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Exposure to silica dust was studied in the grinding of castings in a steel foundry that used conventional personal sampling methods and new real-time sampling techniques developed for the identification of high-exposure tasks and tools. Approximately one-third of the personal samples exceeded the National Institute for Occupational Safety and Health recommended exposure limit for crystalline silica, a fraction similar to that identified in other studies of casting cleaning. Of five tools used to clean the castings, the tools with the largest wheels, a 6-in. grinder and a 4-in. cutoff wheel, were shown to be the major sources of dust exposure. Existing dust control consisted of the use of downdraft grinding benches. The size of the casting precluded working at a distance close enough to the grates of the downdraft benches for efficient capture of the grinding dust. In addition, measurements of air recirculated from the downdraft benches indicated that less than one-half of the respirable particles were removed from the contaminated airstream. Previous studies have shown that silica exposures in the cleaning of castings can be reduced or eliminated through the use of mold coatings, which minimize sand burn-in on the casting surface; by application of high-velocity, low-volume exhaust hoods; and by the use of a nonsilica molding aggregate such as olivine. This study concluded that all these methods would be appropriate control options.

As part of the intervention phase of the New Jersey Department of Health (NJDOH) silicosis surveillance program,[1–3] the Occupational Health Service (OHS) conducts follow-up investigations at all companies identified as having one or more cases of silicosis. As a result of several reported cases of silicosis, a site visit to a steel foundry was conducted. The visit revealed potential employee overexposure to crystalline silica throughout the plant. In November 1989, researchers from the Engineering Control Technology Branch (ECTB) of the National Institute for Occupational Safety and Health (NIOSH) conducted a joint study of this facility with NJDOH. The purpose of this study was to determine if current workers were at risk of developing silicosis by identifying and evaluating worker exposures to silica-containing dusts; to evaluate and recommend improvements in current engineering controls and work practices so that future cases of silicosis could be eliminated; and to determine if these recommended control measures could be applied in similar situations. Because the largest number of workers was engaged in casting cleaning, this area of the foundry received special attention.

Grinding of ferrous castings has long been associated with overexposure to crystalline silica.[4–8] These studies indicated that about one-third of grinding personnel are exposed to free silica in excess of the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL).

*Disclaimer: Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

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Hand-held grinders are used in the cleaning rooms of foundries to remove gate and riser connections, parting-line fins, and other imperfections from large castings. The grinding operation produces a dust cloud in the breathing zone of the operator. The major dust hazard in grinding castings arises from the molding sand, which adheres to the casting surface. Even when castings have been well cleaned by blasting with steel shot, the surface will still contain some silica from the molding sand. When the casting is ground, this silica is shattered and part of it becomes airborne. Large particles leave the wheel more or less tangentially from the point of contact with the casting. Smaller particles are entrained in the wake of these large particles. Other fine particles do not separate appreciably from the wheel and are contained in a layer of air close to the wheel.[9]

PLANT DESCRIPTION

This plant was a captive foundry producing steel and stainless steel castings. Production was divided into approximately 40% steel and 60% stainless steel castings. Induction furnaces were used to melt and adjust the alloys. The foundry produced molds with an alkyd-oil (drying oil/isocyanate) molding system. Zircon- and silica-based washes were used on molds and cores. In general, patterns were waxed to facilitate mold removal, although some nonsilica parting compounds were used. After shakeout and cooling, large casting appendages were removed by means of an oxygen torch in one of two ventilated booths; remaining extraneous material was removed by an arc-air torch in a second booth. A swing frame grinder and cutoff saw (both contained in booths) also were used. Castings were cleaned automatically by steel shot in an abrasive blasting machine or manually by sand blasting in a walk-in cabinet. Additional material was removed from castings primarily by hand-held grinders used on downdraft benches. These benches recirculated filtered air back into the foundry. The benches consisted of L-shaped plenum chambers and metal gratings on which the castings were placed. Flow rates for the grinding benches (measured 150–300 ft/min) were generally above those recommended (150–250 ft/min) in the American Conference of Governmental Industrial Hygienists (ACGIH) publication *Industrial Ventilation: A Manual of Recommended Practice*.[10] The lower part of this plenum supported the grating and served as a drop-out chamber for cleaning debris. The upper section contained primary and secondary sets of filters (efficiency rating unknown), followed by a propeller fan.

