EVALUATION OF SUBSTITUTE MATERIALS FOR SILICA SAND IN ABRASIVE BLASTING

CONTRACT No. 200-95-2946

Prepared For:

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ACKNOWLEDGMENT

<u>Project: Evaluation of Substitute Materials for Silica Sand in Abrasive Blasting</u>

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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	calcium	lead*	nickel*	sodium	yttrium
arsenic*	chromium*	lithium	phosphorous	tellerium	zinc
barium	cobalt	magnesium	platinum	thallium	zirconium
beryllium*	copper	manganese*	selenium	titanium*	quartz*
cadmium*	iron	molybdenum	silver*	vanadium*	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 [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	calcium	lead	nickel	sodium	yttrium
arsenic	chromium	lithium	phosphorous	tellerium	zinc
barium	cobalt	magnesium	platinum	thallium	zirconium
beryllium	copper	manganese	selenium	titanium	quartz
cadmium	iron	molybdenum	silver	vanadium	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^{o} to 120^{o} to the surface. Nozzles held perpendicular (90^{o}) 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^{o} 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:

<u>Expendable Abrasives</u>

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

<u>Recyclable Abrasives (used only one time for Phase 2)</u>

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.

<u>Physical Property Evaluations</u>

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.

<u>Cleaning and Consumption Rate Summary</u>

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

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.

<u>Industrial Hygiene Results</u>

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 $\mu g/m^3$, with a geometric mean level of 8.588 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 6.190 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 4.306 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$. The geometric mean level for this category is 1.229 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$. The geometric mean concentration of beryllium for the silica sand generic abrasive category was 0.792 $\mu g/m^3$. 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 $\mu g/m^3$, with a geometric mean level of 3.334 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 0.766 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 0.577 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 0.505 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 0.150 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 0.094 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 73.7 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 33.52 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$. The geometric mean concentration of lead for the silica sand generic abrasive category was 6.052 $\mu g/m^3$. 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 $\mu g/m^3$, with a geometric mean level of 42.82 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 11.33 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 8.563 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 8.558 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 7.137 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 6.880 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 6.785 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$. The geometric mean level of manganese for the silica sand generic abrasive category is 383.6 $\mu g/m^3$. 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 $\mu g/m^3$, with a geometric mean level of 9,489 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 4,943 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 2,182 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 1,576 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 746.8 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 638.7 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 226.6 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$. The geometric mean level of nickel for the silica sand generic abrasive category was 28.33 $\mu g/m^3$. 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 $\mu g/m^3$, with a geometric mean level of 948.4 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 523.6 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 70.6 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 33.39 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 23.94 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 16.38 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 14.58 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$. 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 $\mu g/m^3$. The geometric mean for this category was 1.045 $\mu g/m^3$, which is slightly higher than silica sand's geometric mean of 0.861 $\mu g/m^3$.

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 $\mu g/m^3$. The geometric mean level of titanium for the silica sand generic abrasive category was 749.6 $\mu g/m^3$. 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 $\mu g/m^3$, with a geometric mean level of 4,892 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 1,786 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 1,289 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 284.3 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 150.8 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 27.79 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 21.7 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$ to 109.2 $\mu g/m^3$. The geometric mean for the silica sand generic abrasive category was 32.62 $\mu g/m^3$. 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 $\mu g/m^3$, with a geometric mean level of 106.3 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 77.16 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 59.16 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 39.56 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 24.88 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 20.37 $\mu g/m^3$. 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 $\mu g/m^3$.

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 $\mu g/m^3$, with a geometric mean level of 3.01 $\mu g/m^3$. 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 $\mu g/m^3$.

