For over 50 years, silica sand has been the traditional media used for abrasive blast cleaning because it was naturally occurring, readily available, economical, and effective. However, silica sand commonly contains high concentrations of crystalline silica (quartz). Respirable silica-quartz causes silicosis after chronic (repeated) exposure. The formation of scattered silica-containing nodules of scar tissue in the lungs characterizes classic silicosis, which may become progressively worse even in the absence of continued exposure. Acute silicosis may occur under conditions of extremely high quartz exposures, and is a rapidly progressive disease with diffuse (widespread) pulmonary involvement. Animal studies have indicated an increased risk of cancer. Because of these concerns, substitutes for silica sand abrasives have been pursued.

The Centers for Disease Control and Prevention (CDC), through the National Institute for Occupational Safety and Health (NIOSH), commissioned a study entitled “Evaluation of Substitute Materials for Silica Sand in Abrasive Blasting—Contract No. 200-95-2946.” In conjunction with NIOSH, the third-party firm that received the study contract developed a project design protocol 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. A Phase 3 report compared data from the laboratory study to the field study. This article summarizes some of the key findings of the study, especially as silicosis may occur under conditions of extremely high quartz exposures, and is a rapidly progressive disease with diffuse (widespread) pulmonary involvement. Animal studies have indicated an increased risk of cancer. Because of these concerns, substitutes for silica sand abrasives have been pursued.

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### Table 1

<table>
<thead>
<tr>
<th>Abrasive</th>
<th>Arsenic Minimum result</th>
<th>Arsenic Maximum result</th>
<th>Beryllium Minimum result</th>
<th>Beryllium Maximum result</th>
<th>Beryllium Geometric mean</th>
<th>Cadmium Minimum result</th>
<th>Cadmium Maximum result</th>
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**Phase 2**

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<th>Beryllium Maximum result</th>
<th>Beryllium Geometric mean</th>
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<th>Cadmium Geometric mean</th>
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</table>

*Unless noted, all results are in micrograms per cubic meter (µg/m³).
they relate to occupational health hazards. Readers are encouraged to review the full reports for a complete discussion of these and other issues. Guidance on obtaining the full reports is included at the end.

**Background Information**
Thirteen generic types of abrasives were evaluated in the Phase 1 laboratory study, and eight generic types of abrasives marked with an asterisk (*) were evaluated in the Phase 2 field study.

- Coal slag (CS)*
- Coal slag with dust suppressant (CSDS)
- Copper slag (CP)*
- Copper slag with dust suppressant (CPDS)
- Crushed glass (CG)
- Garnet (G)*
- Nickel slag (N)*
- Olivine (O)
- Silica sand (SS)*
- Silica sand with dust suppressant (SSDS)*
- Specular hematite (SH)
- Staurolite (S)*
- Steel grit (SG)*

For Phase 1, one to seven individual products from each generic category (40 products total) were obtained from manufacturers and suppliers throughout the U.S. Each abrasive was evaluated for seven performance-related characteristics.

- Cleaning rate
- Consumption rate
- Surface profile
- Breakdown rate
- Abrasive embedment
- Microhardness
- Conductivity

Only one product from each of the eight generic categories was tested in Phase 2. The Phase 2 abrasives were evaluated for the same performance-related characteristics except microhardness and conductivity.

Bulk samples of the abrasive products were analyzed for 30 potential contaminants before and after blasting. During use, they were evaluated for airborne concentrations of the same contaminants. (See box.)

**Protection of Human Subjects**
For both Phases 1 and 2, the blaster wore a Type CE supplied-air helmet (Assigned Protection Factor [APF] of 1,000) with Grade D breathing air supply, cotton coveralls, gloves, boots, and hearing protection (Noise Reduction Rating 29). Support personnel were similarly outfitted, except that they wore half-face, negative-pressure, air-purifying respirators with HEPA filtration (APF of 10) instead of the blast helmet. Training on the health effects of hazardous agents, proper use of personal pro-
Protective equipment and respiratory protection, review of decontamination procedures, and a medical surveillance program were included to help ensure that project personnel were adequately protected during the study.

