. NIOSH RELs will be based on risk evaluations using human or animal health effects data, and on an assessment of what levels can be feasibly achieved by engineering controls and measured by analytical techniques. To the extent feasible, NIOSH will protect not only a no-effect exposure, but also exposure levels at which there may be residual risks.

The effect of this new policy for potential occupational carcinogens will be the development, whenever possible, of quantitative RELs that are based on human and/or animal data, as well as on the consideration of technological feasibility for controlling workplace exposures to the REL. Under the old policy for potential occupational carcinogens, RELs for most carcinogens were non-quantitative values labeled "lowest feasible concentration (LFC)." In 1989, NIOSH adopted several quantitative RELs for carcinogens from OSHA's PEL update. NIOSH will also recommend the complete range of respirators (as determined by the NIOSH Respirator Decision Logic) for carcinogens with quantitative RELs. In this way, respirators will be consistently recommended regardless of whether a substance is a carcinogen or a non-carcinogen.

Air Sample Results - Beryllium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Beryllium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 0.01	ND	< LOD 0.215
97035	2	47.34	SS	1	0.04	< LOQ 0.04	0.84	< LOQ 0.845
97029	3	44.33	SS	1	0.04	< LOQ 0.04	0.90	< LOQ 0.902
97034	OBZ	47.60	SS	1	0.23	> LOQ 0.01	4.83	> LOQ .210
97022	1	47.66	SSDS	2	ND	< LOD 0.004	ND	< LOD 0.084
97032	2	46.72	SSDS	2	0.005	< LOQ 0.01	0.11	< LOQ 0.214
97025	3	49.14	SSDS	2	0.006	< LOQ 0.01	0.12	< LOQ 0.204
97006	OBZ	48.95	SSDS	2	0.007	< LOQ 0.01	0.14	< LOQ 0.204
97024	1	46.50	CS	3	0.04	< LOQ 0.04	0.86	< LOQ 0.860
97020	2	47.34	CS	3	0.24	> LOQ 0.08	5.07	> LOQ 1.690
97015	3	44.33	CS	3	0.26	> LOQ 0.2	5.87	> LOQ 4.512
97037	OBZ	47.60	CS	3	0.23	> LOQ 0.08	4.83	> LOQ 1.681
97014	1	50.38	CP	4	0.019	> LOQ 0.01	0.38	> LOQ 0.199
97011	2	47.98	CP	4	0.042	> LOQ 0.01	0.88	> LOQ 0.208
97031	3	47.92	CP	4	0.04	> LOQ 0.01	0.83	> LOQ 0.209
97019	OBZ	48.30	CP	4	0.06	> LOQ 0.01	1.24	> LOQ 0.207
97030	1	47.64	N	5	0.004	< LOQ 0.01	0.08	< LOQ 0.210
97009	2	44.16	N	5	0.01	< LOQ 0.01	0.23	< LOQ 0.226
97021	3	44.52	N	5	0.007	< LOQ 0.01	0.16	< LOQ 0.225
97036	OBZ	54.48	N	5	0.009	< LOQ 0.01	0.17	< LOQ 0.184
97018	1	48.17	G	6	0.019	> LOQ 0.01	0.39	> LOQ 0.208
97005	2	47.51	G	6	0.02	< LOQ 0.04	0.42	< LOQ 0.842
97017	3	47.11	G	6	0.03	< LOQ 0.04	0.64	< LOQ 0.849
97007	OBZ	48.76	G	6	0.03	< LOQ 0.04	0.62	< LOQ 0.820
97008	1	47.92	S	7	0.016	> LOQ 0.01	0.33	> LOQ 0.209
97023	2	48.40	S	7	0.038	> LOQ 0.01	0.79	> LOQ 0.207
97013	3	48.89	S	7	0.039	> LOQ 0.01	0.80	> LOQ 0.205
97016	OBZ	48.71	S	7	0.026	> LOQ 0.01	0.53	> LOQ 0.205
97001	1	47.89	SG	8	ND	< LOD 0.04	ND	< LOD 0.084
97003	2	48.29	SG	8	ND	< LOD 0.04	ND	< LOD 0.083
97028	3	48.32	SG	8	ND	< LOD 0.04	ND	< LOD 0.083
97038	OBZ	48.97	SG	8	ND	< LOD 0.04	ND	< LOD 0.082

Bulk Elemental Analysis - Beryllium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Beryllium		Sample	Beryllium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	0.11	>LOQ 0.05	J97119P203 PB	0.34	>LOQ 0.05
N	J97119P205 VB	0.04	<LOQ 0.05	J97119P205 PB	0.04	<LOQ 0.05
S	J97119P207 VB	ND	<LOD 0.01	J97119P207 PB	0.03	<LOQ 0.05
SS	J97119P201 VB	0.05	<LOQ 0.05	J97119P201 PB	0.08	>LOQ 0.05
SSDS	J97119P202 VB	ND	<LOD 0.01	J97119P202 PB	ND	<LOD 0.01
CP	J97119P204 VB	0.90	>LOQ 0.1	J97119P204 PB	0.92	>LOQ 0.05
G	J97119P206 VB	0.02	<LOQ 0.05	J97119P206 PB	0.01	<LOQ 0.05
SG	J97119P208 VB	ND	<LOD 0.01	J97119P208 PB	ND	<LOD 0.01

Comparison of Airborne Concentrations to Bulk Concentrations - Beryllium

NIOSH REL 0.50 micrograms/cubic meter
OSHA PEL 2.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Beryllium**	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**µg/g**	**Notes**
CS	0.86	5.07	5.87	4.83	0.11	>LOQ 0.05
N	0.08	0.23	0.16	0.17	0.04	<LOQ 0.05
S	0.33	0.79	0.80	0.53	ND	<LOD 0.01
SS	ND	0.84	0.90	4.83	0.05	<LOQ 0.05
SSDS	ND	0.11	0.12	0.14	ND	<LOD 0.01
CP	0.38	0.88	0.83	1.24	0.90	>LOQ 0.1
G	0.39	0.42	0.64	0.62	0.02	<LOQ 0.05
SG	ND	ND	ND	ND	ND	<LOD 0.01

Cadmium

Cadmium dust may cause irritation of the nose and throat, cough, chest pain, sweating, chills, shortness of breath, and weakness. Repeated exposure may cause loss of the sense of smell, ulceration of the nose, shortness of breath, kidney damage, and mild anemia. An increased incidence of prostrate cancer in men has been reported. The OSHA PEL for cadmium is 5.0 micrograms/cubic meter of air. NIOSH does not currently have a recommended exposure limit (REL) for cadmium.

Cadmium is considered an occupational carcinogen by NIOSH. The NIOSH policy regarding occupational carcinogens has changed from a recommend exposure limit (REL) of "lower feasible concentration". The new NIOSH policy for carcinogens is described in the following paragraph (This policy applies to all workplace hazards, including carcinogens):

For the past 20 plus years, NIOSH has subscribed to a carcinogen policy that was published in 1976 by Edward J. Fairchild, II, Associate Director for Cincinnati Operations, which called for "no detectable exposure levels for proven carcinogenic substances [New York Academy of Sciences Annals 1976]." This was in response to a generic OSHA rulemaking on carcinogens.

Because of advances in science and in approaches to risk assessment and risk management, NIOSH has in more recent years adopted a more inclusive policy. NIOSH RELs will be based on risk evaluations using human or animal health effects data, and on an assessment of what levels can be feasibly achieved by engineering controls and measured by analytical techniques. To the extent feasible, NIOSH will protect not only a no-effect exposure, but also exposure levels at which there may be residual risks.

The effect of this new policy for potential occupational carcinogens will be the development, whenever possible, of quantitative RELs that are based on human and/or animal data, as well as on the consideration of technological feasibility for controlling workplace exposures to the REL. Under the old policy for potential occupational carcinogens, RELs for most carcinogens were non-quantitative values labeled "lowest feasible concentration (LFC)." In 1989, NIOSH adopted several quantitative RELs for carcinogens from OSHA's PEL update. NIOSH will also recommend the complete range of respirators (as determined by the NIOSH Respirator Decision Logic) for carcinogens with quantitative RELs. In this way, respirators will be consistently recommended regardless of whether a substance is a carcinogen or a non-carcinogen.

Air Sample Results - Cadmium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Cadium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	0.003	< LOQ 0.008	0.065	< LOQ 0.172
97035	2	47.34	SS	1	0.014	> LOQ 0.008	0.296	> LOQ 0.169
97029	3	44.33	SS	1	0.014	> LOQ 0.008	0.316	> LOQ 0.180
97034	OBZ	47.60	SS	1	0.0091	> LOQ 0.008	0.191	> LOQ 0.168
97022	1	47.66	SSDS	2	0.005	< LOQ 0.008	0.105	< LOQ 0.168
97032	2	46.72	SSDS	2	0.0084	> LOQ 0.008	0.180	> LOQ 0.171
97025	3	49.14	SSDS	2	0.011	> LOQ 0.008	0.224	> LOQ 0.163
97006	OBZ	48.95	SSDS	2	0.025	> LOQ 0.008	0.511	> LOQ 0.163
97024	1	46.50	CS	3	0.048	> LOQ 0.008	1.032	> LOQ 0.172
97020	2	47.34	CS	3	0.013	> LOQ 0.008	0.275	> LOQ 0.169
97015	3	44.33	CS	3	0.018	> LOQ 0.008	0.406	> LOQ 0.180
97037	OBZ	47.60	CS	3	0.025	> LOQ 0.008	0.525	> LOQ 0.168
97014	1	50.38	CP	4	0.006	< LOQ 0.008	0.119	< LOQ 0.159
97011	2	47.98	CP	4	0.013	> LOQ 0.008	0.271	> LOQ 0.167
97031	3	47.92	CP	4	0.016	> LOQ 0.008	0.334	> LOQ 0.167
97019	OBZ	48.30	CP	4	0.18	> LOQ 0.2	3.727	> LOQ 4.141
97030	1	47.64	N	5	0.011	> LOQ 0.008	0.231	> LOQ 0.168
97009	2	44.16	N	5	0.015	> LOQ 0.008	0.340	> LOQ 0.181
97021	3	44.52	N	5	0.014	> LOQ 0.008	0.314	> LOQ 0.180
97036	OBZ	54.48	N	5	0.031	> LOQ 0.008	0.569	> LOQ 0.147
97018	1	48.17	G	6	0.033	> LOQ 0.008	0.685	> LOQ 0.166
97005	2	47.51	G	6	0.053	> LOQ 0.02	1.116	> LOQ 0.421
97017	3	47.11	G	6	0.071	> LOQ 0.02	1.507	> LOQ 0.425
97007	OBZ	48.76	G	6	0.063	> LOQ 0.02	1.292	> LOQ 0.410
97008	1	47.92	S	7	0.01	> LOQ 0.008	0.209	> LOQ 0.167
97023	2	48.40	S	7	0.014	> LOQ 0.008	0.289	> LOQ 0.165
97013	3	48.89	S	7	0.015	> LOQ 0.008	0.307	> LOQ 0.164
97016	OBZ	48.71	S	7	0.01	> LOQ 0.008	0.205	> LOQ 0.164
97001	1	47.89	SG	8	0.004	< LOQ 0.008	0.084	< LOQ 0.167
97003	2	48.29	SG	8	0.0093	> LOQ 0.008	0.193	> LOQ 0.166
97028	3	48.32	SG	8	0.008	< LOQ 0.008	0.166	< LOQ 0.166
97038	OBZ	48.97	SG	8	0.6	> LOQ 0.2	12.252	> LOQ 4.084

Bulk Elemental Analysis - Cadmium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Cadmium		Sample	Cadmium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	0.03	<LOQ 0.7	J97119P203 PB	ND	<LOD 0.02
N	J97119P205 VB	ND	<LOD 0.02	J97119P205 PB	0.03	<LOQ 0.03
S	J97119P207 VB	ND	<LOD 0.02	J97119P207 PB	0.02	<LOQ 0.7
SS	J97119P201 VB	0.03	<LOQ 0.7	J97119P201 PB	0.03	<LOQ 0.7
SSDS	J97119P202 VB	ND	<LOD 0.02	J97119P202 PB	0.02	<LOQ 0.7
CP	J97119P204 VB	0.03	<LOQ 0.7	J97119P204 PB	0.03	<LOQ 0.7
G	J97119P206 VB	0.05	<LOQ 0.7	J97119P206 PB	0.03	<LOQ 0.7
SG	J97119P208 VB	ND	<LOD 0.02	J97119P208 PB	ND	<LOD 0.02

Comparison of Airborne Concentrations to Bulk Concentrations - Cadmium

NIOSH REL - Limit of Quantification (Lowest Feasible Concentration)
OSHA PEL 5.0 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Cadmium**	
Type	**µg/m³**	**µg/m³**	**µg/m³**	**µg/m³**	**µg/g**	**Notes**
CS	1.03	0.28	0.41	0.53	0.03	<LOQ 0.7
N	0.23	0.34	0.31	0.57	ND	<LOD 0.02
S	0.21	0.29	0.31	0.21	ND	<LOD 0.02
SS	0.07	0.30	0.32	0.19	0.03	<LOQ 0.7
SSDS	0.11	0.18	0.22	0.51	ND	<LOD 0.02
CP	0.12	0.27	0.33	3.73	0.03	<LOQ 0.7
G	0.69	1.12	1.51	1.29	0.05	<LOQ 0.7
SG	0.08	0.19	0.17	12.25	ND	<LOD 0.02

Calcium

Calcium oxide reportedly causes irritation of the eyes, nose, throat and skin and may also cause bronchitis and pneumonitis. Ulceration and perforation of the nasal septum is possible in repeated or prolonged exposure. The NIOSH REL and OSHA PEL for calcium are 10,000 and 15,000 micrograms/cubic meter of air, respectively.

Air Sample Results - Calcium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Calcium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	390	> LOQ 7.0	8172.04	> LOQ 150.54
97035	2	47.34	SS	1	4800	> LOQ 10.0	101394.17	> LOQ 211.24
97029	3	44.33	SS	1	4900	> LOQ 30.0	110539.61	> LOQ 676.77
97034	OBZ	47.60	SS	1	790	> LOQ 7.0	16595.24	> LOQ 147.05
97022	1	47.66	SSDS	2	32	> LOQ 7.0	671.37	> LOQ 146.86
97032	2	46.72	SSDS	2	53	> LOQ 7.0	1134.51	> LOQ 149.84
97025	3	49.14	SSDS	2	71	> LOQ 7.0	1444.85	> LOQ 142.45
97006	OBZ	48.95	SSDS	2	80	> LOQ 7.0	1634.39	> LOQ 143.01
97024	1	46.50	CS	3	5700.00	> LOQ 30	122580.65	> LOQ 645.16
97020	2	47.34	CS	3	990	> LOQ 7.0	20912.55	> LOQ 147.87
97015	3	44.33	CS	3	1200	> LOQ 7.0	27070.93	> LOQ 157.91
97037	OBZ	47.60	CS	3	950	> LOQ 7.0	19956.31	> LOQ 147.05
97014	1	50.38	CP	4	2600	> LOQ 30.0	51611.88	> LOQ 595.52
97011	2	47.98	CP	4	5600	> LOQ 70.0	116725.03	> LOQ 1459.06
97031	3	47.92	CP	4	5600	> LOQ 7.0	116871.19	> LOQ 146.09
97019	OBZ	48.30	CP	4	8500	> LOQ 30.0	175983.44	> LOQ 621.12
97030	1	47.64	N	5	160	> LOQ 7.0	3358.52	> LOQ 146.94
97009	2	44.16	N	5	360	> LOQ 7.0	8152.17	> LOQ 158.51
97021	3	44.52	N	5	280	> LOQ 7.0	6289.31	> LOQ 157.23
97036	OBZ	54.48	N	5	350	> LOQ 7.0	6424.38	> LOQ 128.49
97018	1	48.17	G	6	220	> LOQ 7.0	4567.35	> LOQ 145.32
97005	2	47.51	G	6	350	> LOQ 7.0	7367.18	> LOQ 147.34
97017	3	47.11	G	6	490	> LOQ 7.0	10400.75	> LOQ 148.58
97007	OBZ	48.76	G	6	440	> LOQ 7.0	9024.53	> LOQ 143.57
97008	1	47.92	S	7	50	> LOQ 7.0	1043.49	> LOQ 146.09
97023	2	48.40	S	7	89	> LOQ 7.0	1838.99	> LOQ 144.64
97013	3	48.89	S	7	95	> LOQ 7.0	1943.22	> LOQ 143.18
97016	OBZ	48.71	S	7	65	> LOQ 7.0	1334.48	> LOQ 143.71
97001	1	47.89	SG	8	7.7	> LOQ 7.0	160.78	> LOQ 146.16
97003	2	48.29	SG	8	35	> LOQ 7.0	724.82	> LOQ 144.96
97028	3	48.32	SG	8	31	> LOQ 7.0	641.50	> LOQ 144.86
97038	OBZ	48.97	SG	8	74	> LOQ 30.0	1511.07	> LOQ 612.59

Bulk Elemental Analysis - Calcium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Calcium		Sample	Calcium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	280.00	>LOQ 30.0	J97119P203 PB	370.00	>LOQ 30.0
N	J97119P205 VB	610.00	>LOQ 30.0	J97119P205 PB	770.00	>LOQ 30.0
S	J97119P207 VB	20.00	<LOQ 30.0	J97119P207 PB	500.00	>LOQ 30.0
SS	J97119P201 VB	28000.00	>LOQ 100	J97119P201 PB	8300.00	>LOQ 30.0
SSDS	J97119P202 VB	10.00	<LOQ 30.0	J97119P202 PB	140.00	>LOQ 30.0
CP	J97119P204 VB	110000.00	>LOQ 600	J97119P204 PB	110000.00	>LOQ 600
G	J97119P206 VB	310.00	>LOQ 30.0	J97119P206 PB	460.00	>LOQ 30.0
SG	J97119P208 VB	ND	<LOD 9.0	J97119P208 PB	ND	<LOD 9.0

Comparison of Airborne Concentrations to Bulk Concentrations - Calcium

NIOSH REL 10000.0 micrograms/cubic meter
OSHA PEL 15000.0 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Calcium**	
Type	**$\mu g/m^3$**	**$\mu g/m^3$**	**$\mu g/m^3$**	**$\mu g/m^3$**	**µg/g**	**Notes**
CS	122580.65	20912.55	27070.93	19956.31	280.00	>LOQ 30.0
N	3358.52	8152.17	6289.31	6424.38	610.00	>LOQ 30.0
S	1043.49	1838.99	1943.22	1334.48	20.00	<LOQ 30.0
SS	8172.04	101394.17	110539.61	16595.24	28000.00	>LOQ 100
SSDS	671.37	1134.51	1444.85	1634.39	10.00	<LOQ 30.0
CP	51611.88	116725.03	116871.19	175983.44	110000.00	>LOQ 600
G	4567.35	7367.18	10400.75	9024.53	310.00	>LOQ 30.0
SG	160.78	724.82	641.50	1511.07	ND	<LOD 9.0

Chromium

Chromium metal and divalent and trivalent compounds have been associated with dermatitis and allergic skin reaction. The compounds may cause skin ulceration, ulceration in the mucus membranes, and perforations of the nasal septum. Adverse effects on pulmonary functions, including hypersensitivity, have been reported. The NIOSH REL for chromium are both 500 micrograms/cubic meter of air.

Per the "NIOSH Pocket Guide to Chemical Hazards" the OSHA PEL for chromium depends on the valence. The OSHA PEL for chromium metal and insoluble salts is 100 $\mu g/m^3$. The OSHA PEL for chromium (II) and (III) compounds is 500 $\mu g/m^3$. The NIOSH REL for all valences of chromium is 500 $\mu g/m^3$, with the exception of the REL of 1 $\mu g/m^3$ for the hexavelent chromium, which is based on a 10 hour TWA.

Air Sample Results - Chromium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Chromium			
					Mass (µg/filter	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 0.5	ND	< LOD 10.75
97035	2	47.34	SS	1	2.50	> LOQ 2.0	52.81	> LOQ 42.25
97029	3	44.33	SS	1	2.80	> LOQ 2.0	63.17	> LOQ 45.12
97034	OBZ	47.60	SS	1	4.50	> LOQ 2.0	94.53	> LOQ 42.01
97022	1	47.66	SSDS	2	0.70	< LOQ 2.0	14.69	< LOQ 41.96
97032	2	46.72	SSDS	2	2.00	< LOQ 2.0	42.81	< LOQ 42.81
97025	3	49.14	SSDS	2	2.30	> LOQ 2.0	46.81	> LOQ 40.70
97006	OBZ	48.95	SSDS	2	2.10	> LOQ 2.0	42.90	> LOQ 40.86
97024	1	46.50	CS	3	2.9	> LOQ 2.0	62.37	> LOQ 43.01
97020	2	47.34	CS	3	5.90	> LOQ 2.0	124.63	> LOQ 42.25
97015	3	44.33	CS	3	7.20	> LOQ 2.0	162.43	> LOQ 45.12
97037	OBZ	47.60	CS	3	5.80	> LOQ 2.0	121.84	> LOQ 42.01
97014	1	50.38	CP	4	2.00	< LOQ 2.0	39.70	< LOQ 39.70
97011	2	47.98	CP	4	4.10	> LOQ 2.0	85.46	> LOQ 41.69
97031	3	47.92	CP	4	4.10	> LOQ 2.0	85.57	> LOQ 41.74
97019	OBZ	48.30	CP	4	4.90	> LOQ 2.0	101.45	> LOQ 41.41
97030	1	47.64	N	5	92.00	> LOQ 2.0	1931.15	> LOQ 41.98
97009	2	44.16	N	5	240.00	> LOQ 2.0	5434.78	> LOQ 45.29
97021	3	44.52	N	5	160.00	> LOQ 2.0	3593.89	> LOQ 44.92
97036	OBZ	54.48	N	5	220.00	> LOQ 2.0	4038.18	> LOQ 36.71
97018	1	48.17	G	6	2.70	> LOQ 2.0	56.05	> LOQ 41.52
97005	2	47.51	G	6	4.70	> LOQ 2.0	98.93	> LOQ 42.10
97017	3	47.11	G	6	6.20	> LOQ 2.0	131.60	> LOQ 42.45
97007	OBZ	48.76	G	6	5.30	> LOQ 2.0	108.70	> LOQ 41.02
97008	1	47.92	S	7	2.60	> LOQ 2.0	54.26	> LOQ 41.74
97023	2	48.40	S	7	4.30	> LOQ 2.0	88.85	> LOQ 41.33
97013	3	48.89	S	7	4.80	> LOQ 2.0	98.18	> LOQ 40.91
97016	OBZ	48.71	S	7	3.10	> LOQ 2.0	63.64	> LOQ 41.06
97001	1	47.89	SG	8	16.00	> LOQ 2.0	334.09	> LOQ 41.76
97003	2	48.29	SG	8	15.00	> LOQ 2.0	310.64	> LOQ 41.42
97028	3	48.32	SG	8	60.00	> LOQ 2.0	1241.62	> LOQ 41.39
97038	OBZ	48.97	SG	8	420.00	> LOQ 10.0	8576.33	> LOQ 204.20

Bulk Elemental Analysis - Chromium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Chromium		Sample	Chromium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	<LOD 2.0	J97119P203 PB	3.00	<LOQ 7.0
N	J97119P205 VB	350.00	>LOQ 7.0	J97119P205 PB	450.00	>LOQ 7.0
S	J97119P207 VB	ND	<LOD 2.0	J97119P207 PB	4.00	<LOQ 7.0
SS	J97119P201 VB	3.00	<LOQ 7.0	J97119P201 PB	5.00	<LOQ 7.0
SSDS	J97119P202 VB	ND	<LOD 2.0	J97119P202 PB	2.00	<LOQ 7.0
CP	J97119P204 VB	33.00	>LOQ 7.0	J97119P204 PB	45.00	>LOQ 7.0
G	J97119P206 VB	3.00	<LOQ 7.0	J97119P206 PB	7.00	<LOQ 7.0
SG	J97119P208 VB	1300.00	>LOQ 7.0	J97119P208 PB	1400.00	>LOQ 7.0

Comparison of Airborne Concentrations to Bulk Concentrations - Chromium

NIOSH REL 500.0 micrograms/cubic meter
OSHA PEL 500.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Chromium	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/g	Notes
CS	62.37	124.63	162.43	121.84	ND	<LOD 2.0
N	1931.15	5434.78	3593.89	4038.18	350.00	>LOQ 7.0
S	54.26	88.85	98.18	63.64	ND	<LOD 2.0
SS	ND	52.81	63.17	94.53	3.00	<LOQ 7.0
SSDS	14.69	42.81	46.81	42.90	ND	<LOD 2.0
CP	39.70	85.46	85.57	101.45	33.00	>LOQ 7.0
G	56.05	98.93	131.60	108.70	3.00	<LOQ 7.0
SG	334.09	310.64	1241.62	8576.33	1300.00	>LOQ 7.0

Cobalt

Cobalt metal dust may cause irritation of the nose and throat. Respiratory disease symptoms range from cough and shortness of breath to permanent disability. Exposure to cobalt may cause an allergic skin rash. The NIOSH REL and OSHA PEL for cobalt are 50 and 100 micrograms/cubic meter of air, respectively.