METHODOLOGY

A three-part strategy was employed to evaluate the silica risk and to identify control options for the cleaning of castings. First, 15 personal samples for crystalline silica and respirable dust were collected to estimate the exposure to workers who performed chipping and grinding operations using hand-held tools. Second, real-time measurements were made on two workers to determine which tools and procedures were the primary exposure sources so that control efforts could be prioritized. Last, the removal efficiency of the air recirculation system employed in the downdraft benches was measured. The latter procedure was undertaken to determine if dust captured by the bench was re-entering the work room.

Silica Dust

Time-integrated samples were collected in the breathing zone of hand grinder operators for a full-day shift generally lasting about 7 hr (depending on individual work schedules). Workers were sampled for three consecutive days. These samples were collected on preweighed, 37-mm (diameter), 5-μm (pore size) PVC membrane filters (FWSB, Mine Safety Appliances, Pittsburgh, Pa.) mounted in series with 10-mm nylon cyclones (Mine Safety Appliances). Air was drawn through the filter at a flow rate of 1.7 L/min by using battery-powered sampling pumps (Air Check Sampler, Model 224-PC X R7, SKC Inc., Eighty Four, Pa.).

All filter samples were weighed according to NIOSH Method 0500 and analyzed for crystalline silica content by x-ray diffraction with a modification of NIOSH Method 7500.[11] These modifications were as follows. (1) Quartz quantities were calculated by using secondary quartz standards and the sample's secondary peak intensity. (2) Cristobalite quantities were calculated by measuring primary peak height values of the cristobalite standards and the samples rather than by using the integrated peak areas. The limit of detection (LOD) and the limit of quantification (LOQ) for the samples were 0.015 mg and 0.03 mg per sample, respectively, for both quartz and cristobalite.

Real-Time Measurements

Sampling and analytical methods currently used for fibrogenic dusts are, for the most part, limited to long sampling periods. To determine when dust was generated and which specific tasks or tools were responsible, air sampling was complemented by real-time dust exposure measurements and video recordings.[12] These measurements were made on workers performing chipping and grinding operations in order to determine the relative exposure caused by different tools and operations and to examine the possibility of control by using high-velocity, low-volume (HVLV) exhaust hoods. The instrument used to measure dust concentration was a hand-held aerosol monitor (HAM, PPM, Knoxville, Tenn.). This instrument is a light-scattering device; its response is dependent upon the optical characteristics of the dust being measured. The HAM responds to respirable dust but does not differentiate between crystalline silica and other dusts. The analog output of the HAM was connected to a data logger (Rustrak Ranger, Gulton, East Greenwich, R.I.). When the data collection was completed, the data from the data logger were downloaded to a portable computer (Compaq Portable II, Compaq Computer Corporation, Houston, Tex.) for analysis.

Two workers volunteered to participate in the real-time monitoring. Each worker selected a casting that required the use of a variety of tools. One selected a pump housing; the other selected an impeller. Each worker used a 6-in. horizontal radial wheel grinder (6000 rpm), a 4-in. cutoff wheel (15 000 rpm), and a 3/8-in. diameter burr mounted on a 16-in. extension (18 000 rpm). The worker cleaning the impeller also used a cone wheel mounted on the same type of tool as the 4-in. cutoff wheel. Each tool was pneumatically powered and the tool exhaust was unmuffled. Dust exposures and video recordings were made for 30 min on each worker.

Exhaust Air Recirculation

The performance of exhaust air recirculation systems was evaluated by using a Royco portable optical particle counter (Royco Instruments, Menlo Park, Calif.). This instrument counts and sizes dust particles by measuring the amount of light scattered as individual particles enter a sensing volume. A single-channel pulse analyzer allows all particles greater than a selected size to be counted. By repeated measurements at different minimum sizes, a particle size distribution can be obtained.