Study Design—Phase 1

In Phase 1, 40 abrasives were used in an environmentally-controlled laboratory blast room to blast clean bare carbon steel plates. The objective of the study was to collect industrial hygiene airborne levels and bulk ingredient data for 30 health-related agents as well as economic and technical data regarding the performance of the abrasives. The study design protocol held constant many factors that affect an abrasive blast cleaning process so that a comparative evaluation of the abrasives could be made independent of the substrate, surface cleanliness, equipment set-up, or operator. The individual abrasives that were evaluated in Phases 1 and 2 were selected by NIOSH based on a higher volume of consumption within the blasting industry and on the ability to produce the required profile criteria established by the protocol.

For Phase 1, controls were provided over the purchasing of the steel substrate test panels to ensure homogeneity. Blast pressure at the nozzle was maintained at 100 psi for each trial. A six-cubic foot blast pot was used. Based on recommendations of the abrasive

<table>
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<tr>
<th>Abrasive</th>
<th>Minimum result</th>
<th>Maximum result</th>
<th>Geometric mean</th>
<th>Minimum result</th>
<th>Maximum result</th>
<th>Geometric mean</th>
<th>Minimum result</th>
<th>Maximum result</th>
<th>Geometric mean</th>
<th>Minimum result</th>
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</tbody>
</table>

*Unless noted, all results are in micrograms per cubic meter (µg/m³).

Fig. 1 - Blast room layout. Stars indicate sample collection sites. Figures furnished by authors.

Table 2

Comparison of Airborne Concentration of Health-Related Agents for Paired Abrasives From the Laboratory (Phase 1) and Field (Phase 2) Studies*
supplied, the abrasive metering valve
was adjusted from ¼-inch to ½-inch
in ⅛-inch increments. If a recom-
mendation was not made, the ½-inch
size was used. The cross-draft venti-
lation within the blast room was
maintained at 50 to 75 ft per minute,
and the blast room and blast clean-
ing equipment were thoroughly
cleaned before each run.

Blasting was conducted until 72 sq
ft of uncoated mill scale-bearing
steel was cleaned to an SSPC-SP 10,
Near-White, level of cleanliness, or
until the blast pot ran out of abra-
sive. The operator maintained a con-
stant 18-inch nozzle-to-work piece
distance and held the nozzle per-
pendicular to the test surface.

Before initiating the study, re-
searchers also recognized that vari-
bility could exist among human op-
erators. In an effort to reduce the
variability among individual opera-
tors and within a single operator, a
study was initially conducted to se-
lect a single operator for the project.
The operator who displayed the
least variation across a series of test
attributes was used for all of the
Phase 1 and Phase 2 work.

During each abrasive trial, air-
borne samples were collected in the
blast room as well as on the opera-
tor. Twenty-nine samples were col-
lected for each run (eight at the
make-up air area, eight in the opera-
tor area near the test surfaces, eight
in the exhaust area, three within the
operator's breathing zone, and two
passive samples for the collection of
ricochet in the blast room operator
area). All samples except those
mounted on the operator were at-
tached to fixed sample holders, as-
suring that the sample locations
were identical for each abrasive trial.

Study Design—Phase 2
Phase 2 was conducted to evaluate
eight of the Phase 1 abrasives under
field conditions. Phase 2 was con-
ducted at a shipyard in Elizabeth,
PA. The object of Phase 2 was to
collect data on airborne concentra-
tions and bulk ingredient data for 30
health-related agents as well as eco-
nomic and technical data under par-
tially controlled field conditions.

The work involved open nozzle
dry abrasive blast cleaning of the ex-
terior hull of a coal barge. The hull
was free of any coating and consist-
ed of heavily rusted and pitted steel.
The side of the barge was divided
into eight 14-foot x 5-foot sections
for a maximum surface area of ap-
proximately 70 sq ft per abrasive.