Air Sample Results - Cobalt

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Cobalt			
					Mass (µg/filter	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 0.2	ND	< LOD 4.30
97035	2	47.34	SS	1	0.44	> LOQ 0.4	9.29	> LOQ 8.45
97029	3	44.33	SS	1	0.59	> LOQ 0.4	13.31	> LOQ 9.02
97034	OBZ	47.60	SS	1	0.73	> LOQ 0.4	15.33	> LOQ 8.40
97022	1	47.66	SSDS	2	ND	< LOD 0.2	ND	< LOD 4.20
97032	2	46.72	SSDS	2	ND	< LOD 0.2	ND	< LOD 4.28
97025	3	49.14	SSDS	2	0.40	< LOQ 0.4	8.14	< LOQ 8.14
97006	OBZ	48.95	SSDS	2	ND	< LOD 0.2	ND	< LOD 4.09
97024	1	46.50	CS	3	0.7	> LOQ 0.4	15.05	> LOQ 8.60
97020	2	47.34	CS	3	1.20	> LOQ 0.4	25.35	> LOQ 8.45
97015	3	44.33	CS	3	1.50	> LOQ 0.4	33.84	> LOQ 9.02
97037	OBZ	47.60	CS	3	1.30	> LOQ 0.4	27.31	> LOQ 8.40
97014	1	50.38	CP	4	0.79	> LOQ 0.4	15.68	> LOQ 7.94
97011	2	47.98	CP	4	1.40	> LOQ 0.4	29.18	> LOQ 8.34
97031	3	47.92	CP	4	1.50	> LOQ 0.4	31.30	> LOQ 8.35
97019	OBZ	48.30	CP	4	2.20	> LOQ 0.4	45.55	> LOQ 8.28
97030	1	47.64	N	5	1.30	> LOQ 0.4	27.29	> LOQ 8.40
97009	2	44.16	N	5	3.30	> LOQ 0.4	74.73	> LOQ 9.06
97021	3	44.52	N	5	2.00	> LOQ 0.4	44.92	> LOQ 8.98
97036	OBZ	54.48	N	5	2.70	> LOQ 0.4	49.56	> LOQ 7.34
97018	1	48.17	G	6	0.20	< LOQ 0.4	4.15	< LOQ 8.30
97005	2	47.51	G	6	0.77	> LOQ 0.4	16.21	> LOQ 8.42
97017	3	47.11	G	6	0.99	> LOQ 0.4	21.01	> LOQ 8.49
97007	OBZ	48.76	G	6	0.74	> LOQ 0.4	15.18	> LOQ 8.20
97008	1	47.92	S	7	ND	< LOD 0.2	ND	<LOD 4.17
97023	2	48.40	S	7	0.41	> LOQ 0.4	8.47	> LOQ 8.27
97013	3	48.89	S	7	0.40	> LOQ 0.4	8.18	> LOQ 8.18
97016	OBZ	48.71	S	7	0.42	> LOQ 0.4	8.62	> LOQ 8.21
97001	1	47.89	SG	8	0.30	< LOQ 0.4	6.26	< LOQ 8.35
97003	2	48.29	SG	8	ND	< LOD 0.2	ND	< LOD 4.14
97028	3	48.32	SG	8	2.10	> LOQ 0.4	43.46	> LOQ 8.28
97038	OBZ	48.97	SG	8	13.00	> LOQ 2.0	265.46	> LOQ 40.84

Bulk Elemental Analysis - Cobalt

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Cobalt		Sample	Cobalt	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	1.00	<LOQ 2.0	J97119P203 PB	0.70	<LOQ 2.0
N	J97119P205 VB	8.10	>LOQ 2.0	J97119P205 PB	17.00	>LOQ 2.0
S	J97119P207 VB	1.00	<LOQ 2.0	J97119P207 PB	ND	<LOD 0.5
SS	J97119P201 VB	2.00	<LOQ 2.0	J97119P201 PB	1.00	<LOQ 2.0
SSDS	J97119P202 VB	0.60	<LOQ 2.0	J97119P202 PB	0.50	<LOQ 2.0
CP	J97119P204 VB	26.00	>LOQ 2.0	J97119P204 PB	30.00	>LOQ 2.0
G	J97119P206 VB	0.80	<LOQ 2.0	J97119P206 PB	2.10	>LOQ 2.0
SG	J97119P208 VB	44.00	>LOQ 2.0	J97119P208 PB	46.00	>LOQ 2.0

Comparison of Airborne Concentrations to Bulk Concentrations - Cobalt

NIOSH REL 50.0 micrograms/cubic meter
OSHA PEL 100.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Cobalt**	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**µg/g**	**Notes**
CS	15.05	25.35	33.84	27.31	1.00	<LOQ 2.0
N	27.29	74.73	44.92	49.56	8.10	>LOQ 2.0
S	ND	8.47	8.18	8.62	1.00	<LOQ 2.0
SS	ND	9.29	13.31	15.33	2.00	<LOQ 2.0
SSDS	ND	ND	8.14	ND	0.60	<LOQ 2.0
CP	15.68	29.18	31.30	45.55	26.00	>LOQ 2.0
G	4.15	16.21	21.01	15.18	0.80	<LOQ 2.0
SG	6.26	ND	43.46	265.46	44.00	>LOQ 2.0

Copper

Copper dust may cause sensations of chills and stuffiness of the head. Small copper particles may enter the eye and cause irritation, discoloration, and damage. Repeated or prolonged exposure may cause skin irritation or discoloration of the skin or hair. The NIOSH REL and OSHA PEL for copper are both 1,000 micrograms/cubic meter of air.

Air Sample Results - Copper

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Copper			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	0.33	> LOQ 0.2	7.10	> LOQ 4.30
97035	2	47.34	SS	1	4.40	> LOQ 0.2	92.94	> LOQ 4.22
97029	3	44.33	SS	1	4.80	> LOQ 0.2	108.28	> LOQ 4.51
97034	OBZ	47.60	SS	1	5.90	> LOQ 0.2	123.94	> LOQ 4.20
97022	1	47.66	SSDS	2	1.20	> LOQ 0.2	25.18	> LOQ 4.20
97032	2	46.72	SSDS	2	2.60	> LOQ 0.2	55.66	> LOQ 4.28
97025	3	49.14	SSDS	2	3.50	> LOQ 0.2	71.23	> LOQ 4.07
97006	OBZ	48.95	SSDS	2	3.50	> LOQ 0.2	71.50	> LOQ 4.09
97024	1	46.50	CS	3	5.00	> LOQ 0.2	107.53	> LOQ 4.30
97020	2	47.34	CS	3	8.90	> LOQ 0.2	188.00	> LOQ 4.22
97015	3	44.33	CS	3	11.00	> LOQ 0.2	248.15	> LOQ 4.51
97037	OBZ	47.60	CS	3	9.10	> LOQ 0.2	191.16	> LOQ 4.20
97014	1	50.38	CP	4	35.00	> LOQ 0.2	694.78	> LOQ 3.97
97011	2	47.98	CP	4	80.00	> LOQ 0.2	1667.50	> LOQ 4.17
97031	3	47.92	CP	4	84.00	> LOQ 0.2	1753.07	> LOQ 4.17
97019	OBZ	48.30	CP	4	130.00	> LOQ 0.2	2691.51	> LOQ 4.14
97030	1	47.64	N	5	2.50	> LOQ 0.2	52.48	> LOQ 4.20
97009	2	44.16	N	5	5.30	> LOQ 0.2	120.02	> LOQ 4.53
97021	3	44.52	N	5	4.60	> LOQ 0.2	103.32	> LOQ 4.49
97036	OBZ	54.48	N	5	5.10	> LOQ 0.2	93.61	> LOQ 3.67
97018	1	48.17	G	6	1.50	> LOQ 0.2	31.14	> LOQ 4.15
97005	2	47.51	G	6	2.90	> LOQ 0.2	61.04	> LOQ 4.21
97017	3	47.11	G	6	3.50	> LOQ 0.2	74.29	> LOQ 4.25
97007	OBZ	48.76	G	6	3.10	> LOQ 0.2	63.58	> LOQ 4.10
97008	1	47.92	S	7	2.80	> LOQ 0.2	58.44	> LOQ 4.17
97023	2	48.40	S	7	4.90	> LOQ 0.2	101.25	> LOQ 4.13
97013	3	48.89	S	7	5.50	> LOQ 0.2	112.50	> LOQ 4.09
97016	OBZ	48.71	S	7	3.50	> LOQ 0.2	71.86	> LOQ 4.11
97001	1	47.89	SG	8	11.00	> LOQ 0.2	229.68	> LOQ 4.18
97003	2	48.29	SG	8	9.00	> LOQ 0.2	186.38	> LOQ 4.14
97028	3	48.32	SG	8	41.00	> LOQ 0.2	848.44	> LOQ 4.14
97038	OBZ	48.97	SG	8	280.00	> LOQ 1.0	5717.55	> LOQ 20.42

Bulk Elemental Analysis - Copper

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive Type	Sample No.	Copper		Sample No.	Copper	
		µg/g	Notes		µg/g	Notes
CS	J97119P203 VB	0.80	<LOQ 1.0	J97119P203 PB	7.30	>LOQ 1.0
N	J97119P205 VB	3.70	>LOQ 1.0	J97119P205 PB	9.10	>LOQ 1.0
S	J97119P207 VB	0.40	<LOQ 1.0	J97119P207 PB	3.40	>LOQ 1.0
SS	J97119P201 VB	7.50	>LOQ 1.0	J97119P201 PB	6.60	>LOQ 1.0
SSDS	J97119P202 VB	ND	<LOD 0.3	J97119P202 PB	3.60	>LOQ 1.0
CP	J97119P204 VB	1300.00	>LOQ 1.0	J97119P204 PB	1500.00	>LOQ 1.0
G	J97119P206 VB	0.50	<LOQ 1.0	J97119P206 PB	3.90	>LOQ 1.0
SG	J97119P208 VB	1100.00	>LOQ 1.0	J97119P208 PB	1200.00	>LOQ 1.0

Comparison of Airborne Concentrations to Bulk Concentrations - Copper

NIOSH REL 1000.0 micrograms/cubic meter
OSHA PEL 1000.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Copper	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/g	Notes
CS	107.53	188.00	248.15	191.16	0.80	<LOQ 1.0
N	52.48	120.02	103.32	93.61	3.70	>LOQ 1.0
S	58.44	101.25	112.50	71.86	0.40	<LOQ 1.0
SS	7.10	92.94	108.28	123.94	7.50	>LOQ 1.0
SSDS	25.18	55.66	71.23	71.50	ND	<LOD 0.3
CP	694.78	1667.50	1753.07	2691.51	1300.00	>LOQ 1.0
G	31.14	61.04	74.29	63.58	0.50	<LOQ 1.0
SG	229.68	186.38	848.44	5717.55	1100.00	>LOQ 1.0

Iron

Changes attributed to the inhalation of iron dust generally involve a benign pneumoconiosis (siderosis) not suspected of progression to true fibrosis. The NIOSH REL and OSHA PEL for iron are 5,000 and 10,000 micrograms/cubic meter of air, respectively.

Air Sample Results - Iron

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Iron			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	350	> LOQ 2.0	7526.88	> LOQ 43.01
97035	2	47.34	SS	1	4700	> LOQ 10.0	99281.79	> LOQ 211.24
97029	3	44.33	SS	1	5000	> LOQ 10.0	112795.52	> LOQ 225.59
97034	OBZ	47.60	SS	1	7400	> LOQ 20.0	155449.12	> LOQ 420.13
97022	1	47.66	SSDS	2	1300	> LOQ 40.0	27274.25	> LOQ 839.21
97032	2	46.72	SSDS	2	3000	> LOQ 10.0	64217.83	> LOQ 214.06
97025	3	49.14	SSDS	2	4400	> LOQ 10.0	89540.09	> LOQ 203.50
97006	OBZ	48.95	SSDS	2	4200	> LOQ 10.0	85805.34	> LOQ 204.30
97024	1	46.50	CS	3	5800	> LOQ 10.0	124731.18	> LOQ 215.05
97020	2	47.34	CS	3	11000	> LOQ 20.0	232361.64	> LOQ 422.48
97015	3	44.33	CS	3	14000	> LOQ 40.0	315827.47	> LOQ 902.36
97037	OBZ	47.60	CS	3	11000	> LOQ 20.0	231073.02	> LOQ 420.13
97014	1	50.38	CP	4	3600	> LOQ 10.0	71462.60	> LOQ 198.51
97011	2	47.98	CP	4	8300	> LOQ 20.0	173003.17	> LOQ 416.88
97031	3	47.92	CP	4	8400	> LOQ 20.0	175306.79	> LOQ 417.40
97019	OBZ	48.30	CP	4	11000	> LOQ 20.0	227743.27	> LOQ 414.08
97030	1	47.64	N	5	4100	> LOQ 10.0	86062.13	> LOQ 209.91
97009	2	44.16	N	5	3100	> LOQ 20.0	70199.28	> LOQ 452.90
97021	3	44.52	N	5	8100	> LOQ 20.0	181940.70	> LOQ 449.24
97036	OBZ	54.48	N	5	9300	> LOQ 20.0	170704.85	> LOQ 367.11
97018	1	48.17	G	6	8500	> LOQ 20.0	176465.70	> LOQ 415.21
97005	2	47.51	G	6	13000	> LOQ 40.0	273638.12	> LOQ 841.96
97017	3	47.11	G	6	18000	> LOQ 40.0	382068.26	> LOQ 849.04
97007	OBZ	48.76	G	6	16000	> LOQ 40.0	328164.74	> LOQ 820.41
97008	1	47.92	S	7	4300	> LOQ 10.0	89740.38	> LOQ 208.70
97023	2	48.40	S	7	7400	> LOQ 20.0	152905.20	> LOQ 413.26
97013	3	48.89	S	7	8100	> LOQ 20.0	165684.83	> LOQ 409.10
97016	OBZ	48.71	S	7	5000	> LOQ 10.0	102652.54	> LOQ 205.31
97001	1	47.89	SG	8	7700	> LOQ 20.0	160778.42	> LOQ 417.61
97003	2	48.29	SG	8	7900	> LOQ 20.0	163601.72	> LOQ 414.18
97028	3	48.32	SG	8	28000	> LOQ 80.0	579422.23	> LOQ 1655.49
97038	OBZ	48.97	SG	8	210000	> LOQ 400.0	4288164.67	> LOQ 8167.93

Bulk Elemental Analysis - Iron

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Iron		Sample	Iron	
Type	No.	μg/g	Notes	No.	μg/g	Notes
CS	J97119P203 VB	1600.00	>LOQ 10.0	J97119P203 PB	5000.00	>LOQ 20.0
N	J97119P205 VB	8800.00	>LOQ 50.0	J97119P205 PB	17000.00	>LOQ 50.0
S	J97119P207 VB	83.00	>LOQ 10.0	J97119P207 PB	5600.00	>LOQ 20.0
SS	J97119P201 VB	3600.00	>LOQ 10.0	J97119P201 PB	6900.00	>LOQ 20.0
SSDS	J97119P202 VB	69.00	>LOQ 10.0	J97119P202 PB	5200.00	>LOQ 20.0
CP	J97119P204 VB	96000.00	>LOQ 200	J97119P204 PB	110000.00	>LOQ 400.0
G	J97119P206 VB	4100.00	>LOQ 10.0	J97119P206 PB	15000.00	>LOQ 50.0
SG	J97119P208 VB	660000.00	>LOQ 2000	J97119P208 PB	780000.00	>LOQ 2000

Comparison of Airborne Concentrations to Bulk Concentrations - Iron

NIOSH REL 5000.0 micrograms/cubic meter
OSHA PEL 10000.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Iron**	
Type	**μg/m^3**	**μg/m^3**	**μg/m^3**	**μg/m^3**	**μg/g**	**Notes**
CS	124731.18	#REF!	315827.47	231073.02	1600.00	>LOQ 10.0
N	86062.13	70199.28	181940.70	170704.85	8800.00	>LOQ 50.0
S	89740.38	152905.20	165684.83	102652.54	83.00	>LOQ 10.0
SS	7526.88	99281.79	112795.52	155449.12	3600.00	>LOQ 10.0
SSDS	27274.25	64217.83	89540.09	85805.34	69.00	>LOQ 10.0
CP	71462.60	173003.17	175306.79	227743.27	96000.00	>LOQ 200
G	176465.70	273638.12	382068.26	328164.74	4100.00	>LOQ 10.0
SG	160778.42	163601.72	579422.23	4288164.67	660000.00	>LOQ 2000

Lead

Inhalation or ingestion of inorganic lead has reportedly caused peripheral neuropathy with paralysis of the muscles of the wrists and ankles, encephalopathy, anemia due to decreased red blood cell life and impaired heme synthesis, kidney damage and adverse effects on the reproductive systems of males and females. The NIOSH REL and OSHA PEL for lead are 100 and 50 micrograms/cubic meter of air, respectively.

Air Sample Results - Lead

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Lead			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOQ 0.4	ND	< LOD 2.15
97035	2	47.34	SS	1	0.55	> LOQ 0.4	11.62	> LOQ 8.45
97029	3	44.33	SS	1	0.63	> LOQ 0.04	14.21	> LOQ 0.90
97034	OBZ	47.60	SS	1	0.36	> LOQ 0.04	7.56	> LOQ 0.84
97022	1	47.66	SSDS	2	0.22	> LOQ 0.04	4.62	> LOQ 0.84
97032	2	46.72	SSDS	2	0.44	> LOQ 0.04	9.42	> LOQ 0.86
97025	3	49.14	SSDS	2	0.54	> LOQ 0.04	10.99	> LOQ 0.81
97006	OBZ	48.95	SSDS	2	0.55	> LOQ 0.04	11.24	> LOQ 0.82
97024	1	46.50	CS	3	0.56	> LOQ 0.4	12.04	> LOQ 8.60
97020	2	47.34	CS	3	0.47	> LOQ 0.4	9.93	> LOQ 8.45
97015	3	44.33	CS	3	0.52	> LOQ 0.4	11.73	> LOQ 9.02
97037	OBZ	47.60	CS	3	0.56	> LOQ 0.4	11.76	> LOQ 8.40
97014	1	50.38	CP	4	0.16	> LOQ 0.04	3.18	> LOQ0.79
97011	2	47.98	CP	4	0.42	> LOQ 0.04	8.75	> LOQ0.83
97031	3	47.92	CP	4	0.36	> LOQ 0.04	7.51	> LOQ 0.83
97019	OBZ	48.30	CP	4	0.49	> LOQ 0.04	10.14	> LOQ 0.83
97030	1	47.64	N	5	0.24	> LOQ 0.04	5.04	> LOQ 0.84
97009	2	44.16	N	5	0.37	> LOQ 0.04	8.38	> LOQ 0.91
97021	3	44.52	N	5	0.33	> LOQ 0.04	7.41	> LOQ 0.90
97036	OBZ	54.48	N	5	0.39	> LOQ 0.04	7.16	> LOQ 0.73
97018	1	48.17	G	6	0.25	> LOQ 0.04	5.19	> LOQ 0.83
97005	2	47.51	G	6	0.41	> LOQ 0.04	8.63	> LOQ 0.84
97017	3	47.11	G	6	0.55	> LOQ 0.04	11.67	> LOQ 0.85
97007	OBZ	48.76	G	6	0.5	> LOQ 0.04	10.26	> LOQ 0.82
97008	1	47.92	S	7	1.5	> LOQ 0.04	31.30	> LOQ 0.83
97023	2	48.40	S	7	2.8	> LOQ 0.2	57.86	> LOQ 4.13
97013	3	48.89	S	7	2.6	> LOQ 0.2	53.18	> LOQ 4.09
97016	OBZ	48.71	S	7	1.7	> LOQ 0.04	34.90	> LOQ 0.82
97001	1	47.89	SG	8	0.092	> LOQ 0.04	1.92	> LOQ 0.84
97003	2	48.29	SG	8	0.23	> LOQ 0.04	4.76	> LOQ 0.83
97028	3	48.32	SG	8	0.56	> LOQ 0.04	11.59	> LOQ 0.83
97038	OBZ	48.97	SG	8	1.2	> LOQ 0.04	24.50	> LOQ.0.82

Bulk Elemental Analysis - Lead

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Lead		Sample	Lead	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	<LOD 0.7	J97119P203 PB	ND	<LOD 0.7
N	J97119P205 VB	ND	<LOD 0.7	J97119P205 PB	ND	<LOD 0.7
S	J97119P207 VB	2.50	>LOQ 2.0	J97119P207 PB	2.50	>LOQ 2.0
SS	J97119P201 VB	ND	<LOD 0.7	J97119P201 PB	ND	<LOD 0.7
SSDS	J97119P202 VB	ND	<LOD 0.7	J97119P202 PB	ND	<LOD 0.7
CP	J97119P204 VB	3.20	>LOQ 2.0	J97119P204 PB	2.80	>LOQ 2.0
G	J97119P206 VB	ND	<LOD 0.7	J97119P206 PB	ND	<LOD 0.7
SG	J97119P208 VB	4.70	>LOQ 2.0	J97119P208 PB	4.40	>LOQ 2.0

Comparison of Airborne Concentrations to Bulk Concentrations - Lead

NIOSH REL 100.0 micrograms/cubic meter
OSHA PEL 50.0 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Lead**	
Type	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/g**	**Notes**
CS	12.04	9.93	11.73	11.76	ND	<LOD 0.7
N	5.04	8.38	7.41	7.16	ND	<LOD 0.7
S	31.30	57.86	53.18	34.90	2.50	>LOQ 2.0
SS	ND	11.62	14.21	7.56	ND	<LOD 0.7
SSDS	4.62	9.42	10.99	11.24	ND	<LOD 0.7
CP	3.18	8.75	7.51	10.14	3.20	>LOQ 2.0
G	5.19	8.63	11.67	10.26	ND	<LOD 0.7
SG	1.92	4.76	11.59	24.50	4.70	>LOQ 2.0

Lithium

Lithium hydride causes sneezing, coughing, and severe irritation of the nose and throat. Ingestion may cause nausea, muscle twitches, mental confusion and blurring of vision. Nervous system damages have been reported for high short-term exposure periods. The NIOSH REL and OSHA PEL for lithium are both 25 micrograms/cubic meter of air.

Air Sample Results - Lithium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Lithium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	0.060	< LOQ 0.07	1.29	< LOQ 1.505
97035	2	47.34	SS	1	0.540	> LOQ 0.07	11.41	> LOQ 1.479
97029	3	44.33	SS	1	0.630	> LOQ 0.07	14.21	> LOQ 1.579
97034	OBZ	47.60	SS	1	2.400	> LOQ 0.07	50.42	> LOQ 1.470
97022	1	47.66	SSDS	2	0.090	> LOQ 0.07	1.89	> LOQ 1.469
97032	2	46.72	SSDS	2	0.190	> LOQ 0.07	4.07	> LOQ 1.498
97025	3	49.14	SSDS	2	0.200	> LOQ 0.07	4.07	> LOQ 1.425
97006	OBZ	48.95	SSDS	2	0.170	> LOQ 0.07	3.47	> LOQ 1.430
97024	1	46.50	CS	3	0.57	> LOQ 0.07	12.26	> LOQ 1.505
97020	2	47.34	CS	3	2.900	> LOQ 0.07	61.26	> LOQ 1.479
97015	3	44.33	CS	3	3.500	> LOQ 0.07	78.96	> LOQ 1.579
97037	OBZ	47.60	CS	3	2.800	> LOQ 0.07	58.82	> LOQ 1.470
97014	1	50.38	CP	4	0.420	> LOQ 0.07	8.34	> LOQ 1.390
97011	2	47.98	CP	4	0.850	> LOQ 0.07	17.72	> LOQ 1.459
97031	3	47.92	CP	4	0.910	> LOQ 0.07	18.99	> LOQ 1.461
97019	OBZ	48.30	CP	4	1.300	> LOQ 0.07	26.92	> LOQ 1.449
97030	1	47.64	N	5	0.092	> LOQ 0.07	1.93	> LOQ 1.469
97009	2	44.16	N	5	0.170	> LOQ 0.07	3.85	> LOQ 1.585
97021	3	44.52	N	5	0.140	> LOQ 0.07	3.14	> LOQ 1.572
97036	OBZ	54.48	N	5	0.160	> LOQ 0.07	2.94	> LOQ 1.285
97018	1	48.17	G	6	0.450	> LOQ 0.07	9.34	> LOQ 1.453
97005	2	47.51	G	6	0.680	> LOQ 0.07	14.31	> LOQ 1.473
97017	3	47.11	G	6	0.910	> LOQ 0.07	19.32	> LOQ 1.486
97007	OBZ	48.76	G	6	0.790	> LOQ 0.07	16.20	> LOQ 1.436
97008	1	47.92	S	7	0.450	> LOQ 0.07	9.39	> LOQ 1.461
97023	2	48.40	S	7	0.970	> LOQ 0.07	20.04	> LOQ 1.446
97013	3	48.89	S	7	1.000	> LOQ 0.07	20.45	> LOQ 1.432
97016	OBZ	48.71	S	7	0.630	> LOQ 0.07	12.93	> LOQ 1.437
97001	1	47.89	SG	8	0.040	< LOQ 0.07	0.84	< LOQ 1.462
97003	2	48.29	SG	8	0.050	< LOQ 0.07	1.04	< LOQ 1.450
97028	3	48.32	SG	8	0.050	< LOQ 0.07	1.03	< LOQ 1.449
97038	OBZ	48.97	SG	8	0.200	< LOQ 0.3	4.08	< LOQ 6.126

Bulk Elemental Analysis - Lithium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Lithium		Sample	Lithium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	0.95	>LOQ 0.3	J97119P203 PB	1.30	>LOQ 0.3
N	J97119P205 VB	0.39	>LOQ 0.3	J97119P205 PB	0.48	>LOQ 0.3
S	J97119P207 VB	0.30	<LOQ 0.3	J97119P207 PB	0.62	>LOQ 0.3
SS	J97119P201 VB	1.30	>LOQ 0.3	J97119P201 PB	1.20	>LOQ 0.3
SSDS	J97119P202 VB	0.10	<LOQ 0.3	J97119P202 PB	ND	<LOD 0.09
CP	J97119P204 VB	14.00	>LOQ 0.3	J97119P204 PB	17.00	>LOQ 0.3
G	J97119P206 VB	0.48	>LOQ 0.3	J97119P206 PB	0.30	<LOQ 0.3
SG	J97119P208 VB	ND	<LOD 0.09	J97119P208 PB	ND	<LOD 0.09

Comparison of Airborne Concentrations to Bulk Concentrations - Lithium

NIOSH REL 25.0 micrograms/cubic meter
OSHA PEL 25.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Lithium**	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**µg/g**	**Notes**
CS	12.26	61.26	78.96	58.82	0.95	>LOQ 0.3
N	1.93	3.85	3.14	2.94	0.39	>LOQ 0.3
S	9.39	20.04	20.45	12.93	0.30	<LOQ 0.3
SS	1.29	11.41	14.21	50.42	1.30	>LOQ 0.3
SSDS	1.89	4.07	4.07	3.47	0.10	<LOQ 0.3
CP	8.34	17.72	18.99	26.92	14.00	>LOQ 0.3
G	9.34	14.31	19.32	16.20	0.48	>LOQ 0.3
SG	0.84	1.04	1.03	4.08	ND	<LOD 0.09

Magnesium

Magnesium may cause irritation of the eyes, nose, and throat. Magnesium oxide fume may cause metal fume fever. However, the dust is generally considered a nuisance particulate, which will not produce significant toxic effects when exposures are kept under reasonable control. For the purpose of this study, the NIOSH REL is 10,000 micrograms/cubic meter of air based on the discussion in APPENDIX D to NIOSH POCKET GUIDE TO CHEMICAL HAZARDS[1] concerning magnesium oxide fume, as there is no NIOSH REL listed for magnesium. The OSHA PEL for magnesium oxide fume is 15,000 micrograms/cubic meter of air.