Particle size distribution measurements were made at the inlet and outlet of two grinding benches to determine the removal efficiency of the filter system. The design of the bench precluded the collection of a representative sample during grinding: dust from the grinders was projected into a short plenum connected directly to the filter chamber, which did not permit uniform mixing of the dust with the exhaust air. In addition, the grinding operation did not produce dust at a constant rate. Because of these difficulties, bench performance was measured by using the ambient aerosol present in the casting cleaning department as the test aerosol. Use of ambient aerosol as a challenge dust is a technique that has been used in respirator fit testing.[13] The fan of the first bench was on at the time of the test and visual inspection of the filters indicated that they were intact. The second bench had secondary filters missing, and the fan was first switched on about 5 min before the test.

RESULTS

Silica Exposure

Of the 15 personal samples, 4 exceeded the NIOSH recommended exposure limit[14] (REL) of 50 μg/m³ for quartz; none exceeded the OSHA PEL[15] of 100 μg/m³ for quartz. One sample exceeded both the REL and PEL for cristobalite (50 μg/m³) by a factor of 2; all of the remaining air samples collected contained no detectable respirable quartz or cristobalite, corresponding to an airborne concentration of approximately <20 μg/m³. Table I summarizes the results of the crystalline silica and respirable dust measurements.

TABLE I. Worker Exposure to Respirable Crystalline Silica and Respirable Dust

Grinder	*Time (min)*	*Mass (mg/m³)*	*Quartz (μg/m³)*	*Cristobalite (μg/m³)*
0	424	0.9	47	ND[A]
0	433	0.7	69[B]	ND
1	410	0.2	ND	ND
2	412	0.7	97[B]	ND
2	438	0.8	ND	ND
3	419	0.4	ND	ND
3	438	2.2	91[B]	94[B]
4	415	1.1	48	ND
4	435	1.0	46	ND
5	421	0.3	ND	ND
5	435	0.7	69[B]	27
6	416	0.2	48	ND
7	433	0.5	46	ND
8	419	0.4	ND	ND
9	420	0.2	ND	ND

[A]ND: none detected.
[B]Values in excess of NIOSH REL.

Exposure Sources

Real-time dust exposure data were overlayed as a moving bar onto the video recording[16] and viewed for preliminary determination of the activities that may have affected exposure. This review indicated that the type of tool used, the direction of the grinding swarf (the stream of glowing metal particles), and the position of the tool (inside or outside of the casting) caused

TABLE II. Summary of Real-Time Dust Exposure Measurements

Exposure Source	*Concentration (mg/m³)*	*Time (sec)*	*Integrated Exposure (mg/m³-min)*
Casting: Pump Housing			
Tool			
6-in. grinder	5.1	375	32
4-in. wheel	7.1	470	55
Burr grinder	0.9	165	2
Other activities	0.9	470	7
Tool Location			
Inside casting	5.7	505	48
Outside casting	4.9	505	41
Other activities	0.9	470	7
Swarf Direction			
Up	8.6	340	49
Down	1.4	175	4
Away	4.9	230	19
Toward	9.4	100	16
Undetermined	0.9	635	10
Casting: Impeller			
Tool			
6-in. grinder	1.5	270	7
4-in. wheel	0.1	270	1
Burr grinder	0.2	375	1
Cone grinder	0.5	395	3
Other activities	0.2	215	1
Tool Location			
Inside casting	0.3	1040	5
Outside casting	1.5	270	7
Other activities	0.2	215	1
Swarf Direction			
Up	0.2	20	0
Down	0.9	240	3
Toward	6.7	30	3
Undetermined	0.3	1235	6

noticeable exposure differences. To estimate the extent to which these variables affected exposure, the real-time data were assembled into a commercial spreadsheet consisting of time, exposure, and activity for each 5-sec time period. The exposure measurements were "slipped" 5 sec with respect to the time and activities to allow for instrument delay. The average exposure, the time, and the cumulative exposure (the product of concentration and time) were calculated for each of the activity variables.