A portable containment was con-
structed that measured 16 ft long by
8 ft wide by 8 ft high. It was used to
enclose one section at a time. Tar-
paulins were used to cover the floor.
inside the containment. The containment was equipped with an exhaust fan and a dust collector with a capacity of 5,000 cubic feet per minute (cfm). An average cross-draft air flow of 40 feet per minute was maintained for each trial run. This air flow was based on actual measurements rather than on theoretical calculations derived from the stated capacity of the dust collector.

The same blast cleaning equipment used in Phase 1 was utilized for Phase 2 except that a 7⁄16-inch orifice venturi blast nozzle was used. In addition, the metering valve was uniquely adjusted for the abrasive based on the feel of the operator and the fullness of the abrasive blast pattern. The operator from Phase 1 conducted the Phase 2 trials.

After each abrasive trial run, the containment was cleaned to prevent cross-contamination between abrasives and moved to a new location on the barge. Fourteen airborne samples were collected inside the containment during each trial run (four make-up air area; four operator area; four exhaust area; and two within the operator’s breathing zone). The 12 area samples were mounted on fixed holders to assure that the position remained constant for each abrasive trial. The abrasives were evaluated for cleaning rate, consumption rate, surface profile, breakdown rate, abrasive embedment, microhardness, and conductivity. Based on blast cleaning steel in a blast room under the stringent controls of the study, average cleaning costs showed all of the alternative abrasives except crushed glass and specular hematite to be less expensive to use (as a class). In both exceptions, only one abrasive was evaluated, and, in both cases, at least one silica sand abrasive proved more costly. Cleaning costs generally ranged from $0.65 to

\[ \text{continued} \]
### Table 3
Comparison of Airborne Concentration of Health-Related Agents for Paired Abrasives From the Laboratory (Phase 1) and Field (Phase 2) Studies*

<table>
<thead>
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<th>Phase 1</th>
<th>Nickel</th>
<th>Respirable quartz (mg/m³)</th>
<th>Silver</th>
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<td>Geometric mean</td>
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<td>G-3A</td>
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*Unless noted, all results are in micrograms per cubic meter (µg/m³).

### Table 4
Comparison of Airborne Concentration of Health-Related Agents for Paired Abrasives From the Laboratory (Phase 1) and Field (Phase 2) Studies*

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<tr>
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<tr>
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<td>28.99</td>
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<td>Maximum result</td>
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</table>

*Unless noted, all results are in micrograms per cubic meter (µg/m³).
nozzle from ¼ in. to ⅜ in. reduced the cost by nearly 60%.

For the Phase 2 field study, all alternative abrasives evaluated were capable of producing the desired degree of cleaning and a surface profile suitable for paint performance. Productivity rates of the abrasives were both better and worse than silica sand. Once again, readers should refer to the full report for details on the evaluation of all performance characteristics.

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 prepare the steel using the various abrasives ranged from $0.69 per sq ft to $1.02 per sq ft. The cost of coal slag abrasive was comparable to silica sand ($0.69 per sq ft versus $0.72 for silica sand). Other abrasives were more expensive to use based on the test results (e.g., from 12 to 42% more expensive than silica sand). Similar to phase 1, these costs can be expected to change under actual field use when the operator is given the flexibility to clean from varying distances and angles of attack, and to make adjustments to blast pressure and equipment settings. In addition, if hazardous waste is assumed to be present, the cost of use changes dramatically due to disposal costs, from $0.91/sq ft to $1.67/sq ft, with silica sand at $1.37/sq ft. Steel grit becomes the most cost-effective abrasive at $0.91/sq ft due to its recyclability (100 recycles used for the analysis).