---

[1] *NIOSH Pocket Guide to Chemical Hazards*, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Fourth Printing, June 1994

Air Sample Results - Magnesium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Magnesium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	200.00	> LOQ 2.0	4301.08	> LOQ 43.01
97035	2	47.34	SS	1	2400.00	> LOQ 4.0	50697.08	> LOQ 84.50
97029	3	44.33	SS	1	2500.00	> LOQ 10.0	56397.76	> LOQ 225.59
97034	OBZ	47.60	SS	1	140.00	> LOQ 2.0	2940.93	> LOQ 42.01
97022	1	47.66	SSDS	2	10.00	> LOQ 2.0	209.80	> LOQ 41.96
97032	2	46.72	SSDS	2	17.00	> LOQ 2.0	363.90	> LOQ 42.81
97025	3	49.14	SSDS	2	22.00	> LOQ 2.0	447.70	> LOQ 40.70
97006	OBZ	48.95	SSDS	2	27.00	> LOQ 2.0	551.61	> LOQ 40.86
97024	1	46.50	CS	3	2900	> LOQ 10.0	62365.59	> LOQ 215.05
97020	2	47.34	CS	3	170.00	> LOQ 2.0	3591.04	> LOQ 42.25
97015	3	44.33	CS	3	210.00	> LOQ 2.0	4737.41	> LOQ 45.12
97037	OBZ	47.60	CS	3	160.00	> LOQ 2.0	3361.06	> LOQ 42.01
97014	1	50.38	CP	4	350.00	> LOQ 2.0	6947.75	> LOQ 39.70
97011	2	47.98	CP	4	770.00	> LOQ 2.0	16049.69	> LOQ 41.69
97031	3	47.92	CP	4	800.00	> LOQ 2.0	16695.88	> LOQ 41.74
97013	OBZ	48.30	CP	4	1100.00	> LOQ 2.0	22774.33	> LOQ 41.41
97030	1	47.64	N	5	7900.00	> LOQ 10.0	165827.04	> LOQ 209.91
97009	2	44.16	N	5	8800.00	> LOQ 20.0	199275.36	> LOQ 452.90
97021	3	44.52	N	5	5800.00	> LOQ 20.0	130278.53	> LOQ 449.24
97036	OBZ	54.48	N	5	7900.00	> LOQ 20.0	145007.34	> LOQ 367.11
97018	1	48.17	G	6	290.00	> LOQ 2.0	6020.59	> LOQ 41.52
97005	2	47.51	G	6	450.00	> LOQ 2.0	9472.09	> LOQ 42.10
97017	3	47.11	G	6	640.00	> LOQ 2.0	13584.65	> LOQ 42.45
97007	OBZ	48.76	G	6	570.00	> LOQ 2.0	11690.87	> LOQ 41.02
97008	1	47.92	S	7	14.00	> LOQ 2.0	292.18	> LOQ 41.74
97023	2	48.40	S	7	27.00	> LOQ 2.0	557.90	> LOQ 41.33
97013	3	48.89	S	7	29.00	> LOQ 2.0	593.19	> LOQ 40.91
97016	OBZ	48.71	S	7	20.00	> LOQ 2.0	410.61	> LOQ 41.06
97001	1	47.89	SG	8	11.00	> LOQ 2.0	229.68	> LOQ 41.76
97003	2	48.29	SG	8	30.00	> LOQ 2.0	621.27	> LOQ 41.42
97028	3	48.32	SG	8	32.00	> LOQ 2.0	662.20	> LOQ 41.39
97038	OBZ	48.97	SG	8	54.00	> LOQ 10.0	1102.67	> LOQ.204.20

Bulk Elemental Analysis - Magnesium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Magnesium		Sample	Magnesium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	52.00	>LOQ 7.0	J97119P203 PB	70.00	>LOQ 7.0
N	J97119P205 VB	17000.00	>LOQ 30.0	J97119P205 PB	25000.00	>LOQ 30.0
S	J97119P207 VB	8.40	>LOQ 7.0	J97119P207 PB	260.00	>LOQ 7.0
SS	J97119P201 VB	15000.00	>LOQ 30.0	J97119P201 PB	4100.00	>LOQ 7.0
SSDS	J97119P202 VB	6.00	<LOQ 7.0	J97119P202 PB	26.00	>LOQ 7.0
CP	J97119P204 VB	13000.00	>LOQ 30.0	J97119P204 PB	17000.00	>LOQ 30.0
G	J97119P206 VB	230.00	>LOQ 7.0	J97119P206 PB	160.00	>LOQ 7.0
SG	J97119P208 VB	68.00	>LOQ 7.0	J97119P208 PB	87.00	>LOQ 7.0

Comparison of Airborne Concentrations to Bulk Concentrations - Magnesium

NIOSH REL 10000.0 micrograms/cubic meter (nuisance)
OSHA PEL 15000.0 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Magnesium**	
Type	**µg/m³**	**µg/m³**	**µg/m³**	**µg/m³**	**µg/g**	**Notes**
CS	62365.59	3591.04	4737.41	3361.06	52.00	>LOQ 7.0
N	165827.04	199275.36	130278.53	145007.34	17000.00	>LOQ 30.0
S	292.18	557.90	593.19	410.61	8.40	>LOQ 7.0
SS	4301.08	50697.08	56397.76	2940.93	15000.00	>LOQ 30.0
SSDS	209.80	363.90	447.70	551.61	6.00	<LOQ 7.0
CP	6947.75	16049.69	16695.88	22774.33	13000.00	>LOQ 30.0
G	6020.59	9472.09	13584.65	11690.87	230.00	>LOQ 7.0
SG	229.68	621.27	662.20	1102.67	68.00	>LOQ 7.0

Manganese

Prolonged or repeated exposure to manganese may effect the nervous system with difficulty in walking, weakness, memory lapse, and unstable emotions. Chronic exposure may effect the respiratory system resulting in pneumonitis and bronchitis. The NIOSH REL for manganese metal, fumes, and compounds is 1,000 micrograms/cubic meter of air. The OSHA PEL for manganese is 5,000 micrograms/cubic meter of air as a ceiling limit.

Air Sample Results - Manganese

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Manganese			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	3.00	> LOQ 0.03	64.52	> LOQ 0.645
97035	2	47.34	SS	1	38.00	> LOQ 0.03	802.70	> LOQ 0.634
97029	3	44.33	SS	1	42.00	> LOQ 0.03	947.48	> LOQ 0.677
97034	OBZ	47.60	SS	1	21.00	> LOQ 0.03	441.14	> LOQ 0.630
97022	1	47.66	SSDS	2	4.90	> LOQ 0.03	102.80	> LOQ 0.629
97032	2	46.72	SSDS	2	12.00	> LOQ 0.03	256.87	> LOQ 0.642
97025	3	49.14	SSDS	2	16.00	> LOQ 0.03	325.60	> LOQ 0.611
97006	OBZ	48.95	SSDS	2	15.00	> LOQ 0.03	306.45	> LOQ 0.613
97024	1	46.50	CS	3	42.00	> LOQ 0.03	903.23	> LOQ 0.645
97020	2	47.34	CS	3	30.00	> LOQ 0.03	633.71	> LOQ 0.634
97015	3	44.33	CS	3	37.00	> LOQ 0.03	834.69	> LOQ 0.677
97037	OBZ	47.60	CS	3	31.00	> LOQ 0.03	651.21	> LOQ 0.630
97014	1	50.38	CP	4	55.00	> LOQ 0.03	1091.79	> LOQ 0.596
97011	2	47.98	CP	4	120.00	> LOQ 0.03	2501.25	> LOQ 0.625
97031	3	47.92	CP	4	120.00	> LOQ 0.03	2504.38	> LOQ 0.626
97019	OBZ	48.30	CP	4	160.00	> LOQ 0.03	3312.63	> LOQ 0.621
97030	1	47.64	N	5	42.00	> LOQ 0.03	881.61	> LOQ 0.630
97009	2	44.16	N	5	100.00	> LOQ 0.03	2264.49	> LOQ 0.679
97021	3	44.52	N	5	78.00	> LOQ 0.03	1752.02	> LOQ 0.674
97036	OBZ	54.48	N	5	96.00	> LOQ 0.03	1762.11	> LOQ 0.551
97018	1	48.17	G	6	280.00	> LOQ 0.03	5812.99	> LOQ 0.623
97005	2	47.51	G	6	440.00	> LOQ 0.03	9261.60	> LOQ 0.631
97017	3	47.11	G	6	640.00	> LOQ 0.1	13584.65	> LOQ 2.123
97007	OBZ	48.76	G	6	540.00	> LOQ 0.06	11075.56	> LOQ 1.231
97008	1	47.92	S	7	23.00	> LOQ 0.03	480.01	> LOQ 0.626
97023	2	48.40	S	7	37.00	> LOQ 0.03	764.53	> LOQ 0.620
97013	3	48.89	S	7	40.00	> LOQ 0.03	818.20	> LOQ 0.614
97016	OBZ	48.71	S	7	27.00	> LOQ 0.03	554.32	> LOQ 0.616
97001	1	47.89	SG	8	77.00	> LOQ 0.03	1607.78	> LOQ 0.626
97003	2	48.29	SG	8	77.00	> LOQ 0.03	1594.60	> LOQ 0.621
97028	3	48.32	SG	8	290.00	> LOQ 0.03	6001.16	> LOQ 0.621
97038	OBZ	48.97	SG	8	1900.00	> LOQ 0.1	38797.68	>LOQ 2.042

Bulk Elemental Analysis -Manganese

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Manganese		Sample	Manganese	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	2.80	> LOQ 0.1	J97119P203 PB	24.00	> LOQ 0.1
N	J97119P205 VB	130.00	> LOQ 0.1	J97119P205 PB	190.00	> LOQ 0.1
S	J97119P207 VB	5.30	> LOQ 0.1	J97119P207 PB	26.00	> LOQ 0.1
SS	J97119P201 VB	110.00	> LOQ 0.1	J97119P201 PB	65.00	> LOQ 0.1
SSDS	J97119P202 VB	0.17	> LOQ 0.1	J97119P202 PB	26.00	> LOQ 0.1
CP	J97119P204 VB	1600.00	> LOQ 0.1	J97119P204 PB	2000.00	> LOQ 0.1
G	J97119P206 VB	170.00	> LOQ 0.1	J97119P206 PB	170.00	> LOQ 0.1
SG	J97119P208 VB	7000.00	> LOQ 0.5	J97119P208 PB	7600.00	> LOQ 0.5

Comparison of Airborne Concentrations to Bulk Concentrations - Manganese

NIOSH REL 1000.0 micrograms/cubic meter
OSHA PEL 5000.0 micrograms/cubic meter Ceiling Limit

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Manganese**	
Type	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	**µg/g**	**Notes**
CS	903.23	633.71	834.69	651.21	2.80	> LOQ 0.1
N	881.61	2264.49	1752.02	1762.11	130.00	> LOQ 0.1
S	480.01	764.53	818.20	554.32	5.30	> LOQ 0.1
SS	64.52	802.70	947.48	441.14	110.00	> LOQ 0.1
SSDS	102.80	256.87	325.60	306.45	0.17	> LOQ 0.1
CP	1091.79	2501.25	2504.38	3312.63	1600.00	> LOQ 0.1
G	5812.99	9261.60	13584.65	11075.56	170.00	> LOQ 0.1
SG	1607.78	1594.60	6001.16	38797.68	7000.00	> LOQ 0.5

Molybdenum

Molybdenum exposures include symptoms of anemia, gastrointestinal disturbances, bone disorders, and growth retardation. A few cases of pneumoconiosis have been reported with workers exposed to metallic molybdenum. For the purpose of this study, the NIOSH REL is 10,000 micrograms/cubic meter of air based on the discussion in APPENDIX D to NIOSH POCKET GUIDE TO CHEMICAL HAZARDS[2] concerning molybdenum (insoluble compounds as Mo), as there is no NIOSH REL listed for molybdenum. The OSHA PEL for molybdenum is 15,000 micrograms/cubic meter of air.

---

[2] Ibid.

Air Sample Results - Molybdenum

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Molybdenum			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 0.3	ND	< LOD 6.45
97035	2	47.34	SS	1	ND	< LOD 0.3	ND	< LOD 6.34
97029	3	44.33	SS	1	ND	< LOD 0.3	ND	< LOD 6.77
97034	OBZ	47.60	SS	1	ND	< LOD 0.3	ND	< LOD 6.30
97022	1	47.66	SSDS	2	0.40	< LOQ 0.8	8.39	< LOQ 16.78
97032	2	46.72	SSDS	2	ND	< LOD 0.3	ND	< LOD 6.42
97025	3	49.14	SSDS	2	ND	< LOD 0.3	ND	< LOD 6.11
97006	OBZ	48.95	SSDS	2	ND	< LOD 0.3	ND	< LOD 6.13
97024	1	46.50	CS	3	ND	< LOD 0.3	ND	< LOD 17.20
97020	2	47.34	CS	3	ND	< LOD 0.3	ND	< LOD 6.34
97015	3	44.33	CS	3	ND	< LOD 0.3	ND	< LOD 6.77
97037	OBZ	47.60	CS	3	ND	< LOD 0.3	ND	< LOD 6.30
97014	1	50.38	CP	4	ND	< LOD 0.3	ND	< LOD 5.96
97011	2	47.98	CP	4	ND	< LOD 0.3	ND	< LOD 6.25
97031	3	47.92	CP	4	ND	< LOD 0.3	ND	< LOD 6.26
97019	OBZ	48.30	CP	4	ND	< LOD 0.3	ND	< LOD 6.21
97030	1	47.64	N	5	ND	< LOD 0.3	ND	< LOD 6.30
97009	2	44.16	N	5	ND	< LOD 0.3	ND	< LOD 6.79
97021	3	44.52	N	5	ND	< LOD 0.3	ND	< LOD 6.74
97036	OBZ	54.48	N	5	ND	< LOD 0.3	ND	< LOD 5.51
97018	1	48.17	G	6	ND	< LOD 0.3	ND	< LOD 6.23
97005	2	47.51	G	6	0.30	< LOQ 0.8	6.31	< LOQ 16.84
97017	3	47.11	G	6	0.81	> LOQ 0.8	17.19	> LOQ 16.98
97007	OBZ	48.76	G	6	ND	< LOD 0.3	ND	< LOD 6.15
97008	1	47.92	S	7	ND	< LOD 0.3	ND	< LOD 6.26
97023	2	48.40	S	7	ND	< LOD 0.3	ND	< LOD 6.20
97013	3	48.89	S	7	ND	< LOD 0.3	ND	< LOD 6.14
97016	OBZ	48.71	S	7	ND	< LOD 0.3	ND	< LOD 6.16
97001	1	47.89	SG	8	2.40	> LOQ 0.8	50.11	> LOQ 16.70
97003	2	48.29	SG	8	2.40	> LOQ 0.8	49.70	> LOQ 16.57
97028	3	48.32	SG	8	14.00	> LOQ 0.8	289.71	> LOQ 16.55
97038	OBZ	48.97	SG	8	95.00	> LOQ 4.0	1939.88	> LOQ 81.68

Bulk Elemental Analysis -Molybdenum

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Molybdenum		Sample	Molybdenum	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	< LOD 1.0	J97119P203 PB	1.00	< LOQ 3.0
N	J97119P205 VB	6.60	> LOQ 3.0	J97119P205 PB	2.00	< LOQ 3.0
S	J97119P207 VB	1.00	< LOQ 3.0	J97119P207 PB	3.00	< LOQ 3.0
SS	J97119P201 VB	ND	< LOD 1.0	J97119P201 PB	ND	< LOD 1.0
SSDS	J97119P202 VB	ND	< LOD 1.0	J97119P202 PB	ND	< LOD 1.0
CP	J97119P204 VB	ND	< LOD 1.0	J97119P204 PB	7.20	> LOQ 3.0
G	J97119P206 VB	4.60	> LOQ 3.0	J97119P206 PB	ND	< LOD 1.0
SG	J97119P208 VB	290.00	> LOQ 3.0	J97119P208 PB	310.00	> LOQ 3.0

Comparison of Airborne Concentrations to Bulk Concentrations - Molybdenum

NIOSH REL 10000.0 micrograms/cubic meter (nuisance)
OSHA PEL 15000.0 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Molybdenum**	
Type	**$\mu g/m^3$**	**$\mu g/m^3$**	**$\mu g/m^3$**	**$\mu g/m^3$**	**µg/g**	**Notes**
CS	ND	ND	ND	ND	ND	< LOD 1.0
N	ND	ND	ND	ND	6.60	> LOQ 3.0
S	ND	ND	ND	ND	1.00	< LOQ 3.0
SS	ND	ND	ND	ND	ND	< LOD 1.0
SSDS	8.39	ND	ND	ND	ND	< LOD 1.0
CP	ND	ND	ND	ND	ND	< LOD 1.0
G	ND	6.31	17.19	ND	4.60	> LOQ 3.0
SG	50.11	49.70	289.71	1939.88	290.00	> LOQ 3.0

Nickel

Systemic affects from ingestion or inhalation of low solubility nickel compounds have not been reported. Absorption from the lungs depends on the solubility of the compounds. Occupational exposure to nickel compounds with low solubility, particularly the oxide, has reportedly caused lung cancer. Evidence suggests that soluble nickel compounds may cause respiratory or gastric cancer. Metallic nickel or nickel compounds are sensitizing. Lung reactions in the form of asthma have been attributed to nickel sensitization. Pneumoconiosis has also been reported. The NIOSH REL and OSHA PEL for nickel are 15 and 1,000 micrograms/cubic meter of air, respectively.

Nickel is considered an occupational carcinogen by NIOSH. The NIOSH policy regarding occupational carcinogens has changed from a recommend exposure limit (REL) of "lower feasible concentration". The new NIOSH policy for carcinogens is described in the following paragraph (This policy applies to all workplace hazards, including carcinogens):

For the past 20 plus years, NIOSH has subscribed to a carcinogen policy that was published in 1976 by Edward J. Fairchild, II, Associate Director for Cincinnati Operations, which called for "no detectable exposure levels for proven carcinogenic substances [New York Academy of Sciences Annals 1976]." This was in response to a generic OSHA rulemaking on carcinogens.

Because of advances in science and in approaches to risk assessment and risk management, NIOSH has in more recent years adopted a more inclusive policy. NIOSH RELs will be based on risk evaluations using human or animal health effects data, and on an assessment of what levels can be feasibly achieved by engineering controls and measured by analytical techniques. To the extent feasible, NIOSH will protect not only a no-effect exposure, but also exposure levels at which there may be residual risks.

The effect of this new policy for potential occupational carcinogens will be the development, whenever possible, of quantitative RELs that are based on human and/or animal data, as well as on the consideration of technological feasibility for controlling workplace exposures to the REL. Under the old policy for potential occupational carcinogens, RELs for most carcinogens were non-quantitative values labeled "lowest feasible concentration (LFC)." In 1989, NIOSH adopted several quantitative RELs for carcinogens from OSHA's PEL update. NIOSH will also recommend the complete range of respirators (as determined by the NIOSH Respirator Decision Logic) for carcinogens with quantitative RELs. In this way, respirators will be consistently recommended regardless of whether a substance is a carcinogen or a non-carcinogen.

Air Sample Results - Nickel

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Nickel			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	0.50	< LOQ 1.0	10.75	< LOQ 21.51
97035	2	47.34	SS	1	1.70	> LOQ 1.0	35.91	> LOQ 21.12
97029	3	44.33	SS	1	1.60	> LOQ 1.0	36.09	> LOQ 22.56
97034	OBZ	47.60	SS	1	2.20	> LOQ 1.0	46.21	> LOQ 21.01
97022	1	47.66	SSDS	2	ND	< LOD 0.5	ND	< LOD 10.49
97032	2	46.72	SSDS	2	1.10	> LOQ 1.0	23.55	> LOQ 21.41
97025	3	49.14	SSDS	2	1.10	> LOQ 1.0	22.39	> LOQ 20.35
97006	OBZ	48.95	SSDS	2	0.80	< LOQ 1.0	16.34	< LOQ 20.43
97024	1	46.50	CS	3	1.7	> LOQ 1.0	36.56	> LOQ 21.51
97020	2	47.34	CS	3	3.50	> LOQ 1.0	73.93	> LOQ 21.12
97015	3	44.33	CS	3	4.50	> LOQ 1.0	101.52	> LOQ 22.56
97037	OBZ	47.60	CS	3	4.30	> LOQ 1.0	90.33	> LOQ 21.01
97014	1	50.38	CP	4	0.80	< LOQ 1.0	15.88	< LOQ 19.85
97011	2	47.98	CP	4	1.80	> LOQ 1.0	37.52	> LOQ 20.84
97031	3	47.92	CP	4	2.10	> LOQ 1.0	43.83	> LOQ 20.87
97019	OBZ	48.30	CP	4	2.30	< LOQ 1.0	47.62	< LOQ 20.70
97030	1	47.64	N	5	23.00	> LOQ 1.0	482.79	> LOQ 20.99
97009	2	44.16	N	5	68.00	> LOQ 1.0	1539.86	> LOQ 22.64
97021	3	44.52	N	5	44.00	> LOQ 1.0	988.32	> LOQ 22.46
97036	OBZ	54.48	N	5	60.00	> LOQ 1.0	1101.32	> LOQ 18.36
97018	1	48.17	G	6	ND	< LOD 0.5	ND	< LOD 10.38
97005	2	47.51	G	6	1.20	> LOQ 1.0	25.26	> LOQ 21.05
97017	3	47.11	G	6	1.40	> LOQ 1.0	29.72	> LOQ 21.23
97007	OBZ	48.76	G	6	0.90	< LOQ 1.0	18.46	< LOQ 20.51
97008	1	47.92	S	7	0.80	< LOQ 1.0	16.70	< LOQ 20.87
97023	2	48.40	S	7	1.80	> LOQ 1.0	37.19	> LOQ 20.66
97013	3	48.89	S	7	2.10	> LOQ 1.0	42.96	> LOQ 20.45
97016	OBZ	48.71	S	7	0.60	< LOQ 1.0	12.32	< LOQ 20.53
97001	1	47.89	SG	8	8.60	> LOQ 1.0	179.57	> LOQ 20.88
97003	2	48.29	SG	8	6.30	> LOQ 1.0	130.47	> LOQ 20.71
97028	3	48.32	SG	8	33.00	> LOQ 1.0	682.89	> LOQ 20.69
97038	OBZ	48.97	SG	8	230.00	> LOQ 5.0	4696.56	> LOQ 102.10

Bulk Elemental Analysis -Nickel

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Nickel		Sample	Nickel	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	< LOD 2.0	J97119P203 PB	ND	< LOD 2.0
N	J97119P205 VB	400.00	> LOQ 4.0	J97119P205 PB	1300.00	> LOQ 4.0
S	J97119P207 VB	ND	< LOD 2.0	J97119P207 PB	ND	< LOD 2.0
SS	J97119P201 VB	ND	< LOD 2.0	J97119P201 PB	2.00	< LOQ 4.0
SSDS	J97119P202 VB	ND	< LOD 2.0	J97119P202 PB	ND	< LOD 2.0
CP	J97119P204 VB	19.00	> LOQ 4.0	J97119P204 PB	24.00	> LOQ 4.0
G	J97119P206 VB	ND	< LOD 2.0	J97119P206 PB	ND	< LOD 2.0
SG	J97119P208 VB	680.00	> LOQ 4.0	J97119P208 PB	770.00	> LOQ 4.0

Comparison of Airborne Concentrations to Bulk Concentrations - Nickel

NIOSH REL 15.0 micrograms/cubic meter
OSHA PEL 1000.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Nickel	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/g	Notes
CS	36.56	73.93	101.52	90.33	ND	< LOD 2.0
N	482.79	1539.86	988.32	1101.32	400.00	> LOQ 4.0
S	16.70	37.19	42.96	12.32	ND	< LOD 2.0
SS	10.75	35.91	36.09	46.21	ND	< LOD 2.0
SSDS	ND	23.55	22.39	16.34	ND	< LOD 2.0
CP	15.88	37.52	43.83	47.62	19.00	> LOQ 4.0
G	ND	25.26	29.72	18.46	ND	< LOD 2.0
SG	179.57	130.47	682.89	4696.56	680.00	> LOQ 4.0

Phosphorus

Repeated or prolonged exposure to phosphorus can cause "phossy jaw" with pain and swelling of the jaw, tooth aches, loosening of the teeth and deterioration of the jawbone. Chronic exposure can also cause weakness, anemia, loss of appetite, stomach complaints, cough and paleness. Chronic exposure may also cause bones to become brittle and break. The NIOSH REL and OSHA PEL for phosphorus are both 100 micrograms/cubic meter of air.