FIGURE 1 – ARSENIC AIR SAMPLE RESULTS

FIGURE 2 – BERYLLIUM AIR SAMPLE RESULTS

FIGURE 3 – CADMIUM AIR SAMPLE RESULTS

FIGURE 4 – CHROMIUM AIR SAMPLE RESULTS

FIGURE 5 – LEAD AIR SAMPLE RESULTS

FIGURE 6 – MANGANESE AIR SAMPLE RESULTS

FIGURE 7 – NICKEL AIR SAMPLE RESULTS

FIGURE 8 – QUARTZ AIR SAMPLE RESULTS

FIGURE 9 – TITANIUM AIR SAMPLE RESULTS

FIGURE 10 – VANADIUM AIR SAMPLE RESULTS

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 $\mu g/m^3$ for the coal slag generic abrasive category was nearly 2.5 times higher than that of silica sand at 28.3 $\mu g/m^3$. 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 $\mu g/m^3$ was about 2.4 times higher than that of silica sand at 749.6 $\mu g/m^3$. 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 $\mu g/m^3$ was about 3 times higher than that of silica sand at 32.62 $\mu g/m^3$. 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 $\mu g/m^3$ was slightly higher than that of silica sand at 4.225 $\mu g/m^3$. 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 $\mu g/m^3$ 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 $\mu g/m^3$. 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 $\mu g/m^3$. 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 $\mu g/m^3$. 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 $\mu g/m^3$. 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 $\mu g/m^3$. 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 $\mu g/m^3$. 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 $\mu g/m^3$ was about 1.5 times that of silica sand at 4.225 $\mu g/m^3$. 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 $\mu g/m^3$ was about 12 % that of silica sand at 0.792 $\mu g/m^3$. Silica sand with dust suppressant had the second lowest geometric mean concentration of beryllium. The lowest geometric mean concentration (0.041 $\mu g/m^3$) 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 $\mu g/m^3$ was similar to silica sand (1.2 times higher) at 0.185 $\mu g/m^3$. 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 $\mu g/m^3$ was approximately 93% that of silica sand at 36.08 $\mu g/m^3$. 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 $\mu g/m^3$ was slightly higher (1.4 times) than silica sand at 6.052 $\mu g/m^3$. 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 $\mu g/m^3$ was approximately 60% that of silica sand at 383.6 $\mu g/m^3$. 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 $\mu g/m^3$ was approximately 50% that of silica sand at 28.33 $\mu g/m^3$. 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 $\mu g/m^3$, 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 $\mu g/m^3$ for the copper slag generic abrasive category was slightly higher than that of silica sand at 28.33 $\mu g/m^3$. 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 $\mu g/m^3$ was about 1.7 times higher than that of silica sand at 749.6 $\mu g/m^3$. 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 $\mu g/m^3$ was about 2.4 times higher than that of silica sand at 32.62 $\mu g/m^3$. 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 $\mu g/m^3$ was about 2.2 times that of silica sand at 4.225 $\mu g/m^3$. 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 $\mu g/m^3$ was slightly less than 63% that of silica sand at 0.792 $\mu g/m^3$. 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 $\mu g/m^3$ was nearly 6 times higher than silica sand at 0.185 $\mu g/m^3$. 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 $\mu g/m^3$ was over 5 times higher than silica sand at 4.225 $\mu g/m^3$. 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 $\mu g/m^3$ was 2.3 times higher than silica sand at 0.185 $\mu g/m^3$. 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 $\mu g/m^3$ was approximately 28 times that of silica sand at 36.08 $\mu g/m^3$. 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 $\mu g/m^3$ was slightly higher than silica sand at 6.052 $\mu g/m^3$. 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 $\mu g/m^3$ was approximately 13 times higher than silica sand at 383.6 $\mu g/m^3$. 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 $\mu g/m^3$ was approximately 18.5 times higher than silica sand at 28.3 $\mu g/m^3$. 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 $\mu g/m^3$ was approximately 3% that of silica sand at 749.6 $\mu g/m^3$. 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 $\mu g/m^3$ was approximately 1.8 times higher than silica sand at 32.62 $\mu g/m^3$. 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

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]

These 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

<u>226Ra by Radiochemical Separation and Alpha Spectrometry: Airborne Samples</u>

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 13 – CADMIUM VIRGIN BULK SAMPLE RESULTS

FIGURE 14 – CHROMIUM VIRGIN BULK SAMPLE RESULTS

FIGURE 15 – LEAD VIRGIN BULK SAMPLE RESULTS

FIGURE 16 – MANGANESE VIRGIN BULK SAMPLE RESULTS

FIGURE 17 – NICKEL VIRGIN BULK SAMPLE RESULTS

FIGURE 18 – SILVER VIRGIN BULK SAMPLE RESULTS

FIGURE 19 – TITANIUM VIRGIN BULK SAMPLE RESULTS

FIGURE 20 – VANADIUM VIRGIN BULK SAMPLE RESULTS

FIGURE 21 – QUARTZ VIRGIN BULK SAMPLE RESULTS

TABLE 3

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.

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