**Industrial Hygiene Results—**

**Phase 1**

For the Phase 1 laboratory study, airborne samples were collected at three fixed stations (make-up air, operator area, and exhaust area) and the operator’s breathing zone (Fig. 1). In all, 424 air samples were ana-
analyzed for 28 metals/elements, quartz, and cristobalite. While data were collected on a total of 30 potential contaminants, the analysis focused on 11 health-related agents selected by NIOSH: arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, respirable quartz, silver, titanium, and vanadium. For sake of brevity, this article focuses on the first five of these health-related agents, as well as respirable quartz.

Because the laboratory conditions may not be representative of work site conditions, all of the laboratory data must be viewed only as an indicator of the potential for worker exposures to these health-related agents. Therefore, caution must be used when comparing airborne concentrations of the health-related agents to worksite guidelines and standards, such as NIOSH recommended exposure limits (RELs) or OSHA permissible exposure limits (PELs), which this report cites as points of reference. However, the Phase 2 field study resulted in generally higher airborne concentrations of the health-related agents, indicating that the laboratory data may actually underestimate the potential for worker exposures to these materials.

It must be pointed out that there is considerable variability between individual abrasives within a generic category of abrasive. The following comparisons between generic categories of abrasive mask this individual variability. Therefore, the full report should be reviewed for details on individual abrasives. In viewing Figures 2 to 7 depicting the findings, readers should recognize that the wide range in measured airborne concentrations required the use of a logarithmic scale (i.e., each major horizontal line represents a tenfold increase in concentration). The bars show the range of measured concentrations for each generic category of abrasive, while the diamonds within each bar correspond to the geometric mean (GM) concentration. Geometric means are used as a measure of central tendency (i.e., average) when data are heavily clustered at one end of the measured range. Using the GM downplays the impact of one or two data points that would significantly skew an arithmetic average. The generic categories are ordered according to their GM concentration of the contaminant, going from lowest to highest, from left to right. Silica sand is distinguished from all other abrasives by a red bar.

**Respirable Quartz**

Figure 2 shows that crushed glass, coal slag, nickel slag, olivine, specular hematite, and steel grit had all results below the Limit of Detection.
(LOD) (diamonds colored in pink) for respirable quartz. Copper slag, staurolite, and garnet had at least one result above the LOD.
• Silica sand had 27 out of 28 samples above the LOD, with a GM of 8.83 mg/m³.
• For copper slag, 3 out of 32 samples were above the LOD. The GM was 60 times less than silica sand.
• For staurolite, only 1 out of 8 samples was above the LOD. The GM was 60 times less than silica sand.
• For garnet, 17 out of 52 samples were above the LOD, and the GM was 40 times less than silica sand. However, the analytical techniques utilized had some interferences in properly identifying quartz.

In summary, all of the alternative abrasives resulted in significant reductions in respirable quartz concentrations compared to silica sand.

**Arsenic**

The NIOSH REL and OSHA PEL have been added to Fig. 3 as yellow.
and red colored horizontal lines to provide a visual comparison to the ranges of airborne concentrations measured during the laboratory study. Olivine, crushed glass, specular hematite, and staurolite had all results below the LOD for arsenic. All of the other generic categories had at least one measured concentration above the LOD.

- Garnet had only 1 detectable sample out of 52 samples and a GM that was still below silica sand.
- Silica sand had 2 out of 28 samples above the LOD, with a GM of 2.04 µg/m³.
- The GM for coal slag was 1.4 times higher than silica sand and had a much wider range of measured concentrations (2.1 to 29 µg/m³).
- One of the nickel slags had 4 out of 4 samples below the LOD. The other, however, ranged from 20 to 170 µg/m³. There was a similar occurrence within the two steel grits. One abrasive had 4 out of 8 samples

Fig. 4 - Results of analysis for beryllium

Fig. 5 - Results of analysis for cadmium

ND indicates abrasive category results were all below the limit of detection.
above the LOD for arsenic, resulting in a GM of 5.15 µg/m³ and a range of 1 to 50 µg/m³. The second abrasive had all 8 samples above the LOD, resulting in a GM of 22.31 µg/m³ and a range of 8 to 188 µg/m³.

- The copper slag results, while variable, were all relatively high.