Air Sample Results - Phosphorus

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Phosphorus			
					Mass (μg/filter)	Filter Notes μg/f	Result μg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 2.0	ND	< LOD 43.01
97035	2	47.34	SS	1	20.00	> LOQ 4.0	422.48	> LOQ 84.50
97029	3	44.33	SS	1	19.00	> LOQ 4.0	428.62	> LOQ 90.24
97034	OBZ	47.60	SS	1	11.00	> LOQ 4.0	231.07	> LOQ 84.03
97022	1	47.66	SSDS	2	2.00	< LOQ 4.0	41.96	< LOQ 83.92
97032	2	46.72	SSDS	2	ND	< LOD 2.0	ND	< LOD 42.81
97025	3	49.14	SSDS	2	2.00	< LOQ 4.0	40.70	< LOQ 81.40
97006	OBZ	48.95	SSDS	2	3.00	< LOQ 4.0	61.29	< LOQ 81.72
97024	1	46.50	CS	3	20	> LOQ 4.0	430.11	> LOQ 86.02
97020	2	47.34	CS	3	12.00	> LOQ 4.0	253.49	> LOQ 84.50
97015	3	44.33	CS	3	20.00	> LOQ 4.0	451.18	> LOQ 90.24
97037	OBZ	47.60	CS	3	8.10	> LOQ 4.0	170.15	> LOQ 84.03
97014	1	50.38	CP	4	20.00	> LOQ 4.0	397.01	> LOQ 79.40
97011	2	47.98	CP	4	46.00	> LOQ 4.0	958.81	> LOQ 83.38
97031	3	47.92	CP	4	47.00	> LOQ 4.0	980.88	> LOQ 83.48
97019	OBZ	48.30	CP	4	67.00	> LOQ 4.0	1387.16	> LOQ 82.82
97030	1	47.64	N	5	ND	< LOD 2.0	ND	< LOD 41.98
97009	2	44.16	N	5	ND	< LOD 2.0	ND	< LOD 45.29
97021	3	44.52	N	5	2.00	< LOQ 4.0	44.92	< LOQ 89.85
97036	OBZ	54.48	N	5	ND	< LOD 2.0	ND	< LOD 36.71
97018	1	48.17	G	6	22.00	> LOQ 4.0	456.73	> LOQ 83.04
97005	2	47.51	G	6	41.00	> LOQ 4.0	863.01	> LOQ 84.20
97017	3	47.11	G	6	50.00	> LOQ 4.0	1061.30	> LOQ 84.90
97007	OBZ	48.76	G	6	45.00	> LOQ 4.0	922.96	> LOQ 82.04
97008	1	47.92	S	7	20.00	> LOQ 4.0	417.40	> LOQ 83.48
97023	2	48.40	S	7	32.00	> LOQ 4.0	661.21	> LOQ 82.65
97013	3	48.89	S	7	34.00	> LOQ 4.0	695.47	> LOQ 81.82
97016	OBZ	48.71	S	7	17.00	> LOQ 4.0	349.02	> LOQ 82.12
97001	1	47.89	SG	8	ND	< LOD 2.0	ND	< LOD 41.76
97003	2	48.29	SG	8	ND	< LOD 2.0	ND	< LOD 41.42
97028	3	48.32	SG	8	3.00	< LOQ 4.0	62.08	< LOQ 82.77
97038	OBZ	48.97	SG	8	29.00	> LOQ 20.0	592.18	> LOQ 408.40

Bulk Elemental Analysis - Phosphorus

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Phosphorus		Sample	Phosphorus	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	10.00	< LOQ 20.0	J97119P203 PB	ND	< LOD 5.0
N	J97119P205 VB	6.00	< LOQ 20.0	J97119P205 PB	20.00	< LOQ 20.0
S	J97119P207 VB	23.00	> LOQ 20.0	J97119P207 PB	40.00	> LOQ 20.0
SS	J97119P201 VB	100.00	> LOQ 20.0	J97119P201 PB	51.00	> LOQ 20.0
SSDS	J97119P202 VB	ND	< LOD 5.0	J97119P202 PB	6.00	< LOQ 20.0
CP	J97119P204 VB	860.00	> LOQ 20.0	J97119P204 PB	1100.00	> LOQ 20.0
G	J97119P206 VB	110.00	> LOQ 20.0	J97119P206 PB	130.00	> LOQ 20.0
SG	J97119P208 VB	300.00	> LOQ 20.0	J97119P208 PB	350.00	> LOQ 20.0

Comparison of Airborne Concentrations to Bulk Concentrations - Phosphorus

NIOSH REL 100.0 micrograms/cubic meter
OSHA PEL 100.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Phosphorus	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/g	Notes
CS	430.11	253.49	451.18	170.15	10.00	< LOQ 20.0
N	ND	ND	44.92	ND	6.00	< LOQ 20.0
S	417.40	661.21	695.47	349.02	23.00	> LOQ 20.0
SS	ND	422.48	428.62	231.07	100.00	> LOQ 20.0
SSDS	41.96	ND	40.70	61.29	ND	< LOD 5.0
CP	397.01	958.81	980.88	1387.16	860.00	> LOQ 20.0
G	456.73	863.01	1061.30	922.96	110.00	> LOQ 20.0
SG	ND	ND	62.08	592.18	300.00	> LOQ 20.0

Platinum

Repeated exposure to soluble platinum salts may cause both respiratory and skin allergies. The effects may be followed by chest tightness, shortness of breath, and a blue discoloration of the skin and wheezing. A skin reaction consists of an itchy, red rash. Exposures to pure metallic platinum causes no intoxication. The NIOSH REL for platinum is 1,000 micrograms/cubic meter of air. For purposes of this study, the vacated OSHA PEL for platinum, which was 1,000 micrograms/cubic meter of air, is used, as there is no OSHA PEL listed for platinum.

Air Sample Results - Platinum

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Platinum			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 3.0	ND	< LOD 64.52
97035	2	47.34	SS	1	ND	< LOD 3.0	ND	< LOD 63.37
97029	3	44.33	SS	1	5.00	< LOQ 7.0	112.80	< LOQ 157.91
97034	OBZ	47.60	SS	1	ND	< LOD 3.0	ND	< LOD 63.02
97022	1	47.66	SSDS	2	ND	< LOD 3.0	ND	< LOD 62.94
97032	2	46.72	SSDS	2	ND	< LOD 3.0	ND	< LOD 64.22
97025	3	49.14	SSDS	2	ND	< LOD 3.0	ND	< LOD 61.05
97006	OBZ	48.95	SSDS	2	ND	< LOD 3.0	ND	< LOD 61.29
97024	1	46.50	CS	3	ND	< LOD 3.0	ND	< LOD 64.52
97020	2	47.34	CS	3	ND	< LOD 3.0	ND	< LOD 63.37
97015	3	44.33	CS	3	9.50	> LOQ 7.0	214.31	> LOQ 157.91
97037	OBZ	47.60	CS	3	3.00	< LOQ 7.0	63.02	< LOQ 147.05
97014	1	50.38	CP	4	ND	< LOD 3.0	ND	< LOD 59.55
97011	2	47.98	CP	4	ND	< LOD 3.0	ND	< LOD 62.53
97031	3	47.92	CP	4	ND	< LOD 3.0	ND	< LOD 62.61
97019	OBZ	48.30	CP	4	3.00	< LOQ 7.0	62.11	< LOQ 144.93
97030	1	47.64	N	5	3.00	< LOQ 7.0	62.97	< LOQ 146.94
97009	2	44.16	N	5	ND	< LOD 3.0	ND	< LOD 67.93
97021	3	44.52	N	5	6.00	< LOQ 7.0	134.77	< LOQ 157.23
97036	OBZ	54.48	N	5	4.00	< LOQ 7.0	73.42	< LOQ 128.49
97018	1	48.17	G	6	ND	< LOD 3.0	ND	< LOD 62.28
97005	2	47.51	G	6	12.00	> LOQ 7.0	252.59	> LOQ 147.34
97017	3	47.11	G	6	18.00	> LOQ 7.0	382.07	> LOQ 148.58
97007	OBZ	48.76	G	6	17.00	> LOQ 7.0	348.68	> LOQ 143.57
97008	1	47.92	S	7	ND	< LOD 3.0	ND	< LOD 62.61
97023	2	48.40	S	7	ND	< LOD 3.0	ND	< LOD 61.99
97013	3	48.89	S	7	6.00	< LOQ 7.0	122.73	< LOQ 143.18
97016	OBZ	48.71	S	7	ND	< LOD 3.0	ND	< LOD 61.59
97001	1	47.89	SG	8	4.00	< LOQ 7.0	83.52	< LOQ 146.16
97003	2	48.29	SG	8	ND	< LOD 3.0	ND	< LOD 62.13
97028	3	48.32	SG	8	34.00	> LOQ 7.0	703.58	> LOQ 144.86
97038	OBZ	48.97	SG	8	330.00	> LOQ 30.0	6738.54	> LOQ 612.59

Bulk Elemental Analysis - Platinum

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Platinum		Sample	Platinum	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	< LOD 9.0	J97119P203 PB	20.00	< LOQ 30.0
N	J97119P205 VB	20.00	< LOQ 30.0	J97119P205 PB	35.00	> LOQ 30.0
S	J97119P207 VB	ND	< LOD 9.0	J97119P207 PB	ND	< LOD 9.0
SS	J97119P201 VB	ND	< LOD 9.0	J97119P201 PB	ND	< LOD 9.0
SSDS	J97119P202 VB	ND	< LOD 9.0	J97119P202 PB	9.00	< LOQ 30.0
CP	J97119P204 VB	160.00	> LOQ 30.0	J97119P204 PB	260.00	> LOQ 30.0
G	J97119P206 VB	ND	< LOD 9.0	J97119P206 PB	30.00	< LOQ 30.0
SG	J97119P208 VB	2900.00	> LOQ 30.0	J97119P208 PB	3300.00	> LOQ 30.0

Comparison of Airborne Concentrations to Bulk Concentrations - Platinum

NIOSH REL 1000.0 micrograms/cubic meter
OSHA PEL 1000.0 micrograms/cubic meter (Proposed)

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Platinum**	
Type	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/g**	**Notes**
CS	ND	ND	214.31	63.02	ND	< LOD 9.0
N	62.97	ND	134.77	73.42	20.00	< LOQ 30.0
S	ND	ND	122.73	ND	ND	< LOD 9.0
SS	ND	ND	112.80	ND	ND	< LOD 9.0
SSDS	ND	ND	ND	ND	ND	< LOD 9.0
CP	ND	ND	ND	62.11	160.00	> LOQ 30.0
G	ND	252.59	382.07	348.68	ND	< LOD 9.0
SG	83.52	ND	703.58	6738.54	2900.00	> LOQ 30.0

Selenium

Prolonged exposure to selenium may cause paleness, coated tongue, stomach disorders, metallic taste of the breath; damage to the spleen and liver, and anemia are possible. The NIOSH REL and OSHA PEL for selenium are both 200 micrograms/cubic meter of air.

Air Sample Results - Selenium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Selenium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 2.0	ND	< LOD 43.01
97035	2	47.34	SS	1	3.00	< LOQ 4.0	63.37	< LOQ 84.50
97029	3	44.33	SS	1	ND	< LOD 2.0	ND	< LOD 45.12
97034	OBZ	47.60	SS	1	ND	< LOD 2.0	ND	< LOD 42.01
97022	1	47.66	SSDS	2	ND	< LOD 2.0	ND	< LOD 41.96
97032	2	46.72	SSDS	2	ND	< LOD 2.0	ND	< LOD 42.81
97025	3	49.14	SSDS	2	ND	< LOD 2.0	ND	< LOD 40.70
97006	OBZ	48.95	SSDS	2	ND	< LOD 2.0	ND	< LOD 40.86
97024	1	46.50	CS	3	ND	< LOD 2.0	ND	< LOD 43.01
97020	2	47.34	CS	3	ND	< LOD 2.0	ND	< LOD 42.25
97015	3	44.33	CS	3	ND	< LOD 2.0	ND	< LOD 45.12
97037	OBZ	47.60	CS	3	ND	< LOD 2.0	ND	< LOD 42.01
97014	1	50.38	CP	4	ND	< LOD 2.0	ND	< LOD 39.70
97011	2	47.98	CP	4	ND	< LOD 2.0	ND	< LOD 41.69
97031	3	47.92	CP	4	ND	< LOD 2.0	ND	< LOD 41.74
97019	OBZ	48.30	cp	4	ND	< LOD 2.0	ND	< LOD 41.41
97030	1	47.64	N	5	ND	< LOD 2.0	ND	< LOD 41.98
97009	2	44.16	N	5	ND	< LOD 2.0	ND	< LOD 45.29
97021	3	44.52	N	5	ND	< LOD 2.0	ND	< LOD 44.92
97036	OBZ	54.48	N	5	ND	< LOD 2.0	ND	< LOD 36.71
97018	1	48.17	G	6	ND	< LOD 2.0	ND	< LOD 41.52
97005	2	47.51	G	6	ND	< LOD 2.0	ND	< LOD 42.10
97017	3	47.11	G	6	ND	< LOD 2.0	ND	< LOD 42.45
97007	OBZ	48.76	G	6	ND	< LOD 2.0	ND	< LOD 41.02
97008	1	47.92	S	7	ND	< LOD 2.0	ND	< LOD 41.74
97023	2	48.40	S	7	ND	< LOD 2.0	ND	< LOD 41.33
97013	3	48.89	S	7	ND	< LOD 2.0	ND	< LOD 40.91
97016	OBZ	48.71	S	7	ND	< LOD 2.0	ND	< LOD 41.06
97001	1	47.89	SG	8	2.00	< LOQ 4.0	41.76	< LOQ 83.52
97003	2	48.29	SG	8	ND	< LOD 2.0	ND	< LOD 41.42
97028	3	48.32	SG	8	ND	< LOD 2.0	ND	< LOD 41.39
97038	OBZ	48.97	SG	8	ND	< LOD 20.0	ND	< LOD 408.40

Bulk Elemental Analysis - Selenium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Selenium		Sample	Selenium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	< LOD 5.0	J97119P203 PB	ND	< LOD 5.0
N	J97119P205 VB	ND	< LOD 5.0	J97119P205 PB	ND	< LOD 5.0
S	J97119P207 VB	ND	< LOD 5.0	J97119P207 PB	ND	< LOD 5.0
SS	J97119P201 VB	ND	< LOD 5.0	J97119P201 PB	ND	< LOD 5.0
SSDS	J97119P202 VB	ND	< LOD 5.0	J97119P202 PB	ND	< LOD 5.0
CP	J97119P204 VB	9.00	< LOQ 20.0	J97119P204 PB	ND	< LOD 5.0
G	J97119P206 VB	ND	< LOD 5.0	J97119P206 PB	ND	< LOD 5.0
SG	J97119P208 VB	ND	< LOD 10.0	J97119P208 PB	70.00	< LOQ 100.0

Comparison of Airborne Concentrations to Bulk Concentrations - Selenium

NIOSH REL 200.0 micrograms/cubic meter
OSHA PEL 200.0 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Selenium**	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**µg/g**	**Notes**
CS	ND	ND	ND	ND	ND	< LOD 5.0
N	ND	ND	ND	ND	ND	< LOD 5.0
S	ND	ND	ND	ND	ND	< LOD 5.0
SS	ND	63.37	ND	ND	ND	< LOD 5.0
SSDS	ND	ND	ND	ND	ND	< LOD 5.0
CP	ND	ND	ND	ND	9.00	< LOQ 20.0
G	ND	ND	ND	ND	ND	< LOD 5.0
SG	41.76	ND	ND	ND	ND	< LOD 10.0

Silver

Silver and soluble silver compounds may cause discoloration or a blue-gray coloring of the eyes, nose, throat, and skin. The NIOSH REL and OSHA PEL for silver are both 10 micrograms/cubic meter of air.

Air Sample Results - Silver

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Silver			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 0.08	ND	< LOD 1.72
97035	2	47.34	SS	1	ND	< LOD 0.08	ND	< LOD 1.69
97029	3	44.33	SS	1	ND	< LOD 0.08	ND	< LOD 1.80
97034	OBZ	47.60	SS	1	ND	< LOD 0.08	ND	< LOD 1.68
97022	1	47.66	SSDS	2	ND	< LOD 0.08	ND	< LOD 1.68
97032	2	46.72	SSDS	2	ND	< LOD 0.08	ND	< LOD 1.71
97025	3	49.14	SSDS	2	0.100	< LOQ 0.2	2.04	< LOQ 4.07
97006	OBZ	48.95	SSDS	2	ND	< LOD 0.08	ND	< LOD 1.63
97024	1	46.50	CS	3	ND	< LOD 0.08	ND	< LOD 1.72
97020	2	47.34	CS	3	ND	< LOD 0.08	ND	< LOD 1.69
97015	3	44.33	CS	3	ND	< LOD 0.08	ND	< LOD 1.80
97037	OBZ	47.60	CS	3	ND	< LOD 0.08	ND	< LOD 1.68
97014	1	50.38	CP	4	ND	< LOD 0.08	ND	< LOD 1.59
97011	2	47.98	CP	4	ND	< LOD 0.08	ND	< LOD 1.67
97031	3	47.92	CP	4	ND	< LOD 0.08	ND	< LOD 1.67
97019	OBZ	48.30	CP	4	ND	< LOD 0.08	ND	< LOD 1.66
97030	1	47.64	N	5	ND	< LOD 0.08	ND	< LOD 1.68
97009	2	44.16	N	5	ND	< LOD 0.08	ND	< LOD 1.81
97021	3	44.52	N	5	ND	< LOD 0.08	ND	< LOD 1.80
97036	OBZ	54.48	N	5	ND	< LOD 0.08	ND	< LOD 1.47
97018	1	48.17	G	6	ND	< LOD 0.08	ND	< LOD 1.66
97005	2	47.51	G	6	ND	< LOD 0.08	ND	< LOD 1.68
97017	3	47.11	G	6	ND	< LOD 0.08	ND	< LOD 1.70
97007	OBZ	48.76	G	6	ND	< LOD 0.08	ND	< LOD 1.64
97008	1	47.92	S	7	ND	< LOD 0.08	ND	< LOD 1.67
97023	2	48.40	S	7	ND	< LOD 0.08	ND	< LOD 1.65
97013	3	48.89	S	7	ND	< LOD 0.08	ND	< LOD 1.64
97016	OBZ	48.71	S	7	ND	< LOD 0.08	ND	< LOD 1.64
97001	1	47.89	SG	8	ND	< LOD 0.08	ND	< LOD 1.67
97003	2	48.29	SG	8	ND	< LOD 0.08	ND	< LOD 1.66
97028	3	48.32	SG	8	ND	< LOD 0.08	ND	< LOD 1.66
97038	OBZ	48.97	SG	8	ND	< LOD 0.08	ND	< LOD 1.63

Bulk Elemental Analysis - Silver

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Silver		Sample	Silver	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	< LOD 0.3	J97119P203 PB	ND	< LOD 0.3
N	J97119P205 VB	ND	< LOD 0.3	J97119P205 PB	ND	< LOD 0.3
S	J97119P207 VB	0.40	< LOQ 1.0	J97119P207 PB	ND	< LOD 0.3
SS	J97119P201 VB	ND	< LOD 0.3	J97119P201 PB	ND	< LOD 0.3
SSDS	J97119P202 VB	ND	< LOD 0.3	J97119P202 PB	ND	< LOD 0.3
CP	J97119P204 VB	1.00	< LOQ 1.0	J97119P204 PB	1.10	> LOQ 1.0
G	J97119P206 VB	ND	< LOD 0.3	J97119P206 PB	ND	< LOD 0.3
SG	J97119P208 VB	ND	< LOD 3.0	J97119P208 PB	ND	< LOD 1.0

Comparison of Airborne Concentrations to Bulk Concentrations - Silver

NIOSH REL 10.0 micrograms/cubic meter
OSHA PEL 10.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Silver**	
Type	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/g**	**Notes**
CS	ND	ND	ND	ND	ND	< LOD 0.3
N	ND	ND	ND	ND	ND	< LOD 0.3
S	ND	ND	ND	ND	0.40	< LOQ 1.0
SS	ND	ND	ND	ND	ND	< LOD 0.3
SSDS	ND	ND	2.04	ND	ND	< LOD 0.3
CP	ND	ND	ND	ND	1.00	< LOQ 1.0
G	ND	ND	ND	ND	ND	< LOD 0.3
SG	ND	ND	ND	ND	ND	< LOD 3.0

Sodium

Sodium and sodium compounds may be irritating to the eyes, skin and mucus membranes. The NIOSH REL and OSHA PEL for sodium are 10,000 and 15,000 micrograms/cubic meter of air, respectively.