Summary data are presented in Table II. The average dust concentration for each tool type and the percentage of the time each tool was used are presented in Figure 1. During cleaning of the pump housing, dust concentrations were highest for the 6-in. grinder and the 4-in. cutoff wheel. For the impeller, dust concentrations were highest for the 6-in. grinder and the cone grinder. The cone grinder was not used on the pump housing. The cumulative exposure is described graphically in Figure 2 as a function of tool type, tool location, and swarf direction. The cumulative exposure was almost an order of magnitude greater for the pump housing than for the impeller. The 4-in. cutoff wheel was the greatest contributor (57%) to cumulative exposure for the worker cleaning the pump housing; the 6-in. grinder was the greatest contributor (54%) to the cumulative exposure for the worker cleaning the impeller. Cleaning the inside of the casting appeared to have a beneficial effect on cumulative exposure for the case of the impeller: although the worker spent about five times as long cleaning the inside of the casting as the outside, inside cleaning only resulted in about 39% of the total cumulative exposure for this worker. This beneficial effect may be caused by the impeller diffusing the grinding swarf. Swarf direction appeared to be a major exposure factor: for the pump housing, concentrations ranged from highest to lowest in the order of "toward," "up," "away," "down," and "undetermined." For the impeller, only minimal periods were observed where the swarf was directed "up," or "away."

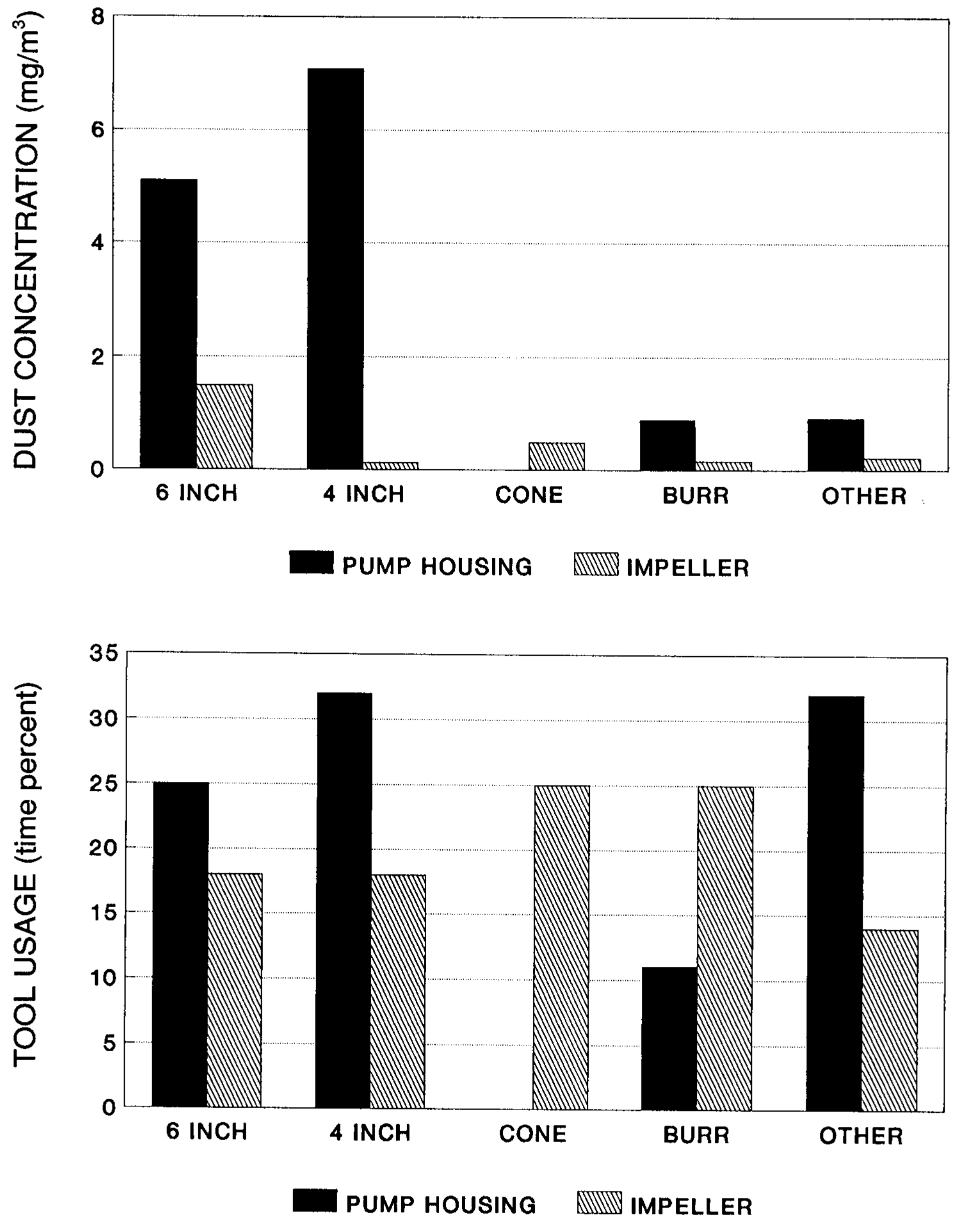

FIGURE 1. Average dust exposure and tool usage during the cleaning of the pump housing and impeller castings