In summary, several generic categories of abrasive (coal slag, nickel slag, steel grit, and copper slag) show potential for generating airborne concentrations above the NIOSH REL and OSHA PEL for arsenic. However, individual abrasives within these generic categories may not exhibit this tendency.

**Beryllium**

As illustrated in Fig. 4, all of the generic categories of abrasive had at least one result above the LOD for beryllium. The GM concentrations for olivine, steel grit, staurolite, specular hematite, and crushed glass were all similar to silica sand.

- Garnet and nickel slag had GMs close to silica, with slightly broader measured ranges (0.021 to 2.3 µg/m³ for garnet and 0.031 to 1.2 µg/m³ for nickel slag).
- Copper slag and coal slag were highest, with the GM for the coal slag at or above the PEL and 23 times higher than silica sand.

In summary, the GMs for all the generic categories except copper and coal slag were below the NIOSH REL. Copper slag, coal slag, and garnet had individual results above the OSHA PEL for beryllium.

**Cadmium**

Figure 5 shows that olivine and crushed glass had all results below the LOD for cadmium. For all but copper slag, the bars reflect the tendency of the data within a generic category to be in the lower part of the measured range, as evidenced by the GM being low in the bar. The graphs for nickel slag and copper slag indicate concentrations were measured that exceeded the OSHA PEL. Individual abrasives may have much lower concentrations. For example, one nickel slag had all results below the LOD.

**Chromium**

As Fig. 6 shows, specular hematite was the only abrasive with all results below the LOD for chromium, while the GMs for staurolite and crushed glass were similar to silica sand.

- The GM for garnet was 2.5 times higher than silica sand, and a much broader range (from less than the LOD to 207 µg/m³), but all concentrations were still less than the OSHA PEL.
- The GMs for coal slag, copper slag, olivine, and steel grit were all substantially greater than silica sand (6, 9, 16, and 33 times higher, respectively), but all were less than the OSHA PEL.
- Nickel slag had a GM that was 114 times higher than silica sand, and above the OSHA PEL.

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Data were collected on the airborne concentrations of 30 contaminants. The 11 health-related agents selected by NIOSH for detailed analysis are marked with an asterisk (*).
In summary, copper slag, steel grit, and nickel slag had measured concentrations above the OSHA PEL for chromium, but only nickel slag had a GM above the OSHA PEL.

**Lead**

Figure 7 shows that specular hematite had all results below the LOD for lead. In addition, while olivine and garnet each had measurable concentrations above the LOD, the GMs for the generic categories were less than specular hematite. Steel grit was the remaining abrasive with a GM for lead less than silica sand; however, measured concentrations approached the OSHA PEL of 50 µg/m³.

- Coal slag, nickel slag, staurolite, and crushed glass had GM concentrations that were slightly greater than silica sand, with the highest measured concentrations between 30 µg/m³ and 50 µg/m³ (the OSHA Action Level and PEL, respectively).
- Copper slag had 29 out of 32 results above the LOD. The GM for
the generic category of 92 µg/m³ was 33.5 times higher than silica sand and above the OSHA PEL. The maximum measured concentration exceeded 100,000 µg/m³.

In summary, all but one of the generic categories of abrasive resulted in GM concentrations that were similar to silica sand and below the OSHA PEL. Individual abrasives within the steel grit and nickel slag generic categories may result in airborne concentrations that approach the OSHA PEL. The GM concentration for the copper slag generic category exceeded the OSHA PEL.

**Treated Versus Untreated Abrasives**

Two coal slags, three silica sands, and one copper slag were treated with dust suppressant. A comparison of the measured airborne concentrations of 11 health-related agents for paired sets (i.e., treated and untreated varieties of the same products) was made to determine the effects dust suppressants might have in reducing airborne concentrations. For the 66 paired sets of data, the following was identified:

- 32 paired sets of data (48.5%) were essentially identical (i.e., within ±15%);
- 20 paired sets of data (30.3%) showed a decrease in measured concentrations (i.e., more than 15% lower) with the treated abrasive;
- 14 paired sets of data (21.2%) showed an increase in measured concentrations (i.e., more than 15% higher) with the treated abrasive.