Air Sample Results - Sodium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Sodium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	24	> LOQ 7.0	516.13	> LOQ 150.54
97035	2	47.34	SS	1	51	> LOQ 7.0	1077.31	> LOQ 147.87
97029	3	44.33	SS	1	53	> LOQ 7.0	1195.63	> LOQ 157.91
97034	OBZ	47.60	SS	1	100	> LOQ 7.0	2100.66	> LOQ 147.05
97022	1	47.66	SSDS	2	13	> LOQ 7.0	272.74	> LOQ 146.86
97032	2	46.72	SSDS	2	12	> LOQ 7.0	256.87	> LOQ 149.84
97025	3	49.14	SSDS	2	14	> LOQ 7.0	284.90	> LOQ 142.45
97006	OBZ	48.95	SSDS	2	14	> LOQ 7.0	286.02	> LOQ 143.01
97024	1	46.50	CS	3	48.00	> LOQ 7.0	1032.26	> LOQ 150.54
97020	2	47.34	CS	3	120.00	> LOQ 7.0	2534.85	> LOQ 147.87
97015	3	44.33	CS	3	150.00	> LOQ 7.0	3383.87	> LOQ 157.91
97037	OBZ	47.60	CS	3	120.00	> LOQ 7.0	2520.80	> LOQ 147.05
97014	1	50.38	CP	4	21	> LOQ 7.0	416.87	> LOQ 138.96
97011	2	47.98	CP	4	30	> LOQ 7.0	625.31	> LOQ 145.91
97031	3	47.92	CP	4	33	> LOQ 7.0	688.71	> LOQ 146.09
97019	OBZ	48.30	CP	4	43	> LOQ 7.0	890.27	> LOQ 144.93
97030	1	47.64	N	5	14	> LOQ 7.0	293.87	> LOQ 146.94
97009	2	44.16	N	5	27	> LOQ 7.0	611.41	> LOQ 158.51
97021	3	44.52	N	5	20	> LOQ 7.0	449.24	> LOQ 157.23
97036	OBZ	54.48	N	5	21	> LOQ 7.0	385.46	> LOQ 128.49
97018	1	48.17	G	6	9.5	> LOQ 7.0	197.23	> LOQ 145.32
97005	2	47.51	G	6	8.2	> LOQ 7.0	172.60	> LOQ 147.34
97017	3	47.11	G	6	9.1	> LOQ 7.0	193.16	> LOQ 148.58
97007	OBZ	48.76	G	6	9.1	> LOQ 7.0	186.64	> LOQ 143.57
97008	1	47.92	S	7	15	> LOQ 7.0	313.05	> LOQ 146.09
97023	2	48.40	S	7	21	> LOQ 7.0	433.92	> LOQ 144.64
97013	3	48.89	S	7	21	> LOQ 7.0	429.55	> LOQ 143.18
97016	OBZ	48.71	S	7	15	> LOQ 7.0	307.96	> LOQ 143.71
97001	1	47.89	SG	8	8.2	> LOQ 7.0	171.22	> LOQ 146.16
97003	2	48.29	SG	8	12	> LOQ 7.0	248.51	> LOQ 144.96
97028	3	48.32	SG	8	18	> LOQ 7.0	372.49	> LOQ 144.86
97038	OBZ	48.97	SG	8	ND	< LOD 10.0	ND	< LOD 204.20

Bulk Elemental Analysis - Sodium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Sodium		Sample	Sodium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	44.00	> LOQ 30.0	J97119P203 PB	54.00	> LOQ 30.0
N	J97119P205 VB	50.00	> LOQ 30.0	J97119P205 PB	64.00	> LOQ 30.0
S	J97119P207 VB	20.00	< LOQ 30.0	J97119P207 PB	20.00	< LOQ 30.0
SS	J97119P201 VB	61.00	> LOQ 30.0	J97119P201 PB	30.00	> LOQ 30.0
SSDS	J97119P202 VB	ND	< LOD 30.0	J97119P202 PB	9.00	< LOQ 30.0
CP	J97119P204 VB	390.00	> LOQ 30.0	J97119P204 PB	490.00	> LOQ 30.0
G	J97119P206 VB	10.00	< LOQ 30.0	J97119P206 PB	10.00	< LOD 30.0
SG	J97119P208 VB	ND	< LOD 60.0	J97119P208 PB	ND	< LOD 100.0

Comparison of Airborne Concentrations to Bulk Concentrations - Sodium

NIOSH REL 10000.0 micrograms/cubic meter (nuisance)
OSHA PEL 15000.0 micrograms/cubic meter (nuisance)

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Sodium**	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**µg/g**	**Notes**
CS	1032.26	2534.85	3383.87	2520.80	44.00	> LOQ 30.0
N	293.87	611.41	449.24	385.46	50.00	> LOQ 30.0
S	313.05	433.92	429.55	307.96	20.00	< LOQ 30.0
SS	516.13	1077.31	1195.63	2100.66	61.00	> LOQ 30.0
SSDS	272.74	256.87	284.90	286.02	ND	< LOD 30.0
CP	416.87	625.31	688.71	890.27	390.00	> LOQ 30.0
G	197.23	172.60	193.16	186.64	10.00	< LOQ 30.0
SG	171.22	248.51	372.49	ND	ND	< LOD 60.0

Tellurium

Physical complaints and findings from reports on exposure to tellurium include sleeplessness, loss of appetite, nausea, metallic taste, and a garlic odor to the breath and perspiration. Tellurium accumulates in the blood, liver, kidneys, lungs, thyroid and spleen. These organs may be affected by acute poisoning. Chronic exposure may result in respiratory depression and circulatory collapse. The NIOSH REL and OSHA PEL for tellurium are both 100 micrograms/cubic meter of air.

Air Sample Results - Tellurium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Tellurium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 0.8	ND	< LOD 17.20
97035	2	47.34	SS	1	ND	< LOD 0.8	ND	< LOD 16.90
97029	3	44.33	SS	1	ND	< LOD 0.8	ND	< LOD 18.05
97034	OBZ	47.60	SS	1	ND	< LOD 0.8	ND	< LOD 16.81
97022	1	47.66	SSDS	2	ND	< LOD 0.8	ND	< LOD 16.78
97032	2	46.72	SSDS	2	ND	< LOD 0.8	ND	< LOD 17.12
97025	3	49.14	SSDS	2	ND	< LOD 0.8	ND	< LOD 16.28
97006	OBZ	48.95	SSDS	2	ND	< LOD 0.8	ND	< LOD 16.34
97024	1	46.50	CS	3	ND	< LOD 0.8	ND	< LOD 17.20
97020	2	47.34	CS	3	ND	< LOD 0.8	ND	< LOD 16.90
97015	3	44.33	CS	3	ND	< LOD 0.8	ND	< LOD 18.05
97037	OBZ	47.60	CS	3	ND	< LOD 0.8	ND	< LOD 16.81
97014	1	50.38	CP	4	ND	< LOD 0.8	ND	< LOD 15.88
97011	2	47.98	CP	4	ND	< LOD 0.8	ND	< LOD 16.68
97031	3	47.92	CP	4	ND	< LOD 0.8	ND	< LOD 16.70
97019	OBZ	48.30	CP	4	ND	< LOD 0.8	ND	< LOD 16.56
97030	1	47.64	N	5	ND	< LOD 0.8	ND	< LOD 16.79
97009	2	44.16	N	5	ND	< LOD 0.8	ND	< LOD 18.12
97021	3	44.52	N	5	ND	< LOD 0.8	ND	< LOD 17.97
97036	OBZ	54.48	N	5	ND	< LOD 0.8	ND	< LOD 14.68
97018	1	48.17	G	6	ND	< LOD 0.8	ND	< LOD 16.61
97005	2	47.51	G	6	ND	< LOD 0.8	ND	< LOD 16.84
97017	3	47.11	G	6	ND	< LOD 0.8	ND	< LOD 16.98
97007	OBZ	48.76	G	6	ND	< LOD 0.8	ND	< LOD 16.41
97008	1	47.92	S	7	ND	< LOD 0.8	ND	< LOD 16.70
97023	2	48.40	S	7	ND	< LOD 0.8	ND	< LOD 16.53
97013	3	48.89	S	7	ND	< LOD 0.8	ND	< LOD 16.36
97016	OBZ	48.71	S	7	ND	< LOD 0.8	ND	< LOD 16.42
97001	1	47.89	SG	8	ND	< LOD 0.8	ND	< LOD 16.70
97003	2	48.29	SG	8	ND	< LOD 0.8	ND	< LOD 16.57
97028	3	48.32	SG	8	ND	< LOD 0.8	ND	< LOD 16.55
97038	OBZ	48.97	SG	8	ND	< LOD 4.0	ND	< LOD 81.68

Bulk Elemental Analysis - Tellurium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Tellurium		Sample	Tellurium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	< LOD 3.0	J97119P203 PB	ND	< LOD 3.0
N	J97119P205 VB	ND	< LOD 3.0	J97119P205 PB	ND	< LOD 3.0
S	J97119P207 VB	ND	< LOD 3.0	J97119P207 PB	ND	< LOD 3.0
SS	J97119P201 VB	ND	< LOD 3.0	J97119P201 PB	ND	< LOD 3.0
SSDS	J97119P202 VB	ND	< LOD 3.0	J97119P202 PB	ND	< LOD 3.0
CP	J97119P204 VB	9.00	< LOQ 10.0	J97119P204 PB	ND	< LOD 3.0
G	J97119P206 VB	ND	< LOD 3.0	J97119P206 PB	ND	< LOD 3.0
SG	J97119P208 VB	49.00	> LOQ 10.0	J97119P208 PB	62.00	> LOQ 10.0

Comparison of Airborne Concentrations to Bulk Concentrations - Tellurium

NIOSH REL 100.0 micrograms/cubic meter
OSHA PEL 100.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Tellurium	
Type	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	µg/g	Notes
CS	ND	ND	ND	ND	ND	< LOD 3.0
N	ND	ND	ND	ND	ND	< LOD 3.0
S	ND	ND	ND	ND	ND	< LOD 3.0
SS	ND	ND	ND	ND	ND	< LOD 3.0
SSDS	ND	ND	ND	ND	ND	< LOD 3.0
CP	ND	ND	ND	ND	9.00	< LOQ 10.0
G	ND	ND	ND	ND	ND	< LOD 3.0
SG	ND	ND	ND	ND	49.00	> LOQ 10.0

Thallium

Thallium is one of the more toxic elements from a standpoint of both acute and chronic poisoning, specifically due to ingestion. However, poisoning from industrial exposure has been rarely reported. A characteristic symptom of acute poisoning is loss of hair. Other symptoms of poisoning relate chiefly to gastrointestinal tract or nervous systems disorders. Incoordination, paralysis of the extremities, endocrine disorders and psychosis may develop. The NIOSH REL and OSHA PEL for thallium are both 100 micrograms/cubic meter of air.

Air Sample Results - Thallium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Thallium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	ND	< LOD 3.0	ND	< LOD 64.52
97035	2	47.34	SS	1	ND	< LOD 3.0	ND	< LOD 63.37
97029	3	44.33	SS	1	ND	< LOD 3.0	ND	< LOD 67.68
97034	OBZ	47.60	SS	1	ND	< LOD 3.0	ND	< LOD 63.02
97022	1	47.66	SSDS	2	ND	< LOD 3.0	ND	< LOD 62.94
97032	2	46.72	SSDS	2	ND	< LOD 3.0	ND	< LOD 64.22
97025	3	49.14	SSDS	2	ND	< LOD 3.0	ND	< LOD 61.05
97006	OBZ	48.95	SSDS	2	ND	< LOD 3.0	ND	< LOD 61.29
97024	1	46.50	CS	3	ND	< LOD 3.0	ND	< LOD 64.52
97020	2	47.34	CS	3	ND	< LOD 3.0	ND	< LOD 63.37
97015	3	44.33	CS	3	ND	< LOD 3.0	ND	< LOD 67.68
97037	OBZ	47.60	CS	3	ND	< LOD 3.0	ND	< LOD 63.02
97014	1	50.38	CP	4	ND	< LOD 3.0	ND	< LOD 59.55
97011	2	47.98	CP	4	ND	< LOD 3.0	ND	< LOD 62.53
97031	3	47.92	CP	4	ND	< LOD 3.0	ND	< LOD 62.61
97019	OBZ	48.30	CP	4	ND	< LOD 3.0	ND	< LOD 62.11
97030	1	47.64	N	5	ND	< LOD 3.0	ND	< LOD 62.97
97009	2	44.16	N	5	ND	< LOD 3.0	ND	< LOD 67.93
97021	3	44.52	N	5	ND	< LOD 3.0	ND	< LOD 67.39
97036	OBZ	54.48	N	5	ND	< LOD 3.0	ND	< LOD 55.07
97018	1	48.17	G	6	ND	< LOD 3.0	ND	< LOD 62.28
97005	2	47.51	G	6	ND	< LOD 3.0	ND	< LOD 63.15
97017	3	47.11	G	6	ND	< LOD 3.0	ND	< LOD 63.68
97007	OBZ	48.76	G	6	ND	< LOD 3.0	ND	< LOD 61.53
97008	1	47.92	S	7	ND	< LOD 3.0	ND	< LOD 62.61
97023	2	48.40	S	7	ND	< LOD 3.0	ND	< LOD 61.99
97013	3	48.89	S	7	ND	< LOD 3.0	ND	< LOD 61.36
97016	OBZ	48.71	S	7	ND	< LOD 3.0	ND	< LOD 61.59
97001	1	47.89	SG	8	ND	< LOD 3.0	ND	< LOD 62.64
97003	2	48.29	SG	8	ND	< LOD 3.0	ND	< LOD 62.13
97028	3	48.32	SG	8	ND	< LOD 3.0	ND	< LOD 62.08
97038	OBZ	48.97	SG	8	ND	< LOD 10.0	ND	< LOD 204.20

Bulk Elemental Analysis - Thallium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Thallium		Sample	Thallium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	< LOD 9.0	J97119P203 PB	ND	< LOD 9.0
N	J97119P205 VB	ND	< LOD 9.0	J97119P205 PB	ND	< LOD 9.0
S	J97119P207 VB	ND	< LOD 9.0	J97119P207 PB	ND	< LOD 9.0
SS	J97119P201 VB	ND	< LOD 9.0	J97119P201 PB	ND	< LOD 9.0
SSDS	J97119P202 VB	ND	< LOD 9.0	J97119P202 PB	ND	< LOD 9.0
CP	J97119P204 VB	ND	< LOD 9.0	J97119P204 PB	ND	< LOD 9.0
G	J97119P206 VB	ND	< LOD 9.0	J97119P206 PB	ND	< LOD 9.0
SG	J97119P208 VB	ND	< LOD 20.0	J97119P208 PB	ND	< LOD 40.0

Comparison of Airborne Concentrations to Bulk Concentrations - Thallium

NIOSH REL 100.0 micrograms/cubic meter
OSHA PEL 100.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Thallium	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/g	Notes
CS	ND	ND	ND	ND	ND	< LOD 9.0
N	ND	ND	ND	ND	ND	< LOD 9.0
S	ND	ND	ND	ND	ND	< LOD 9.0
SS	ND	ND	ND	ND	ND	< LOD 9.0
SSDS	ND	ND	ND	ND	ND	< LOD 9.0
CP	ND	ND	ND	ND	ND	< LOD 9.0
G	ND	ND	ND	ND	ND	< LOD 9.0
SG	ND	ND	ND	ND	ND	< LOD 20.0

Titanium Dioxide

The effects of titanium dioxide on the body reveal that the substance is relatively inert, not absorbed readily by the body, and exerts little toxic effects. Animal studies show no fibrous effect from inhalation although an increase incidence of lung tumors in animals has been reported. NIOSH previously recommended that "occupational exposures to carcinogens be limited to the lowest feasible concentrations". Therefore, for this study, the analytical limit of quantification is used as the NIOSH REL for titanium. The OSHA PEL for titanium is 15,000 micrograms/cubic meter of air.

Titanium dioxide is considered an occupational carcinogen by NIOSH. The NIOSH policy regarding occupational carcinogens has changed from a recommend exposure limit (REL) of "lower feasible concentration". The new NIOSH policy for carcinogens is described in the following paragraph (This policy applies to all workplace hazards, including carcinogens):

For the past 20 plus years, NIOSH has subscribed to a carcinogen policy that was published in 1976 by Edward J. Fairchild, II, Associate Director for Cincinnati Operations, which called for "no detectable exposure levels for proven carcinogenic substances [New York Academy of Sciences Annals 1976]." This was in response to a generic OSHA rulemaking on carcinogens.

Because of advances in science and in approaches to risk assessment and risk management, NIOSH has in more recent years adopted a more inclusive policy. NIOSH RELs will be based on risk evaluations using human or animal health effects data, and on an assessment of what levels can be feasibly achieved by engineering controls and measured by analytical techniques. To the extent feasible, NIOSH will protect not only a no-effect exposure, but also exposure levels at which there may be residual risks.

The effect of this new policy for potential occupational carcinogens will be the development, whenever possible, of quantitative RELs that are based on human and/or animal data, as well as on the consideration of technological feasibility for controlling workplace exposures to the REL. Under the old policy for potential occupational carcinogens, RELs for most carcinogens were non-quantitative values labeled "lowest feasible concentration (LFC)." In 1989, NIOSH adopted several quantitative RELs for carcinogens from OSHA's PEL update. NIOSH will also recommend the complete range of respirators (as determined by the NIOSH Respirator Decision Logic) for carcinogens with quantitative RELs. In this way, respirators will be consistently recommended regardless of whether a substance is a carcinogen or a non-carcinogen.

Air Sample Results - Titanium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Titanium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	4.80	> LOQ 0.4	103.23	> LOQ 8.60
97035	2	47.34	SS	1	47.00	> LOQ 0.4	992.82	> LOQ 8.45
97029	3	44.33	SS	1	50.00	> LOQ 0.4	1127.96	> LOQ 9.02
97034	OBZ	47.60	SS	1	130.00	> LOQ 0.4	2730.86	> LOQ 8.40
97022	1	47.66	SSDS	2	0.75	> LOQ 0.4	15.74	> LOQ 8.39
97032	2	46.72	SSDS	2	1.40	> LOQ 0.4	29.97	> LOQ 8.56
97025	3	49.14	SSDS	2	1.60	> LOQ 0.4	32.56	> LOQ 8.14
97006	OBZ	48.95	SSDS	2	1.90	> LOQ 0.4	38.82	> LOQ 8.17
97024	1	46.50	CS	3	47	> LOQ 0.4	1010.75	> LOQ 8.60
97020	2	47.34	CS	3	90.00	> LOQ 0.4	1901.14	> LOQ 8.45
97015	3	44.33	CS	3	130.00	> LOQ 0.4	2932.68	> LOQ 9.02
97037	OBZ	47.60	CS	3	86.00	> LOQ 0.4	1806.57	> LOQ 8.40
97014	1	50.38	CP	4	32.00	> LOQ 0.4	635.22	> LOQ 7.94
97011	2	47.98	CP	4	69.00	> LOQ 0.4	1438.22	> LOQ 8.34
97031	3	47.92	CP	4	70.00	> LOQ 0.4	1460.89	> LOQ 8.35
97019	OBZ	48.30	CP	4	100.00	> LOQ 0.4	2070.39	> LOQ 8.28
97030	1	47.64	N	5	4.30	> LOQ 0.4	90.26	> LOQ 8.40
97009	2	44.16	N	5	9.60	> LOQ 0.4	217.39	> LOQ 9.06
97021	3	44.52	N	5	7.10	> LOQ 0.4	159.48	> LOQ 8.98
97036	OBZ	54.48	N	5	9.00	> LOQ 0.4	165.20	> LOQ 7.34
97018	1	48.17	G	6	11.00	> LOQ 0.4	228.37	> LOQ 8.30
97005	2	47.51	G	6	13.00	> LOQ 0.4	273.64	> LOQ 8.42
97017	3	47.11	G	6	16.00	> LOQ 0.4	339.62	> LOQ 8.49
97007	OBZ	48.76	G	6	15.00	> LOQ 0.4	307.65	> LOQ 8.20
97008	1	47.92	S	7	220.00	> LOQ 0.4	4591.37	> LOQ 8.35
97023	2	48.40	S	7	250.00	> LOQ 0.4	5165.72	> LOQ 8.27
97013	3	48.89	S	7	250.00	> LOQ 0.4	5113.73	> LOQ 8.18
97016	OBZ	48.71	S	7	230.00	> LOQ 0.4	4722.02	> LOQ 8.21
97001	1	47.89	SG	8	0.30	> LOQ 0.4	6.26	> LOQ 8.35
97003	2	48.29	SG	8	1.10	> LOQ 0.4	22.78	> LOQ 8.28
97028	3	48.32	SG	8	0.92	> LOQ 0.4	19.04	> LOQ 8.28
97038	OBZ	48.97	SG	8	4.00	> LOQ 2.0	81.68	> LOQ 40.84

Bulk Elemental Analysis - Titanium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Titanium		Sample	Titanium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	33.00	> LOQ 2.0	J97119P203 PB	35.00	> LOQ 2.0
N	J97119P205 VB	12.00	> LOQ 2.0	J97119P205 PB	15.00	> LOQ 2.0
S	J97119P207 VB	97.00	> LOQ 2.0	J97119P207 PB	120.00	> LOQ 2.0
SS	J97119P201 VB	67.00	> LOQ 2.0	J97119P201 PB	72.00	> LOQ 2.0
SSDS	J97119P202 VB	3.40	> LOQ 2.0	J97119P202 PB	1.00	> LOQ 2.0
CP	J97119P204 VB	790.00	> LOQ 2.0	J97119P204 PB	940.00	> LOQ 2.0
G	J97119P206 VB	7.90	> LOQ 2.0	J97119P206 PB	5.20	> LOQ 2.0
SG	J97119P208 VB	7.50	> LOQ 2.0	J97119P208 PB	7.50	> LOQ 2.0

Comparison of Airborne Concentrations to Bulk Concentrations - Titanium

NIOSH REL Limit of Quantification (Lowest Feasible Concentration)
OSHA PEL 15000.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Titanium	
Type	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	µg/g	Notes
CS	1010.75	1901.14	2932.68	1806.57	33.00	> LOQ 2.0
N	90.26	217.39	159.48	165.20	12.00	> LOQ 2.0
S	4591.37	5165.72	5113.73	4722.02	97.00	> LOQ 2.0
SS	103.23	992.82	1127.96	2730.86	67.00	> LOQ 2.0
SSDS	15.74	29.97	32.56	38.82	3.40	> LOQ 2.0
CP	635.22	1438.22	1460.89	2070.39	790.00	> LOQ 2.0
G	228.37	273.64	339.62	307.65	7.90	> LOQ 2.0
SG	6.26	22.78	19.04	81.68	7.50	> LOQ 2.0

Vanadium

Vanadium dust may cause irritation of the eyes, nose, throat, and also the respiratory tract. It may also cause bronchitis with wheezing and chest pain. Repeated or prolonged exposure may also cause an allergic skin rash. The NIOSH REL and OSHA PEL (Respirable) for vanadium (except vanadium metal and vanadium carbide) are 50 and 500 micrograms/cubic meter of air as ceiling limits, respectively. For the purpose of this study, the OSHA PEL for respirable vanadium was used for total vanadium dust, as there is no PEL for total vanadium dust listed.

Air Sample Results - Vanadium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Vanadium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	0.200	< LOQ 0.2	4.30	< LOQ 4.30
97035	2	47.34	SS	1	2.200	> LOQ 0.2	46.47	> LOQ 4.22
97029	3	44.33	SS	1	2.300	> LOQ 0.2	51.89	> LOQ 4.51
97034	OBZ	47.60	SS	1	5.200	> LOQ 0.2	109.23	> LOQ 4.20
97022	1	47.66	SSDS	2	0.100	< LOQ 0.2	2.10	< LOQ 4.20
97032	2	46.72	SSDS	2	0.220	> LOQ 0.2	4.71	> LOQ 4.28
97025	3	49.14	SSDS	2	0.200	< LOQ 0.2	4.07	< LOQ 4.07
97006	OBZ	48.95	SSDS	2	0.100	< LOQ 0.2	2.04	< LOQ 4.09
97024	1	46.50	CS	3	2.1	> LOQ 0.2	45.16	> LOQ 43.01
97020	2	47.34	CS	3	6.300	> LOQ 0.2	133.08	> LOQ 4.22
97015	3	44.33	CS	3	7.600	> LOQ 0.2	171.45	> LOQ 4.51
97037	OBZ	47.60	CS	3	5.900	> LOQ 0.2	123.94	> LOQ 4.20
97014	1	50.38	CP	4	2.000	> LOQ 0.2	39.70	> LOQ 3.97
97011	2	47.98	CP	4	4.000	> LOQ 0.2	83.38	> LOQ 4.17
97031	3	47.92	CP	4	4.200	> LOQ 0.2	87.65	> LOQ 4.17
97019	OBZ	48.30	CP	4	5.900	> LOQ 0.2	122.15	> LOQ 4.14
97030	1	47.64	N	5	1.100	> LOQ 0.2	23.09	> LOQ 4.20
97009	2	44.16	N	5	2.600	> LOQ 0.2	58.88	> LOQ 4.53
97021	3	44.52	N	5	1.900	> LOQ 0.2	42.68	> LOQ 4.49
97036	OBZ	54.48	N	5	2.300	> LOQ 0.2	42.22	> LOQ 3.67
97018	1	48.17	G	6	0.700	> LOQ 0.2	14.53	> LOQ 4.15
97005	2	47.51	G	6	0.980	> LOQ 0.2	20.63	> LOQ 4.21
97017	3	47.11	G	6	1.200	> LOQ 0.2	25.47	> LOQ 4.25
97007	OBZ	48.76	G	6	1.100	> LOQ 0.2	22.56	> LOQ 4.10
97008	1	47.92	S	7	0.900	> LOQ 0.2	18.78	> LOQ 4.17
97023	2	48.40	S	7	1.400	> LOQ 0.2	28.93	> LOQ 4.13
97013	3	48.89	S	7	1.400	> LOQ 0.2	28.64	> LOQ 4.09
97016	OBZ	48.71	S	7	1.200	> LOQ 0.2	24.64	> LOQ 4.11
97001	1	47.89	SG	8	0.920	> LOQ 0.2	19.21	> LOQ 4.18
97003	2	48.29	SG	8	0.920	> LOQ 0.2	19.05	> LOQ 4.14
97028	3	48.32	SG	8	3.300	> LOQ 0.2	68.29	> LOQ 4.14
97038	OBZ	48.97	SG	8	24.000	> LOQ 1.0	490.08	> LOQ 20.42

Bulk Elemental Analysis - Vanadium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Vanadium		Sample	Vanadium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	1.80	> LOQ 1.0	J97119P203 PB	2.30	> LOQ 1.0
N	J97119P205 VB	2.90	> LOQ 1.0	J97119P205 PB	3.70	> LOQ 1.0
S	J97119P207 VB	0.90	< LOQ 1.0	J97119P207 PB	1.20	> LOQ 1.0
SS	J97119P201 VB	6.90	> LOQ 1.0	J97119P201 PB	3.60	> LOQ 1.0
SSDS	J97119P202 VB	ND	< LOD 0.3	J97119P202 PB	ND	< LOD 0.3
CP	J97119P204 VB	58.00	> LOQ 1.0	J97119P204 PB	71.00	> LOQ 1.0
G	J97119P206 VB	0.70	< LOQ 1.0	J97119P206 PB	0.40	< LOQ 1.0
SG	J97119P208 VB	67.00	> LOQ 1.0	J97119P208 PB	77.00	> LOQ 1.0

Comparison of Airborne Concentrations to Bulk Concentrations - Vanadium

NIOSH REL 50.0 micrograms/cubic meter Ceiling Limit
OSHA PEL 500.0 micrograms/cubic meter Ceiling Limit

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Vanadium**	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	**µg/g**	**Notes**
CS	45.16	133.08	171.45	123.94	1.80	> LOQ 1.0
N	23.09	58.88	42.68	42.22	2.90	> LOQ 1.0
S	18.78	28.93	28.64	24.64	0.90	< LOQ 1.0
SS	4.30	46.47	51.89	109.23	6.90	> LOQ 1.0
SSDS	2.10	4.71	4.07	2.04	ND	< LOD 0.3
CP	39.70	83.38	87.65	122.15	58.00	> LOQ 1.0
G	14.53	20.63	25.47	22.56	0.70	< LOQ 1.0
SG	19.21	19.05	68.29	490.08	67.00	> LOQ 1.0

Yttrium

Yttrium compounds that have become embedded in the eye have caused chemical eye damage in humans. Animal studies have shown yttrium compounds to cause irritation of the lungs, lung damage, and liver damage. The NIOSH REL and OSHA PEL for yttrium are both 1,000 micrograms/cubic meter of air.