Because not all combinations of variables were present, each existing combination was assigned as an individual independent variable (combination of tool, position, and swarf direction) for statistical analysis. The logarithm of the exposure was the dependent variable. The SAS General Linear Models Procedure[17] was used to fit the data. The Ryan-Einot-Gabriel-Welsch (REGW) Multiple Range Test[18] was used to determine if significant differences (alpha = 0.05) existed between the log mean exposure for each independent variable. The results of the analyses are presented in Table III. The combinations of tool, grinding location, and swarf direction are listed in order of exposure from highest (top) to lowest (bottom). Those combinations with the same letter assigned by the REGW test are not significantly

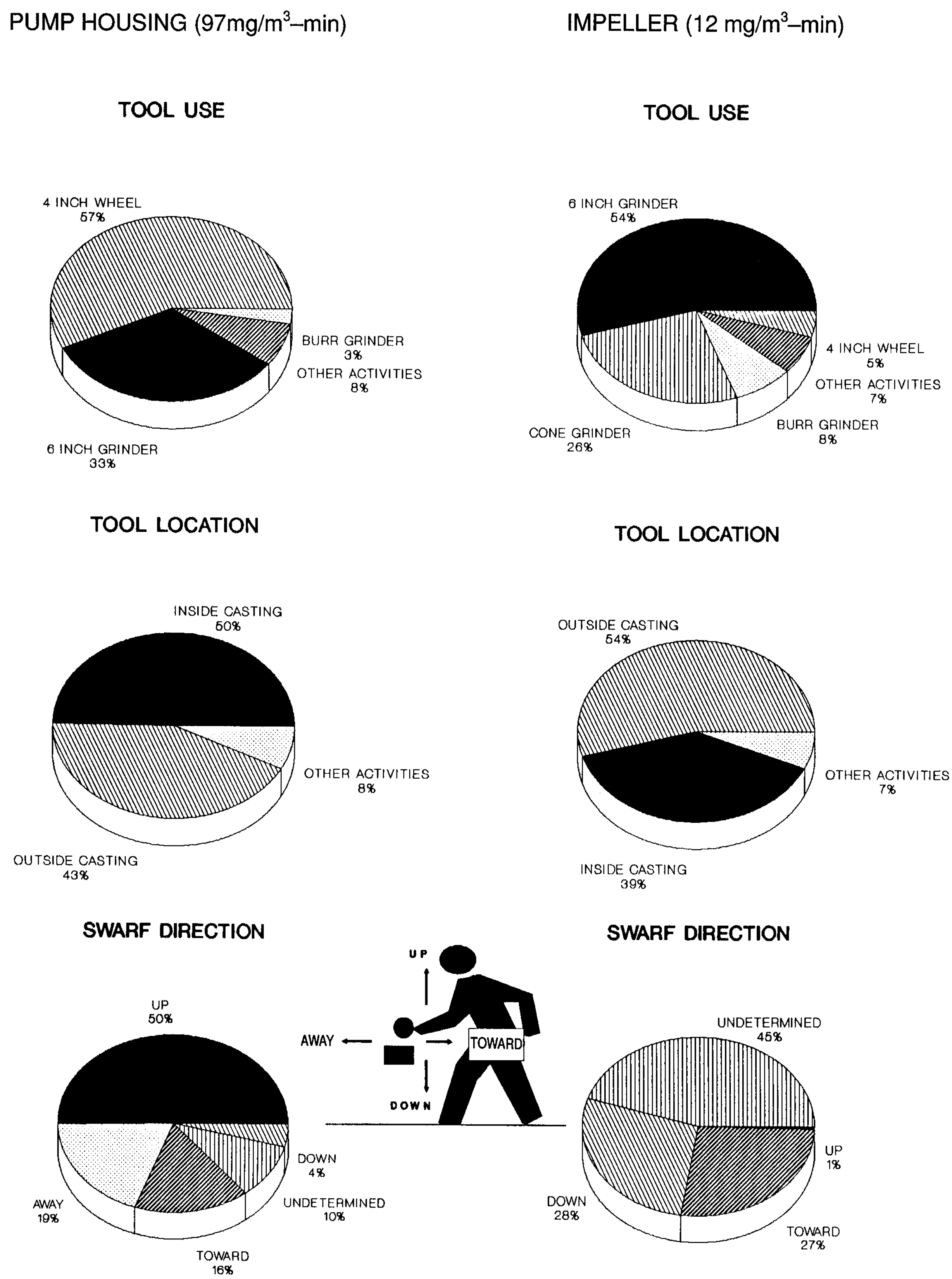

FIGURE 2. Analysis of dust exposure during the cleaning of the pump housing and impeller castings

different. These analyses indicate that the tools with the larger wheels cause more exposure than the smaller tools and that the greatest exposure occurred when the direction of the grinding swarf was directed back into the breathing zone.

Exhaust Air Recirculation

Overall particle penetration from the bench with intact filters was 56% for particles greater in size than about 0.5 μm (based on the factory calibration). For the bench with missing filters, the overall particle penetration was 113%. This increase in the number of particles may be caused by errors in measurement because simultaneous inlet and outlet measurements were not possible. The increase also may be caused by the release of dust that had settled into the outlet of the bench because the bench had been operating for only 5 min prior to the test. Results of the particle size distribution measurements are reported in Figure 3.

CONCLUSIONS

Overexposure to crystalline silica did not appear consistently throughout the cleaning department. The four samples exceeding the NIOSH REL for crystalline silica were on four different workers. Three of these four workers had another sample that was below the NIOSH REL. This suggests that some uncontrolled process variable (such as sand burn-in) or other casting differences such as size and shape may be responsible for exposure variability rather than individual work practices. The fraction of samples exceeding the NIOSH REL was similar to that identified in other studies of casting cleaning.[5-7] Thus, it may be inferred that the operations and silica exposures at this plant are typical of other ferrous foundries and the findings for this plant in regard to control measures could be applicable to other facilities.