Combined, nearly 70% of the paired data sets indicated measured concentrations of health-related agents either remained the same (i.e., ±15%) or actually increased (i.e., greater than 15%) for the abrasive treated with dust suppressant over the paired untreated abrasive.

**Summary of Phase 1 Industrial Hygiene Results**

In summary, while no single abrasive category had reduced levels of all health-related agents, all the substitutes offer advantages over silica sand with regard to respirable quartz. All but two of the alternative abrasive categories (crushed glass and specular hematite) have substantially higher levels of some other health-related agents, as compared to silica sand.

In addition, several generic categories had measured concentrations, and even GM concentrations, above the corresponding NIOSH REL and OSHA PEL. If workers were exposed to these concentrations for an eight-hour day, these prescribed limits would be exceeded. However, it must be recognized that there was considerable variability between the individual abrasives within a given...
generic category of abrasives.

These variations are likely the result of varying raw material sources (e.g., coal slags derived from different coal seams) or manufacturing processes (e.g., variations in copper or nickel smelting). Unfortunately, the data on the concentration of these contaminants in the virgin abrasive (on a percent by weight basis) was insufficient to establish definitive thresholds for use in materials selection, as described below.

For 110 out of 998 measured airborne concentrations of the eleven health-related agents above the LOD, the contaminant in the virgin bulk abrasives was non-detectable. Other sources of contamination may be possible (e.g., substrate to be blasted). However, data from the steel supplier suggest that iron (97.3%), manganese (0.96%), copper (0.01%), chromium (0.01%), nickel (0.01%), phosphorous (0.006%), molybdenum (0.004%), and vanadium (0.004%) should be the only contaminants in the substrate that was blast cleaned. Therefore, the substrate was not the source of the measured concentrations of health-related agents.

If a minimum threshold for each health-related agent could be established, selection of alternative abrasives based upon elemental analysis of virgin abrasives would be of benefit in identifying potential worker exposure levels. In order to do so, a statistically valid correlation between the concentration of the contaminant in the virgin bulk samples and the corresponding airborne concentrations must first be demonstrated in order for a selection criteria to be developed. The data from this study were not sufficient to evaluate this correlation.

**Industrial Hygiene Results—Phase 2**

The laboratory collected 64 airborne dust samples and 16 bulk samples of abrasive (pre- and post-run) for each of the 8 individual abrasives used during the Phase 2 field study. Once again, these samples were analyzed for the same 28 metals/elements, quartz, and cristobalite as in Phase 1, and the same 11 health-related agents were evaluated in detail. It is easiest to present the data for the health-related agents in direct comparison to corresponding results from Phase 1 so that the results for Phase 2 can be appreciated. Tables 1 through 4 present a comparison of the minimum, maximum, and geometric mean concentrations for paired sets of abrasives. That is, the results of the 8 abrasives run during
the field study are directly compared to the same individual abrasive from the laboratory study.

Based upon 8 abrasives and 11 health-related agents, there are 88 sets of paired data of GM airborne concentrations.

• 71 of 88 paired sets of data showed higher GM concentrations of the health-related agents during the field study.
• Of the 17 paired sets of data showing lower GM concentrations during the field study, 7 were from the copper slag abrasive and 7 were from steel grit. Coal slag had a lower concentration for one health-related agent, and staurolite had a lower concentration for two agents.
• The results for all 11 health-related agents were higher during the field study for nickel slag, silica sand with dust suppressant, garnet, and silica sand.