Air Sample Results - Yttrium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Yttrium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	0.064	> LOQ 0.04	1.38	> LOQ 0.860
97035	2	47.34	SS	1	0.800	> LOQ 0.04	16.90	> LOQ 0.845
97029	3	44.33	SS	1	0.860	> LOQ 0.04	19.40	> LOQ 0.902
97034	OBZ	47.60	SS	1	1.400	> LOQ 0.04	29.41	> LOQ 0.840
97022	1	47.66	SSDS	2	0.075	> LOQ 0.04	1.57	> LOQ 0.839
97032	2	46.72	SSDS	2	0.170	> LOQ 0.04	3.64	> LOQ 0.856
97025	3	49.14	SSDS	2	0.230	> LOQ 0.04	4.68	> LOQ 0.814
97006	OBZ	48.95	SSDS	2	0.210	> LOQ 0.04	4.29	> LOQ 0.817
97024	1	46.50	CS	3	0.82	> LOQ 0.04	17.63	> LOQ 0.860
97020	2	47.34	CS	3	1.800	> LOQ 0.04	38.02	> LOQ 0.845
97015	3	44.33	CS	3	2.100	> LOQ 0.04	17.37	> LOQ 0.902
97037	OBZ	47.60	CS	3	1.700	> LOQ 0.04	35.71	> LOQ 0.840
97014	1	50.38	CP	4	0.280	> LOQ 0.04	5.56	> LOQ 0.794
97011	2	47.98	CP	4	0.590	> LOQ 0.04	12.30	> LOQ 0.834
97031	3	47.92	CP	4	0.590	> LOQ 0.04	12.31	> LOQ 0.835
97019	OBZ	48.30	CP	4	0.830	> LOQ 0.04	17.18	> LOQ 0.828
97030	1	47.64	N	5	0.053	> LOQ 0.04	1.11	> LOQ 0.840
97009	2	44.16	N	5	0.083	> LOQ 0.04	1.88	> LOQ 0.906
97021	3	44.52	N	5	0.083	> LOQ 0.04	1.86	> LOQ 0.898
97036	OBZ	54.48	N	5	0.083	> LOQ 0.04	1.52	> LOQ 0.734
97018	1	48.17	G	6	11.000	> LOQ 0.04	228.37	> LOQ 0.830
97005	2	47.51	G	6	17.000	> LOQ 0.04	357.83	> LOQ 0.842
97017	3	47.11	G	6	25.000	> LOQ 0.04	530.65	> LOQ .0.849
97007	OBZ	48.76	G	6	22.000	> LOQ 0.04	451.23	> LOQ .0.820
97008	1	47.92	S	7	1.800	> LOQ 0.04	37.57	> LOQ 0.835
97023	2	48.40	S	7	2.800	> LOQ 0.04	57.86	> LOQ 0.827
97013	3	48.89	S	7	2.800	> LOQ 0.04	57.27	> LOQ 0.818
97016	OBZ	48.71	S	7	1.700	> LOQ 0.04	34.90	> LOQ 0.821
97001	1	47.89	SG	8	ND	< LOD 0.02	ND	< LOQ 0.418
97003	2	48.29	SG	8	ND	< LOD 0.02	ND	< LOQ 0.414
97028	3	48.32	SG	8	0.040	< LOQ 0.04	0.83	<LOQ 0.828
97038	OBZ	48.97	SG	8	0.042	> LOQ 0.04	0.86	> LOQ 0.817

Bulk Elemental Analysis - Yttrium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive Type	Sample No.	Yttrium		Sample No.	Yttrium	
		µg/g	Notes		µg/g	Notes
CS	J97119P203 VB	0.50	> LOQ 0.2	J97119P203 PB	0.60	> LOQ 0.2
N	J97119P205 VB	0.10	< LOQ 0.2	J97119P205 PB	0.20	> LOQ 0.2
S	J97119P207 VB	0.56	> LOQ 0.2	J97119P207 PB	0.94	> LOQ 0.2
SS	J97119P201 VB	2.40	> LOQ 0.2	J97119P201 PB	1.40	> LOQ 0.2
SSDS	J97119P202 VB	0.08	< LOQ 0.2	J97119P202 PB	0.20	< LOQ 0.2
CP	J97119P204 VB	7.40	> LOQ 0.2	J97119P204 PB	9.50	> LOQ 0.2
G	J97119P206 VB	7.90	> LOQ 0.2	J97119P206 PB	5.50	> LOQ 0.2
SG	J97119P208 VB	0.07	< LOQ 0.2	J97119P208 PB	0.10	< LOQ 0.2

Comparison of Airborne Concentrations to Bulk Concentrations - Yttrium

NIOSH REL 1000.0 micrograms/cubic meter
OSHA PEL 1000.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Yttrium	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/g	Notes
CS	17.63	38.02	17.37	35.71	0.50	> LOQ 0.2
N	1.11	1.88	1.86	1.52	0.10	< LOQ 0.2
S	37.57	57.86	57.27	34.90	0.56	> LOQ 0.2
SS	1.38	16.90	19.40	29.41	2.40	> LOQ 0.2
SSDS	1.57	3.64	4.68	4.29	0.08	< LOQ 0.2
CP	5.56	12.30	12.31	17.18	7.40	> LOQ 0.2
G	228.37	357.83	530.65	451.23	7.90	> LOQ 0.2
SG	ND	ND	0.83	0.86	0.07	< LOQ 0.2

Zinc

Zinc dust is generally considered to be a nuisance dust and have little or no adverse effect on the lungs and does not produce any significant organic disease when exposures are kept under reasonable control. The NIOSH REL and OSHA PEL for zinc are 5,000 and 15,000 micrograms/cubic meter of air, respectively.

Air Sample Results - Zinc

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Zinc			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	1.00	< LOQ 2.0	21.51	< LOQ 43.01
97035	2	47.34	SS	1	4.20	> LOQ 2.0	88.72	> LOQ 42.25
97029	3	44.33	SS	1	4.80	> LOQ 2.0	108.28	> LOQ 45.12
97034	OBZ	47.60	SS	1	1.20	> LOQ 2.0	88.23	> LOQ 42.01
97022	1	47.66	SSDS	2	2.00	> LOQ 2.0	41.96	> LOQ 41.96
97032	2	46.72	SSDS	2	2.80	> LOQ 2.0	59.94	> LOQ 42.81
97025	3	49.14	SSDS	2	3.60	> LOQ 2.0	73.26	> LOQ 40.70
97006	OBZ	48.95	SSDS	2	3.50	> LOQ 2.0	71.50	> LOQ 40.86
97024	1	46.50	CS	3	5.2	> LOQ 2.0	111.83	> LOQ 43.01
97020	2	47.34	CS	3	5.20	> LOQ 2.0	109.84	> LOQ 42.25
97015	3	44.33	CS	3	5.70	> LOQ 2.0	128.59	> LOQ 45.12
97037	OBZ	47.60	CS	3	5.50	> LOQ 2.0	115.54	> LOQ 42.01
97014	1	50.38	CP	4	3.80	> LOQ 2.0	75.43	> LOQ 39.70
97011	2	47.98	CP	4	7.70	> LOQ 2.0	160.50	> LOQ 41.69
97031	3	47.92	CP	4	8.00	> LOQ 2.0	166.96	> LOQ 41.74
97019	OBZ	48.30	CP	4	11.00	> LOQ 2.0	227.74	> LOQ 41.41
97030	1	47.64	N	5	4.90	> LOQ 2.0	102.85	> LOQ 41.98
97009	2	44.16	N	5	9.70	> LOQ 2.0	219.66	> LOQ 45.29
97021	3	44.52	N	5	7.90	> LOQ 2.0	177.45	> LOQ 44.92
97036	OBZ	54.48	N	5	9.60	> LOQ 2.0	176.21	> LOQ 36.71
97018	1	48.17	G	6	3.80	> LOQ 2.0	78.89	> LOQ 41.52
97005	2	47.51	G	6	5.20	> LOQ 2.0	109.46	> LOQ 42.10
97017	3	47.11	G	6	6.90	> LOQ 2.0	146.46	> LOQ 42.45
97007	OBZ	48.76	G	6	6.80	> LOQ 2.0	139.47	> LOQ 41.02
97008	1	47.92	S	7	4.10	> LOQ 2.0	85.57	> LOQ 41.74
97023	2	48.40	S	7	6.50	> LOQ 2.0	134.31	> LOQ 41.33
97013	3	48.89	S	7	6.50	> LOQ 2.0	132.96	> LOQ 40.91
97016	OBZ	48.71	S	7	4.50	> LOQ 2.0	92.39	> LOQ 41.06
97001	1	47.89	SG	8	2.00	< LOQ 2.0	41.76	< LOQ 41.76
97003	2	48.29	SG	8	4.10	> LOQ 2.0	84.91	> LOQ 41.42
97028	3	48.32	SG	8	5.10	> LOQ 2.0	105.54	< LOQ 41.39
97038	OBZ	48.97	SG	8	10.00	< LOQ 10.0	204.20	< LOQ 204.20

Bulk Elemental Analysis - Zinc

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Zinc		Sample	Zinc	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	ND	< LOD 2.0	J97119P203 PB	ND	< LOD 2.0
N	J97119P205 VB	7.30	> LOQ 7.0	J97119P205 PB	10.00	> LOQ 7.0
S	J97119P207 VB	ND	< LOD 2.0	J97119P207 PB	2.00	< LOQ 7.0
SS	J97119P201 VB	4.00	< LOQ 7.0	J97119P201 PB	5.00	< LOQ 7.00
SSDS	J97119P202 VB	ND	< LOD 2.0	J97119P202 PB	ND	< LOD 2.0
CP	J97119P204 VB	92.00	> LOQ 7.0	J97119P204 PB	100.00	> LOQ 7.0
G	J97119P206 VB	ND	< LOD 2.0	J97119P206 PB	ND	< LOD 2.0
SG	J97119P208 VB	48.00	> LOQ 7.0	J97119P208 PB	57.00	> LOQ 7.0

Comparison of Airborne Concentrations to Bulk Concentrations - Zinc

NIOSH REL 5000.0 micrograms/cubic meter
OSHA PEL 15000.0 micrograms/cubic meter

	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	Fixed Station #1	Fixed Station #2	Fixed Station #3	(OBZ)	Zinc	
Type	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/g	Notes
CS	111.83	109.84	128.59	115.54	ND	< LOD 2.0
N	102.85	219.66	177.45	176.21	7.30	> LOQ 7.0
S	85.57	134.31	132.96	92.39	ND	< LOD 2.0
SS	21.51	88.72	108.28	88.23	4.00	< LOQ 7.0
SSDS	41.96	59.94	73.26	71.50	ND	< LOD 2.0
CP	75.43	160.50	166.96	227.74	92.00	> LOQ 7.0
G	78.89	109.46	146.46	139.47	ND	< LOD 2.0
SG	41.76	84.91	105.54	204.20	48.00	> LOQ 7.0

Zirconium

Most animal studies indicate zirconium to be of relative low toxicity. Most zirconium compounds are insoluble and are considered to be inert. Some zirconium compounds have been reported to cause radiographic changes in animals due to pulmonary retention or granulomas of the skin. The NIOSH REL and OSHA PEL for zirconium are both 5,000 micrograms/cubic meter of air.

Air Sample Results - Zirconium

Sample No.	Station No.	Volume (l/filter)	Abrasive Type	Run	Zirconium			
					Mass (µg/filter)	Filter Notes µg/f	Result µg/m^3	Result Notes
97040	1	46.50	SS	1	0.200	< LOQ 0.2	4.30	< LOQ 4.30
97035	2	47.34	SS	1	1.500	> LOQ 0.2	31.69	> LOQ 4.22
97029	3	44.33	SS	1	1.800	> LOQ 0.2	40.61	> LOQ 4.51
97034	OBZ	47.60	SS	1	2.600	> LOQ 0.2	54.62	> LOQ 4.20
97022	1	47.66	SSDS	2	0.100	< LOQ 0.2	2.10	< LOQ 4.20
97032	2	46.72	SSDS	2	0.360	> LOQ 0.2	7.71	> LOQ 4.28
97025	3	49.14	SSDS	2	0.450	> LOQ 0.2	9.16	> LOQ 4.07
97006	OBZ	48.95	SSDS	2	0.410	> LOQ 0.2	8.38	> LOQ 4.09
97024	1	46.50	CS	3	1.3	> LOQ 0.2	27.96	> LOQ 4.30
97020	2	47.34	CS	3	1.800	> LOQ 0.2	38.02	> LOQ 4.22
97015	3	44.33	CS	3	2.300	> LOQ 0.2	51.89	> LOQ 4.51
97037	OBZ	47.60	CS	3	1.700	> LOQ 0.2	35.71	> LOQ 4.20
97014	1	50.38	CP	4	0.690	> LOQ 0.2	13.70	> LOQ 3.97
97011	2	47.98	CP	4	1.500	> LOQ 0.2	31.27	> LOQ 4.17
97031	3	47.92	CP	4	1.500	> LOQ 0.2	31.30	> LOQ 4.17
97019	OBZ	48.30	CP	4	2.200	> LOQ 0.2	45.55	> LOQ 4.14
97030	1	47.64	N	5	0.100	< LOQ 0.2	2.10	< LOQ 4.20
97009	2	44.16	N	5	0.230	> LOQ 0.2	5.21	> LOQ 4.53
97021	3	44.52	N	5	0.200	< LOQ 0.2	4.49	< LOQ 4.49
97036	OBZ	54.48	N	5	0.220	> LOQ 0.2	4.04	> LOQ 3.67
97018	1	48.17	G	6	0.390	> LOQ 0.2	8.10	> LOQ 4.15
97005	2	47.51	G	6	0.630	> LOQ 0.2	13.26	> LOQ 4.21
97017	3	47.11	G	6	0.920	> LOQ 0.2	19.53	> LOQ 4.25
97007	OBZ	48.76	G	6	0.840	> LOQ 0.2	17.23	> LOQ 4.10
97008	1	47.92	S	7	4.300	> LOQ 0.2	89.74	> LOQ 4.17
97023	2	48.40	S	7	7.300	> LOQ 0.2	150.84	> LOQ 4.13
97013	3	48.89	S	7	7.800	> LOQ 0.2	159.55	> LOQ 4.09
97016	OBZ	48.71	S	7	4.900	> LOQ 0.2	100.60	> LOQ 4.11
97001	1	47.89	SG	8	ND	< LOD 0.08	ND	< LOD 1.67
97003	2	48.29	SG	8	ND	< LOD 0.08	ND	< LOD 1.66
97028	3	48.32	SG	8	ND	< LOD 0.08	ND	< LOD 1.66
97038	OBZ	48.97	SG	8	ND	< LOD 0.08	ND	< LOD 1.63

Bulk Elemental Analysis - Zirconium

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Zirconium		Sample	Zirconium	
Type	No.	µg/g	Notes	No.	µg/g	Notes
CS	J97119P203 VB	0.90	< LOQ 1.0	J97119P203 PB	1.30	> LOQ 1.0
N	J97119P205 VB	0.60	LOQ 1.0	J97119P205 PB	0.80	< LOQ 1.0
S	J97119P207 VB	5.80	> LOQ 1.0	J97119P207 PB	6.20	> LOQ 1.0
SS	J97119P201 VB	2.30	> LOQ 1.0	J97119P201 PB	2.10	> LOQ 1.0
SSDS	J97119P202 VB	ND	< LOD 3.0	J97119P202 PB	ND	< LOD 3.0
CP	J97119P204 VB	27.00	> LOQ 1.0	J97119P204 PB	32.00	> LOQ 1.0
G	J97119P206 VB	0.40	< LOQ 1.0	J97119P206 PB	0.40	< LOQ 1.0
SG	J97119P208 VB	ND	< LOD 3.0	J97119P208 PB	ND	< LOD 3.0

Comparison of Airborne Concentrations to Bulk Concentrations - Zirconium

NIOSH REL 5000.0 micrograms/cubic meter
OSHA PEL 5000.0 micrograms/cubic meter

	@ Make-up Air Area	**@ Operator Area**	**@ Exhaust Area**	**Operator 's Breathing Zone**	**Virgin (Pre Blast) Bulk**	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Zirconium**	
Type	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/m^3**	**µg/g**	**Notes**
CS	27.96	38.02	51.89	35.71	0.90	< LOQ 1.0
N	2.10	5.21	4.49	4.04	0.60	LOQ 1.0
S	89.74	150.84	159.55	100.60	5.80	> LOQ 1.0
SS	4.30	31.69	40.61	54.62	2.30	> LOQ 1.0
SSDS	2.10	7.71	9.16	8.38	ND	< LOD 3.0
CP	13.70	31.27	31.30	45.55	27.00	> LOQ 1.0
G	8.10	13.26	19.53	17.23	0.40	< LOQ 1.0
SG	ND	ND	ND	ND	ND	< LOD 3.0

Respirable Silica-Cristobalite

Animal studies have shown cristobalite to be more fibrotic than quartz, and the fibrosis that develops to be more diffuse than nodular. Thus, the OSHA limit set for cristobalite is set at one-half that of quartz. The NIOSH REL for respirable cristobalite is 0.05 milligrams/cubic meter of air. The OSHA PEL for respirable cristobalite is one-half of 10 milligrams/cubic meter of air divided by % silica + 2.

NIOSH did not detect any cristobalite in any of the airborne or bulk samples.

Respirable Silica-Quartz

Respirable silica-quartz causes silicosis after chronic exposure. The formation of scattered, rounded or stellate silica-containing nodules of scar tissue in the lungs characterize classical silicosis. It may be slowly progressive, even in the absence of continued exposure. Acute silicosis may occur under conditions of extremely high crystalline quartz dust exposures, particularly when the particle size of the dust is very small. This disease differs from classical silicosis in that it is rapidly progressive with diffuse pulmonary involvement. Animal studies have indicated an increased risk of lung cancer. The NIOSH REL for respirable quartz is 0.05 milligrams/cubic meter of air. The OSHA PEL for respirable quartz is 10 milligrams/cubic meter of air divided by % silica + 2.

Respirable Quartz Airborne Samples:

The following seven of the respirable quartz airborne samples were quantified by primary peak height measurement due to problematical integration data for these samples: (96-4771 garnet G-2B), (96-4795 garnet G-2B), (96-4783 garnet G-2B), (96-4380 garnet G-4A), (96-4774 garnet G-3A), (96-4781 garnet G-3A), and (96-4819 silica sand with dust suppressant SSDS-03). Samples (96-4441 silica sand with dust suppressant SSDS-03) and (96-4537 nickel slag N-01) were analyzed by secondary peak height analysis due to nearby interference of the primary peak.

Total Quartz Bulk Samples:

The following virgin and post bulk samples had interference problems in the primary peak area and were analyzed by peak height measurement of the secondary peak: garnet G-2A, garnet G-2B, specular hematite, and nickel slag N-01. The virgin and post bulk samples of garnet G-2B and nickel slag N-01were also checked microscopically for quartz which identified the samples as non-detectable (<5%, <3%, <3%, and <1%). The garnet virgin bulk samples G-1B and G-4A had interference problems, but were analyzed by long range qualititative scan (5 to 90 degrees two theta). They appeared to have primary and secondary quartz peaks, but showed no other quartz peaks. The virgin and post bulk samples of garnet G-3A and steel grit SG-1A and the post bulk samples of garnet G-1B and garnet G-4A had interference problems in the primary peak area and were checked microscopically for quartz.

Air Sample Results - Respirable Quartz

Sample	Station	Volume	Abrasive	Run	Gravemetric		Quartz Gravemetric			Calculations		
No.	No.	(l/filter)	Type		mg/filter	Filter Notes mg/f	mg/filter	Filter Notes mg/f	%	mg/m3	Notes	OSHA PEL
97-2022	1	40.37	SS	1	2.23	> LOD 0.02	0.40	> LOQ 0.03	17.94%	9.91	>LOQ 0.7432	0.502
97-2023	2	40.06	SS	1	7.73	> LOD 0.02	1.30	> LOQ 0.03	16.82%	32.46	>LOQ 0.7490	0.531
97-2058	3	40.42	SS	1	10.21	> LOD 0.02	0.00		20.00%	50.52	>LOQ 0.7423	0.455
97-2060	OBZ	40.96	SS	1	6.76	> LOD 0.02	1.54	> LOQ 0.03	22.78%	37.60	>LOQ 0.7325	0.404
97-2003	1	40.28	SSDS	2	0.93	> LOD 0.02	0.37	> LOQ 0.03	39.78%	9.18	>LOQ 0.7447	0.239
97-2024	2	40.92	SSDS	2	2.48	> LOD 0.02	0.87	> LOQ 0.03	35.08%	21.26	>LOQ 0.7331	0.27
97-2025	3	40.78	SSDS	2	2.93	> LOD 0.02	1.15	> LOQ 0.03	39.25%	28.20	>LOQ 0.7357	0.242
97-2056	OBZ	41.33	SSDS	2	2.19	> LOD 0.02	1.00	> LOQ 0.03	45.66%	24.20	>LOQ 0.7259	0.21
97-2012	1	40.36	CS	3	1.33	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2478	NA
97-2018	2	39.02	CS	3	0.27	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2563	NA
97-2004	3	40.02	CS	3	6.69	> LOD 0.02	0.01	< LOQ 0.03	0.15%	0.25	<LOQ 0.7496	4.651
97-2037	OBZ	41.12	CS	3	4.56	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2432	NA
97-2188	1	40.68	CP	4	1.19	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2458	NA
97-2182	2	40.32	CP	4	5.37	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2480	NA
97-2179	3	40.82	CP	4	3.68	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2450	NA
97-2173	OBZ	41.30	CP	4	2.41	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2421	NA
97-2175	1	40.52	N	5	2.16	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2468	NA
97-2195	2	40.06	N	5	6.67	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2497	NA
97-2196	3	40.27	N	5	8.23	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2483	NA
97-2189	OBZ	41.39	N	5	5.41	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2416	NA
97-2054	1	42.46	G	6	1.48	> LOD 0.02	0.037	> LOQ 0.03	2.50%	0.87	>LOQ 0.7066	2.222
97-2050	2	39.86	G	6	10.37	> LOD 0.02	0.00		2.80%	7.28	>LOQ 0.7526	2.083
97-2198	3	40.87	G	6	8.21	> LOD 0.02	0.16	> LOQ 0.03	1.95%	3.92	>LOQ 0.7340	2.532
97-2040	OBZ	41.33	G	6	5.1	> LOD 0.02	0.076	> LOQ 0.03	1.49%	1.84	>LOQ 0.7259	2.865
97-2049	1	40.43	S	7	2.56	> LOD 0.02	0.04	> LOQ 0.03	1.60%	1.01	>LOQ 0.7421	2.778
97-2033	2	40.90	S	7	7.55	> LOD 0.02	0.11	> LOQ 0.03	1.46%	2.70	>LOQ 0.7336	2.89
97-2047	3	40.58	S	7	8.16	> LOD 0.02	0.00		2.50%	5.03	>LOQ 0.7392	2.222
97-2029	OBZ	41.30	S	7	5.19	> LOD 0.02	0.085	> LOQ 0.03	1.64%	2.06	>LOQ 0.7263	2.747
97-2213	1	40.56	SG	8	0.41	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2465	NA
97-2200	2	40.51	SG	8	1.44	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2468	NA
97-2186	3	40.50	SG	8	1.57	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2469	NA
97-2207	OBZ	41.58	SG	8	0.97	> LOD 0.02	ND	< LOD 0.01	ND	ND	<LOD 0.2405	NA