In the cleaning of castings, silica exposure may be a function of the degree (although not easily quantifiable) of sand burn-in (and subsequent conversion to cristobalite) of the individual casting. The size of the casting may preclude working at a distance close enough to the grates of downdraft benches for efficient capture of the grinding dust, as the capture velocity drops off rapidly with distance above the grate. The real-time measurements indicated that the type of tool used, the direction of the grinding swarf, and the position of the tool (inside or outside of the casting) caused noticeable exposure differences. The 6-in. grinder and the 4-in. cutoff wheel, the largest grinders used, were the tools that contributed most heavily to dust exposure. Fortunately, designs for high-velocity, low-volume exhaust hoods are available for both of these tools.[10,19]

To minimize the hazard from sand burn-in, castings should be as clean as possible before grinding. The use of various mold surface coatings can reduce the amount of sand that is burned into the surface of the casting. Substitution of olivine sand has been shown to reduce the incidence of silicosis.[20] For conditions similar to those found in the foundry discussed herein, olivine could be substituted with little or no change in operations, as it is compatible with the alkyd-oil binder system that was used. This would involve increased cost of molding aggregate when compared to silica sand but may reduce dust control costs.

As is the case in many foundry cleaning rooms,[6] the exhaust from the downdraft tables was recirculated back into the foundry that was studied. Detailed recommendations for air recirculation and downdraft bench airflow requirements are contained in *Industrial Ventilation: A Manual of Recommended Practice*.[10] Measurements of dust removal efficiency indicated that an improperly maintained bench offered no protection and that even an apparently well-maintained bench removed less than half of respirable-sized dust particles. Therefore, the grinding benches in this plant could be redesigned by upgrading the filter efficiency to ensure the effective removal of dust particles from the exhaust air prior to recirculation or the exhaust air could be vented into a duct system discharging outdoors (according to federal, state, and local codes) through a central dust collection unit.