Several factors may have contributed to the trend for higher GM concentrations during the field study than during the laboratory study. One possible source is the potential for variation in the composition of the virgin abrasives, even though they were purchased from the same source. Phase 2 used abrasives from the same source but different batches since they had to be ordered at a later date. A comparison of the concentration of the 11 health-related agents in the virgin bulk abrasive for the laboratory and field studies was completed. While there were differences in concentrations between the materials, these differences did not correlate with the airborne concentrations. That is, the general trend for higher airborne concentrations during the Phase 2 field study does not necessarily correspond with an increase in the concentration of the health-related agent in the virgin bulk abrasive. In fact, in many instances, the concentration in the bulk material for the field study was the same or less than the bulk material for the laboratory study.

Other factors may have contributed to the trend for higher GM concentrations during the field study. The combination of increased volume of abrasive used per unit of time (because of the larger nozzle), in conjunction with the reduced cross-sectional airflow in the field study, may have contributed to the generally higher GM concentrations. Notwithstanding this observation, the data clearly reflect the conservative nature of the laboratory results. That is, artificial constraints were placed on the operating parameters during the laboratory study to improve the comparability of the data. Many of these constraints (e.g., nozzle size) were
removed during the field study to more closely approximate actual work site conditions. In general, field conditions resulted in higher concentrations of the measured health-related agents. This implies that the laboratory study may underestimate the potential for elevated airborne concentrations of the measured health-related agents.

Conclusions

Summary of Findings
While this study collected data on 30 potential contaminants, the analysis focused on 11 health-related agents selected by NIOSH: arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, respirable quartz, silver, titanium, and vanadium. While no single abrasive category had reduced levels of all 11 health-related agents, all the substitutes offer advantages over silica sand with regard to respirable quartz concentrations. All but two (crushed glass and specular hematite) of the alternative abrasives had higher levels of some other health-related agents, as compared to silica sand. There is considerable individual product variability within the generic types of abrasives evaluated, which limits the possibility of developing recommendations regarding airborne concentrations of hazardous health-related agents based upon broad generic categories of abrasives.

Implications of Study
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. This study demonstrates that worker exposures continued
to toxic metals in excess of the corresponding NIOSH and OSHA limits can also occur from contaminants found in the virgin abrasives. 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. Instead of the continued development of substance-specific comprehensive OSHA health standards (e.g., arsenic, lead, cadmium, etc.), consideration should be given to establishing a vertical health standard encompassing all health hazards associated with abrasive blasting operations to give industry a single set of guidelines or criteria necessary to properly protect workers.

**Fundamental Recommendations**

A series of recommendations was presented in both the Phase 1 laboratory study report and the Phase 2 field study report. In most instances, the basis and content to those recommendations were similar. The principal recommendations germane to both phases are repeated below.

- While no direct correlation has been established, comparison of the relative concentration of health-related agents in the virgin abrasive and assessment of the source of the raw materials and/or the manufacturing process should be used as initial selection criteria for all of the abrasives and in particular for coal slag, nickel slag, copper slag, garnet, and steel grit abrasives.

- Given the potential exposures to multiple contaminants from both the abrasive and 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 or existing coatings for all possible metals.

**Additional Research**

This study also identified the need for additional research. The recommended studies should be used as follows.

- Investigate the relationship between the concentration of quartz in silica sand abrasives with airborne concentrations of other hazardous health-related agents, including an assessment of relative health risks. That is, what effect does a change in the concentration of quartz in the virgin abrasive make on the airborne
concentrations of the health-related agents?

- 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 criterion.
- Conduct further evaluations of crushed glass, staurolite, specular hematite, and olivine because this study evaluated only one supplier of each of these abrasives. (Note that staurolite and specular hematite are each provided from only one source.)
- 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 comparability of the study and introduce subjective design criteria, these detractions will result in improved cleaning rate, consumption rate, and cost data.
- Collect information from the field on other types of steel structures in order to expand the available database. Representative structures in the marine, water/wastewater, transportation, and industrial sectors should be included in these studies.

Copies of the full report are available through the National Technical Information Services (NTIS) at 1-800-553-6487. Portions of the full reports will also be available at the NIOSH home page at http://www.cdc.gov/niosh/home-page.html.

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