Bulk Elemental Analysis, Percent by Weight - Quartz

	Virgin (Pre Blast) Bulk			Post (Blast) Bulk		
Abrasive	Sample	Quartz		Sample	Quartz	
Type	No.	%	Notes	No.	%	Notes
CS	J97119P203 VB	ND	< LOD 0.80	J97119P203 PB	ND	< LOD 0.80
N	J97119P205 VB	ND	< LOD 0.80	J97119P205 PB	ND	< LOD 0.80
S	J97119P207 VB	1.60	< LOQ 2.00	J97119P207 PB	1.40	< LOQ 2.00
SS	J97119P201 VB	51.00	> LOQ 2.0	J97119P201 PB	62.00	> LOQ 2.0
SSDS	J97119P202 VB	71.00	> LOQ 2.0	J97119P202 PB	86.00	> LOQ 2.0
CP	J97119P204 VB	ND	< LOD 0.80	J97119P204 PB	ND	< LOD 0.80
G	J97119P206 VB	1.90	< LOQ 2.00	J97119P206 PB	1.40	< LOQ 2.00
SG	J97119P208 VB	ND	< LOD 0.80	J97119P208 PB	ND	< LOD 0.80

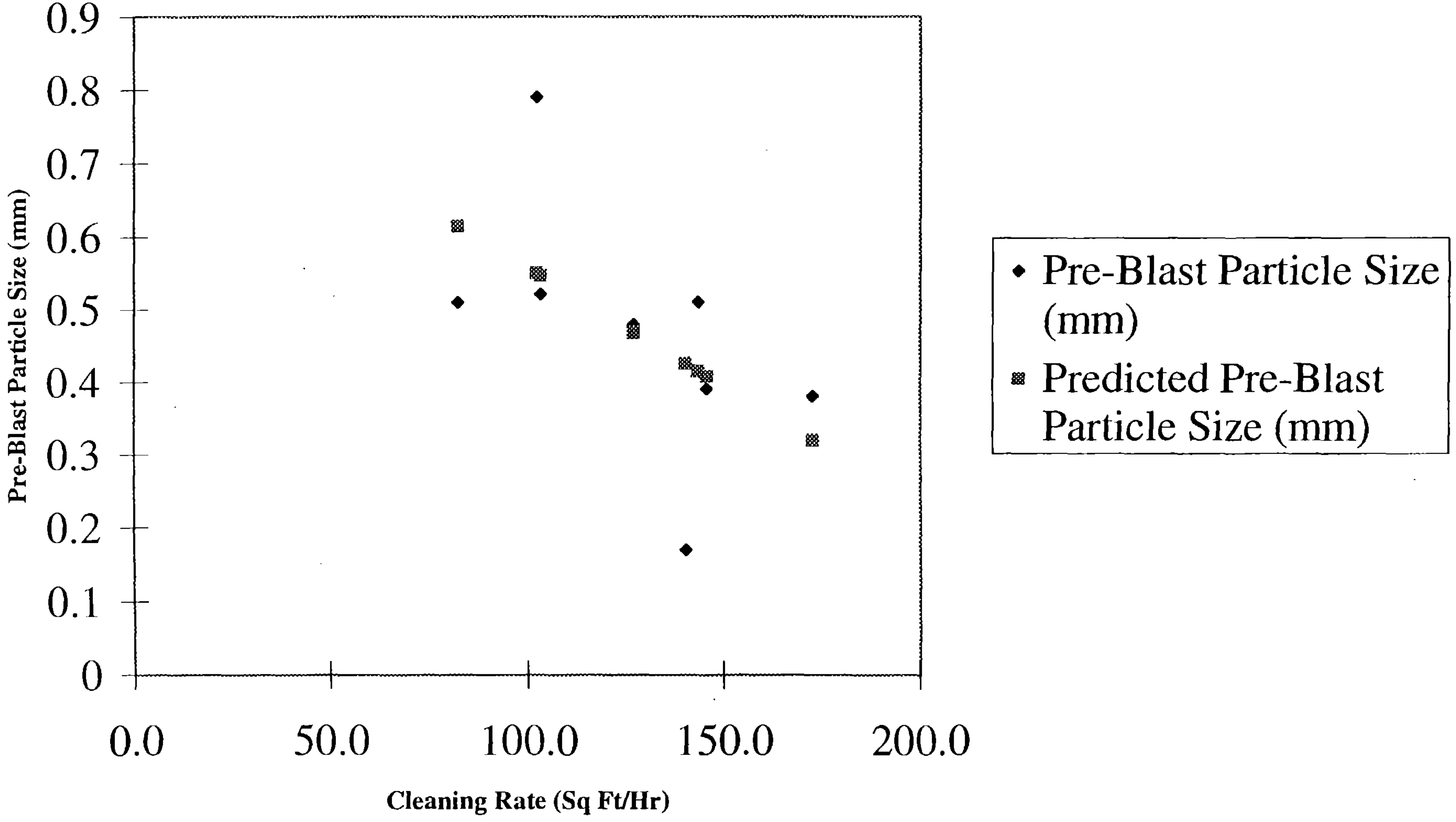
Comparison of Airborne Concentrations to Bulk Concentrations - Respirable Quartz

NIOSH REL 0.05 milligrams/cubic meter
OSHA PEL As Calculated

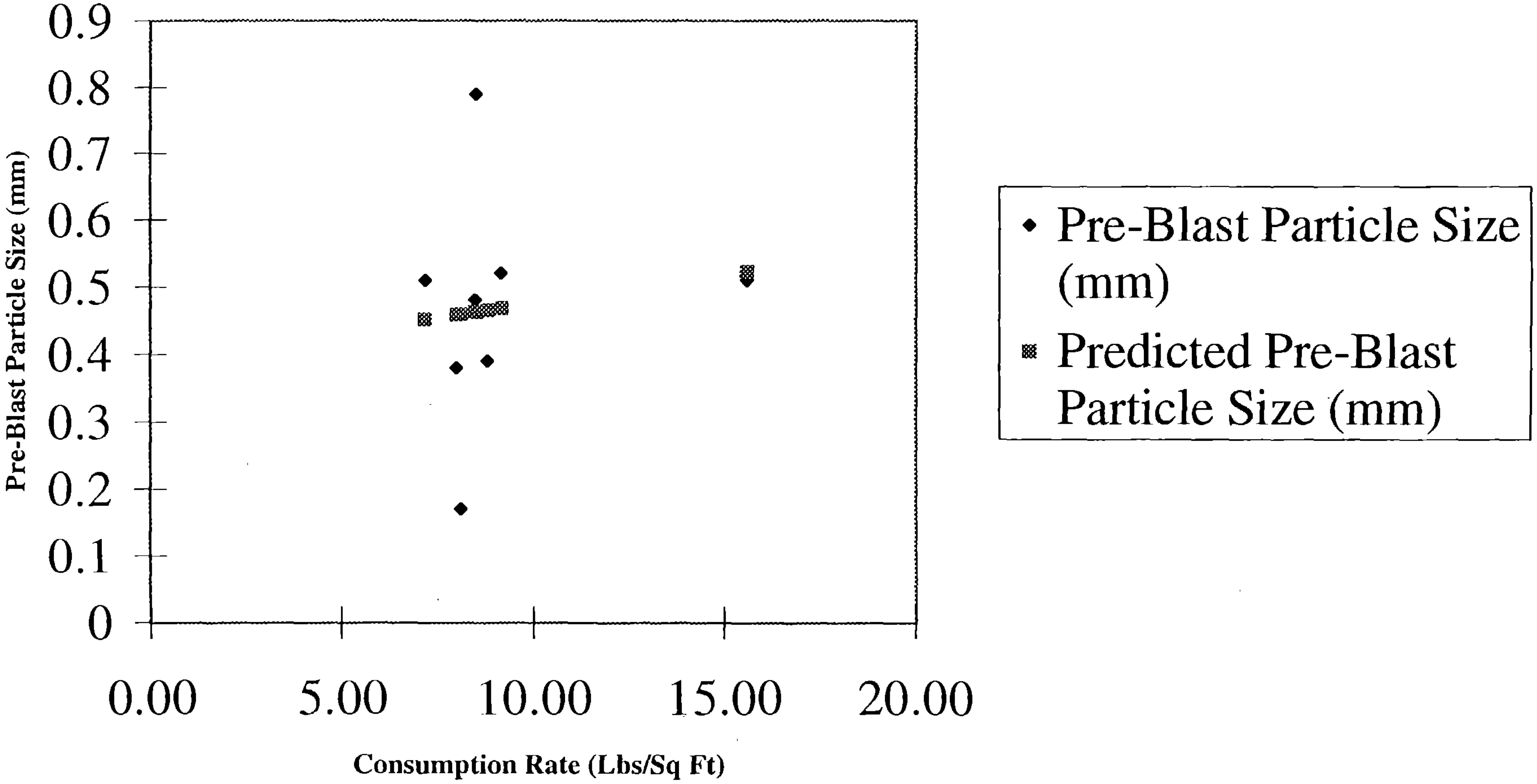
	@ Make-up Air Area	@ Operator Area	@ Exhaust Area	Operator 's Breathing Zone	Virgin (Pre Blast) Bulk	
Abrasive	**Fixed Station #1**	**Fixed Station #2**	**Fixed Station #3**	**(OBZ)**	**Respirable Quartz**	
Type	**mg/m3**	**mg/m3**	**mg/m3**	**mg/m3**	**%**	**Notes**
CS	ND	ND	0.25	ND	ND	< LOD 0.80
N	ND	ND	ND	ND	ND	< LOD 0.80
S	1.01	2.70	5.03	2.06	1.60	< LOQ 2.00
SS	9.91	32.46	50.52	37.60	51.00	> LOQ 2.0
SSDS	9.18	21.26	28.20	24.20	71.00	> LOQ 2.0
CP	ND	ND	ND	ND	ND	< LOD 0.80
G	0.87	7.28	3.92	1.84	1.90	< LOQ 2.00
SG	ND	ND	ND	ND	ND	< LOD 0.80

APPENDIX C

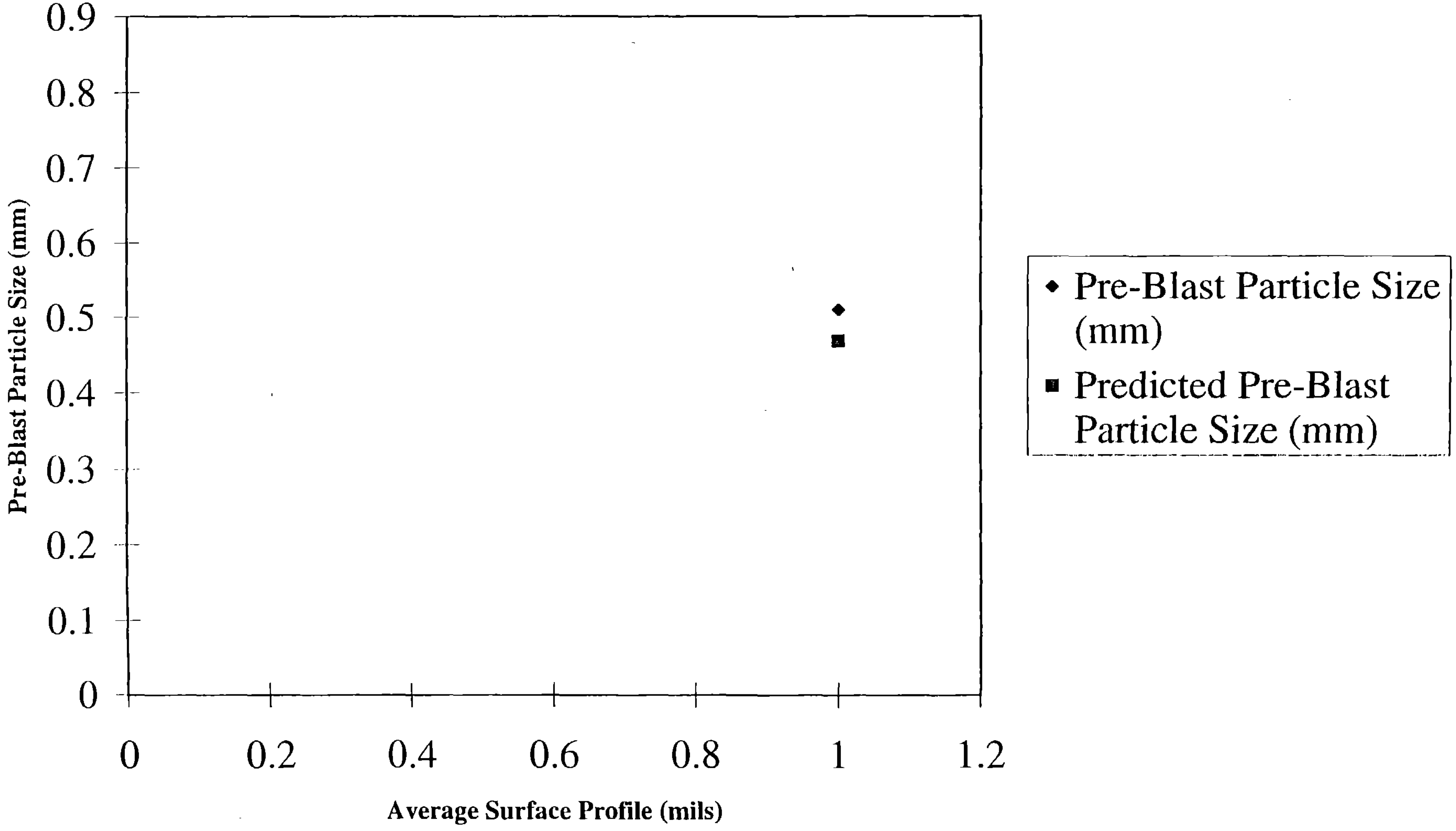
Cleaning Rate Line Fit Plot



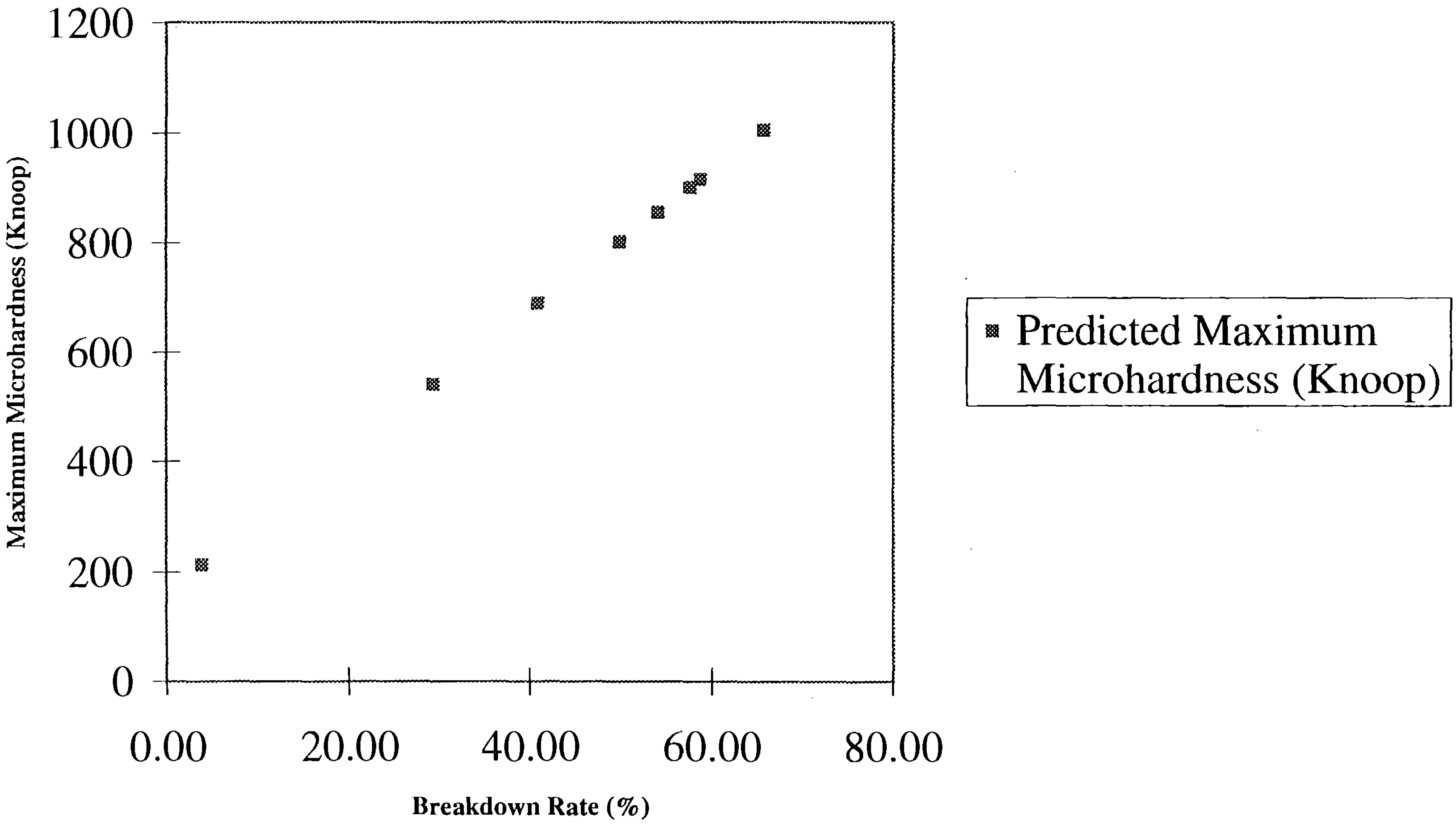
Consumption Rate Line Fit Plot



Average Surface Profile Line Fit Plot



Breakdown Rate Line Fit Plot



APPENDIX D

TABLE D1
Abrasive Cleaning Cost Summary
Non Hazardous Waste

Abrasive No.	Generic Abrasive	Size Designation	Nozzle Size	Flow Rate* (ton/hr.)	Avg. Mat'l Cost ($/ton)	Disposal ($/ton)	Equipment ($/hr.)	Crew Labor** ($/hr.)	No. of Uses	Cleaning Rate* (sq ft/hr.)	Cleaning Cost ($/sq ft)
CS-06	Coal Slag	2040	7/16"	1.03248	42.56	30.00	23.78	100.74	1	287	0.69
N-01	Nickel Slag	2050	7/16"	0.94703	49.28	30.00	23.78	100.74	1	207	0.96
S-02	Staurolite	Regular	7/16"	1.13724	113.45	30.00	23.78	100.74	1	281	1.02
SS-04	Silica Sand	2340	7/16"	1.07738	24.08	30.00	23.78	100.74	1	254	0.72
SSDS-03	Silica Sand with Dust Suppressant	3	7/16"	1.28392	33.35	30.00	23.78	100.74	1	292	0.71
CP-2A	Copper Slag	16/30	7/16"	0.87040	50.63	30.00	32.43	100.74	2	205	0.82
G-3A	Garnet	#40	7/16"	1.38320	223.29	30.00	32.43	100.74	2	346	0.89
SG-2A	Steel Grit	40/50	7/16"	1.28700	477.00	30.00	40.13	100.74	100	165	0.89

* Field study results doubled to account for two (2) abrasive blast nozzles

** Abrasive blast cleaning crew consisting of two (2) nozzle operators and one (1) laborer

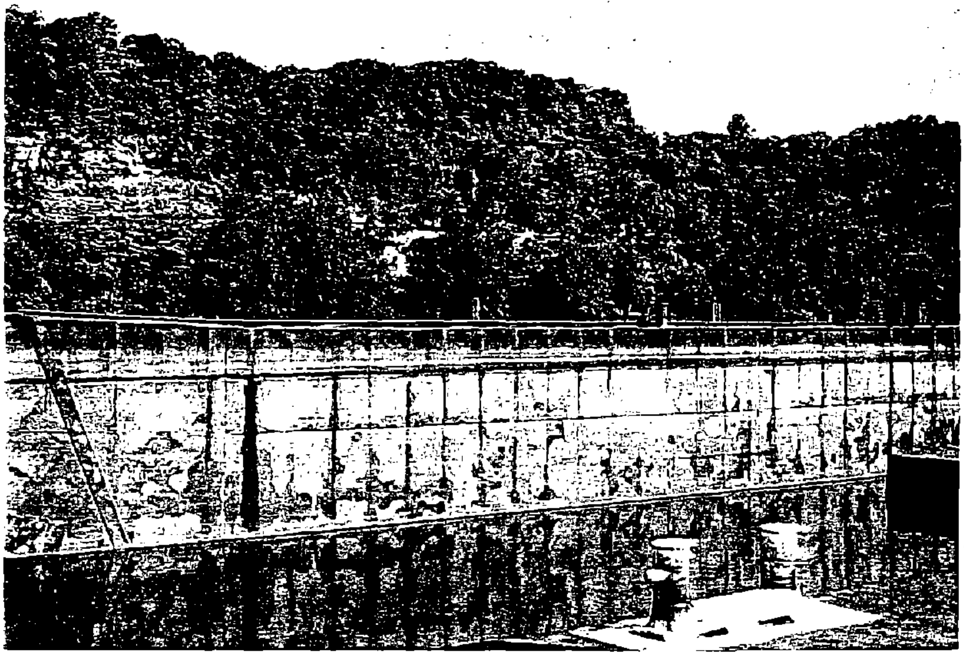
TABLE D2
Abrasive Cleaning Cost Summary
Hazardous Waste

Abrasive No.	Generic Abrasive	Size Designation	Nozzle Size	Flow Rate* (ton/hr.)	Disposal ($/ton)	Avg. Mat'l Cost ($/ton)	Equipment ($/hr.)	Crew Labor** ($/hr.)	No. of Uses	Cleaning Rate* (sq ft/hr.)	Cleaning Cost ($/sq ft)
CS-06	Coal Slag	2040	7/16"	1.03248	184.00	42.56	23.78	100.74	1	287	1.25
N-01	Nickel Slag	2050	7/16"	0.94703	184.00	49.28	23.78	100.74	1	207	1.67
S-02	Staurolite	Regular	7/16"	1.13724	184.00	113.45	23.78	100.74	1	281	1.65
SS-04	Silica Sand	2340	7/16"	1.07738	184.00	24.08	23.78	100.74	1	254	1.37
SSDS-03	Silica Sand with Dust Suppressant	3	7/16"	1.28392	184.00	33.35	23.78	100.74	1	292	1.38
CP-2A	Copper Slag	16/30	7/16"	0.87040	184.00	50.63	32.43	100.74	2	205	1.15
G-3A	Garnet	#40	7/16"	1.38320	184.00	223.29	32.43	100.74	2	346	1.20
SG-2A	Steel Grit	40/50	7/16"	1.28700	184.00	477.00	40.13	100.74	100	165	0.91

* Field study results doubled to account for two (2) abrasive blast nozzles

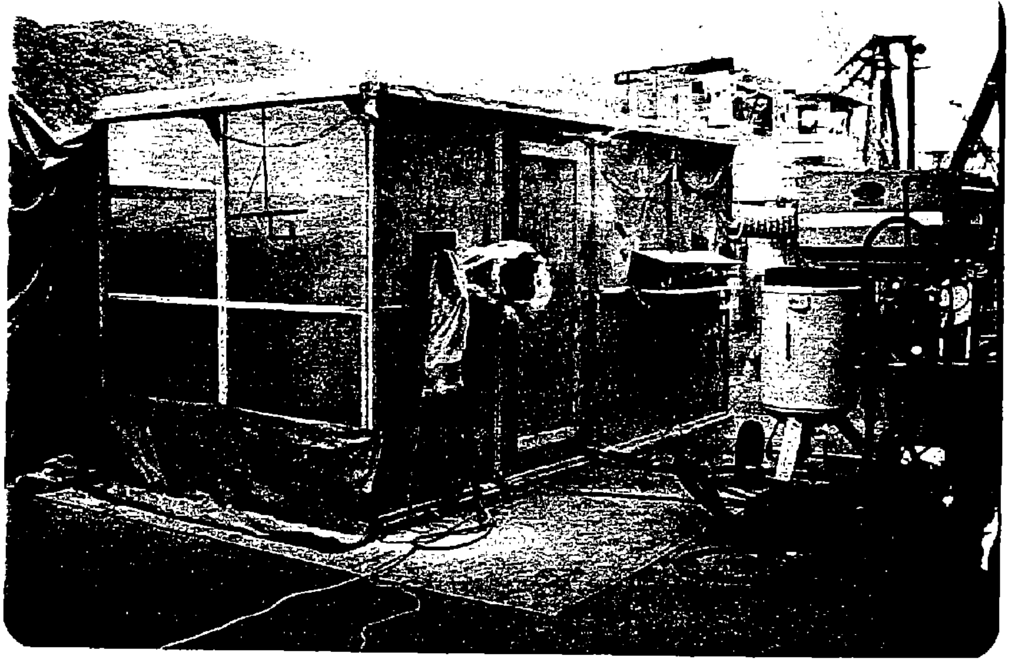
** Abrasive blast cleaning crew consisting of two (2) nozzle operators and one (1) laborer

APPENDIX E



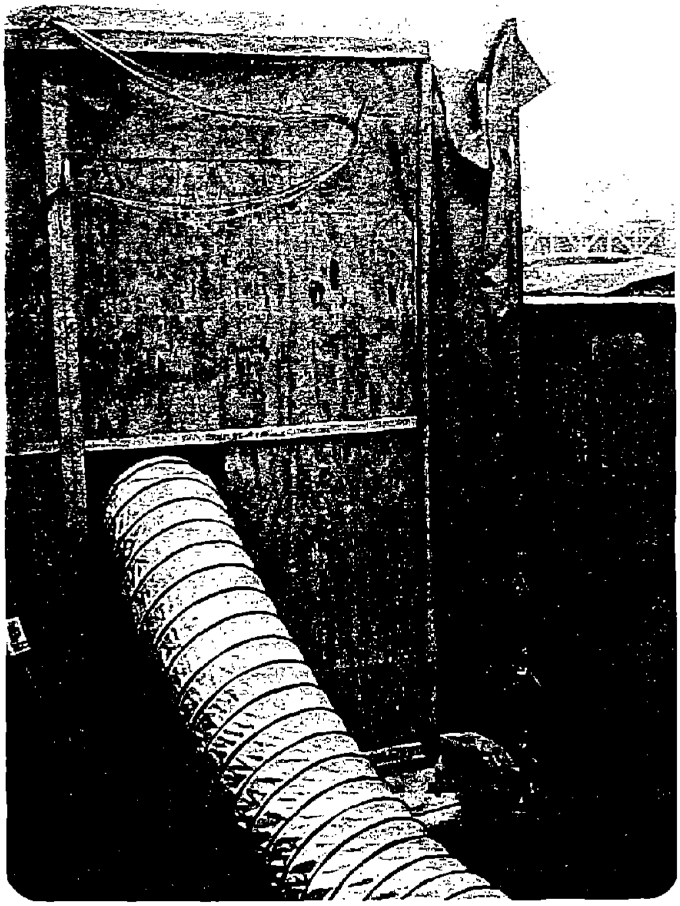
PHOTOGRAPH NO. 1

Initial condition of coal barge



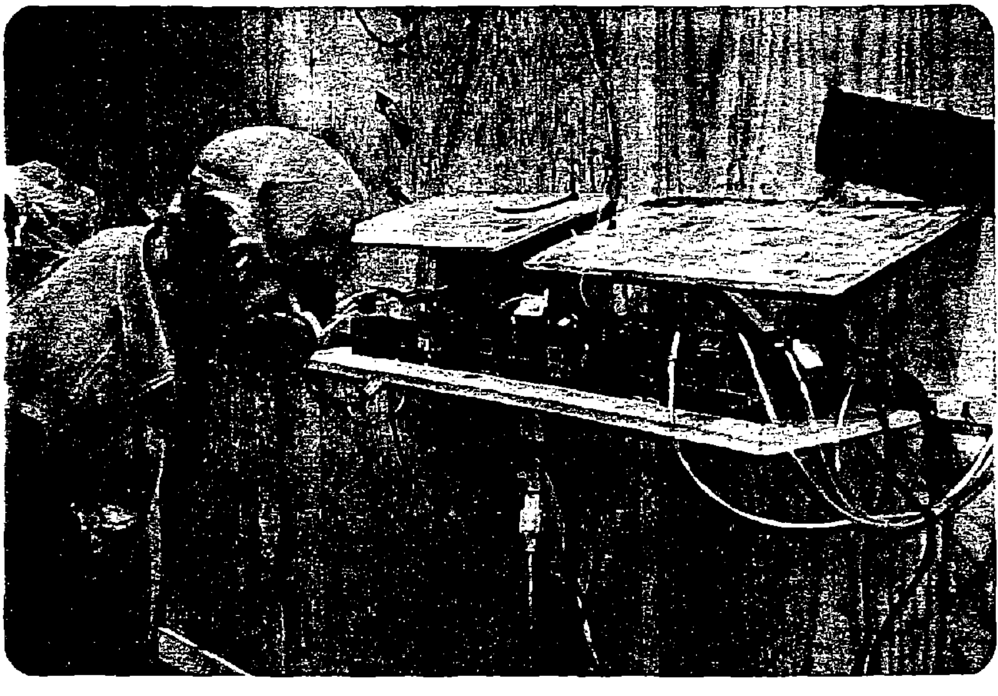
PHOTOGRAPH NO. 2

Containment and equipment staging



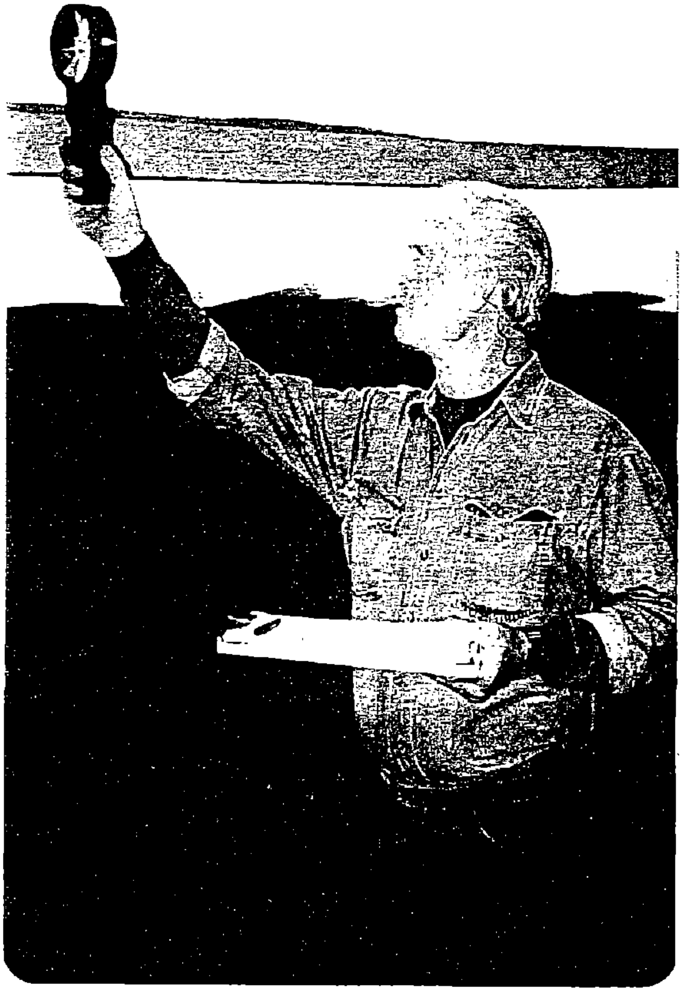
PHOTOGRAPH NO. 3

Duct work positioning for ventilation of containment to dust collector



PHOTOGRAPH NO. 4

Monitoring station outside of containment structure



PHOTOGRAPH NO. 5

IH Technician measuring air flow inside containment

PHOTOGRAPH NO. 6

Positioning of filter media on operator

PHOTOGRAPH NO. 7

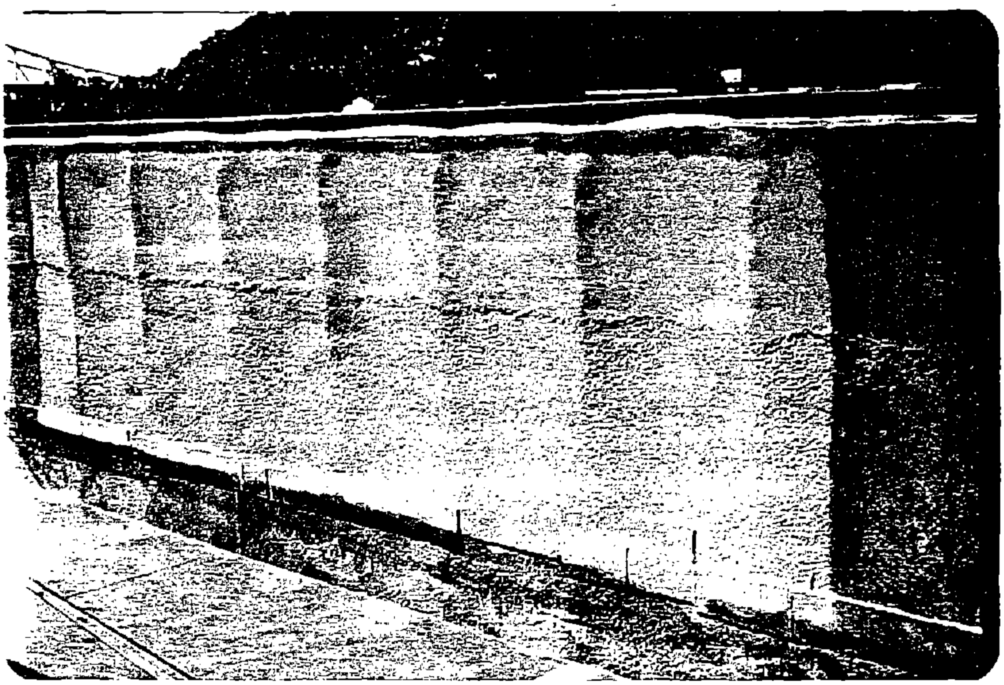
Properly protected operator prior to blast cleaning

PHOTOGRAPH NO. 8

Operator inside containment blast cleaning. Note personal sampling pumps on belt.

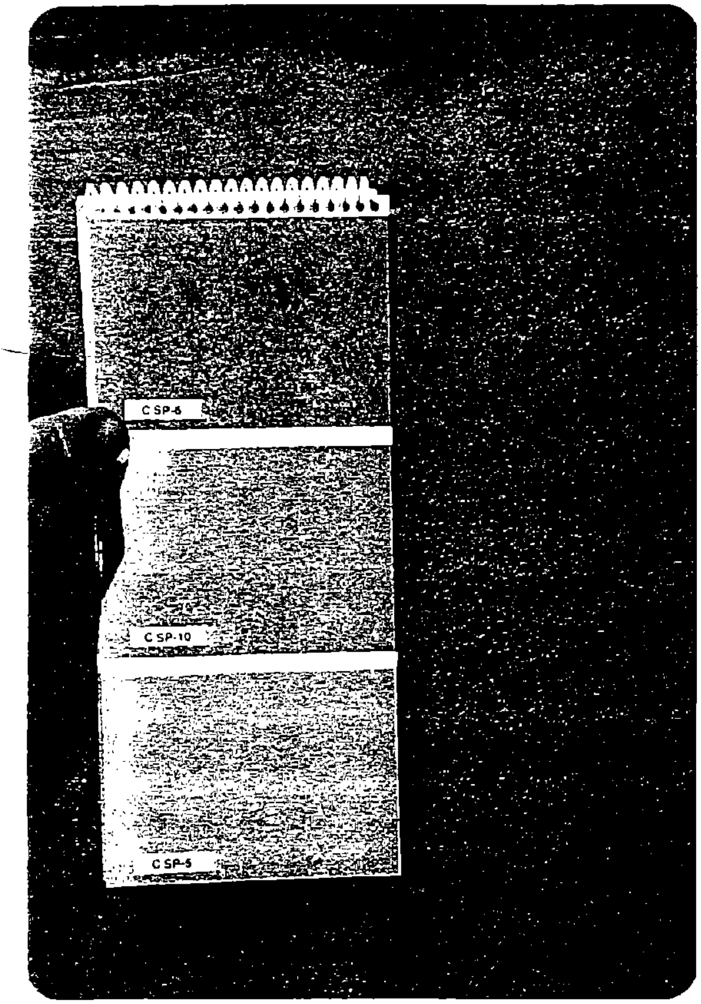
PHOTOGRAPH NO. 9

Blast cleaning operations



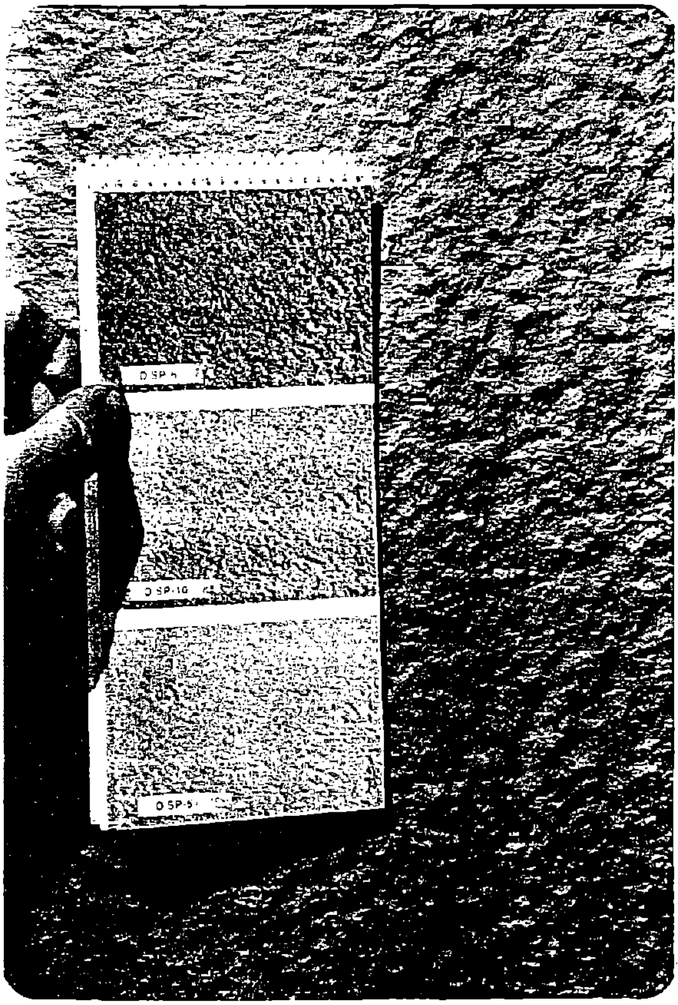
PHOTOGRAPH NO. 10

Blast cleaned section of coal barge after movement of containment



PHOTOGRAPH NO. 11

Verification of blast cleanliness on flat area using SSPC VIS 1-89

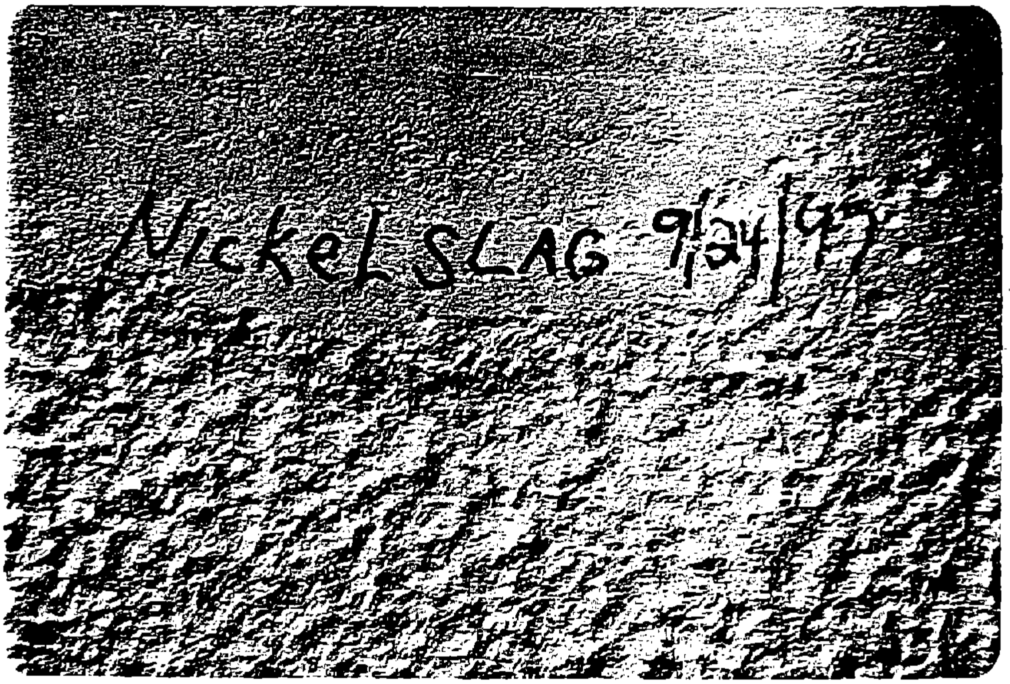


PHOTOGRAPH NO. 12

Verification of blast cleanliness on pitted area using SSPC VIS 1-89

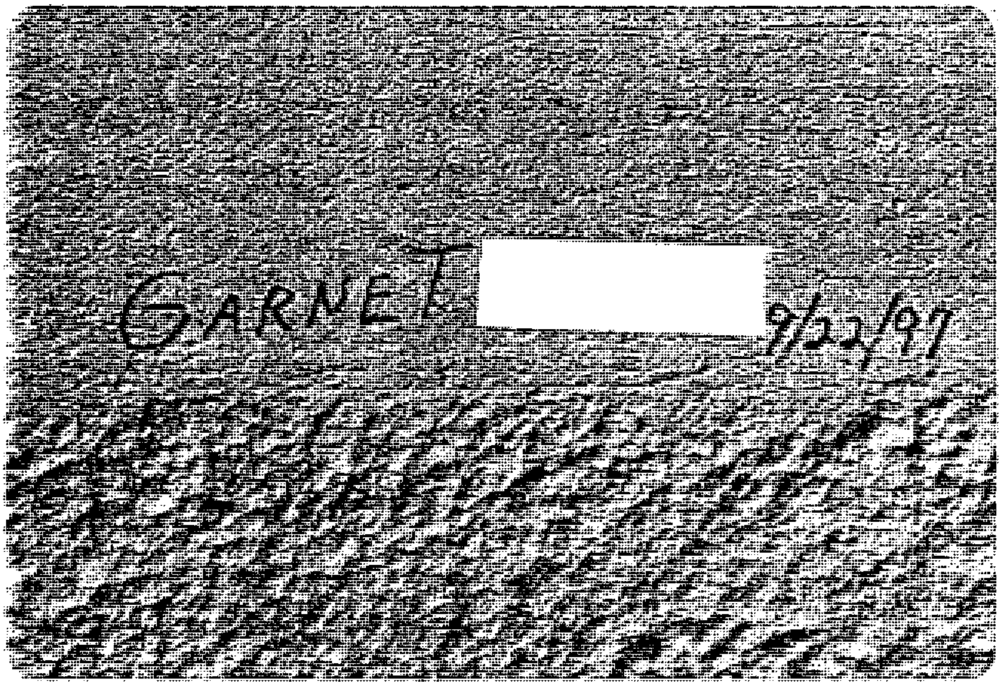
PHOTOGRAPH NO. 13

Post-blast surfaces cleaned using copper slag



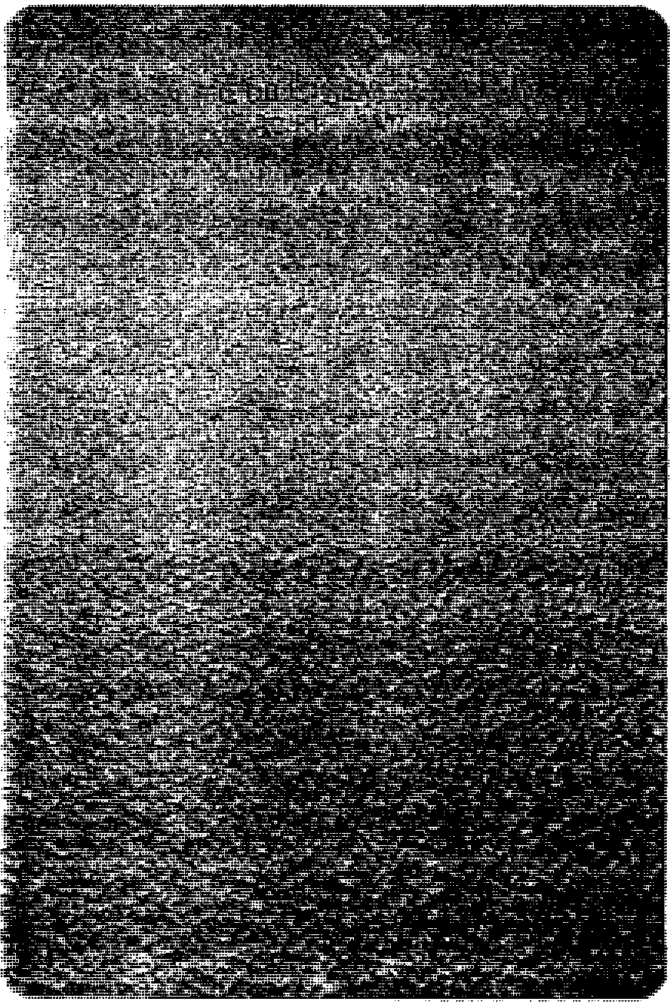
PHOTOGRAPH NO. 14

Post-blast surfaces cleaned using nickel slag



PHOTOGRAPH NO. 15

Post-blast surfaces cleaned using garnet



PHOTOGRAPH NO. 16

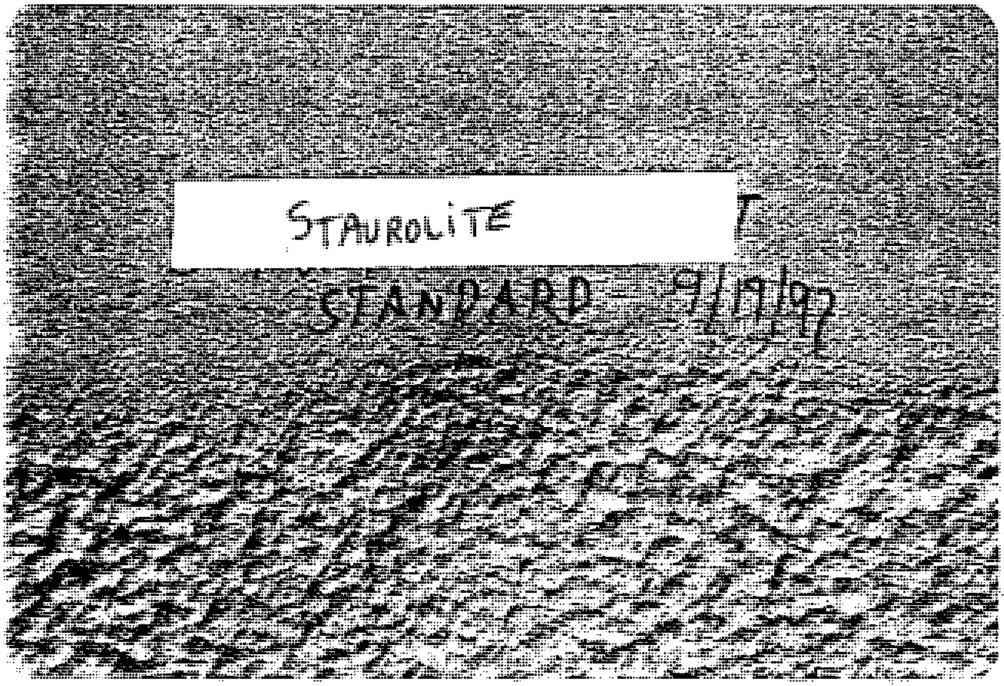
Post-blast surfaces cleaned using coal slag

PHOTOGRAPH NO. 17

Post-blast surfaces cleaned using silica sand with dust suppressant

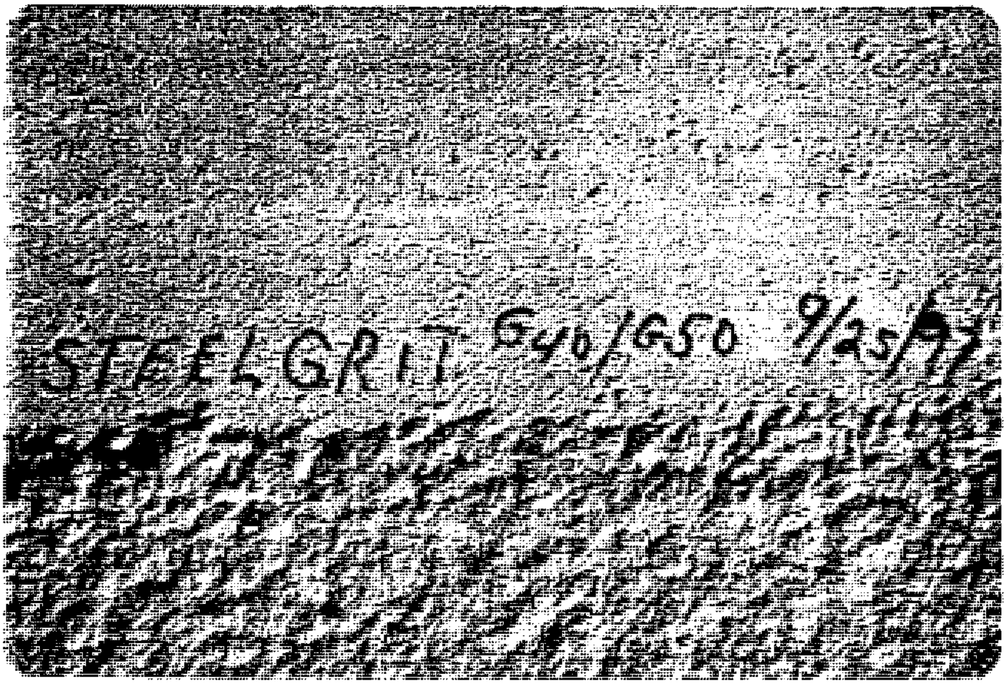
PHOTOGRAPH NO. 18

Post-blast surfaces cleaned using flint silica sand



PHOTOGRAPH NO. 19

Post-blast surfaces cleaned using staurolite sand



PHOTOGRAPH NO. 20

Post-blast surfaces cleaned using steel grit