TABLE III. Ryan-Einot-Gabriel-Welsch (REGW) Multiple Range Test for Concentration/Activity Data[A]

REGW Group	*Log Mean*	*N*	*Combination*[B]
Casting: Pump Housing			
A	2.673	2	SOT
A	2.294	2	GOU
B A	2.080	3	GIU
B A	1.743	5	SOU
B A	1.682	58	SIU
B A	1.669	17	GOA
B A	1.612	18	GOT
B C	1.130	7	SIA
D C	0.597	22	SOA
D E	−0.119	35	GOD
E	−0.455	33	BIN
E	−0.617	94	NNN
Casting: Impeller			
A	1.816	6	GOT
B	−0.643	48	GOD
C	−1.024	75	CIN
D	−1.622	4	CIU
D	−1.847	43	NNN
D	−1.918	75	BIN
E	−2.267	54	SIN

[A]Means with the same letter are not significantly different.

[B]Key to combinations:

1st letter tool	2d letter grinding location	3d letter swarf direction
G: 6-in. grinder	I: inside casting	T: toward worker
S: 4-in. cutoff saw	O: outside casting	A: away from worker
C: cone grinder	N: other activity	D: down
B: burr grinder		U: up
N: other activity		N: undetermined or other activity

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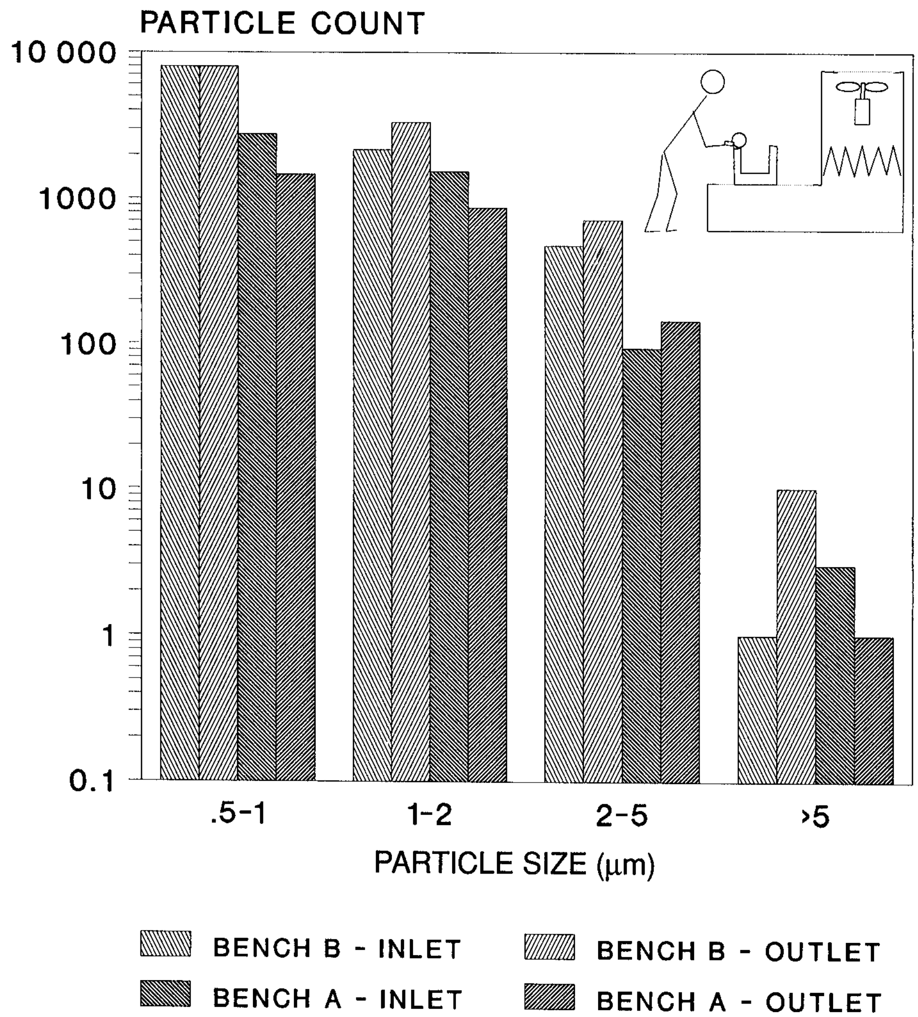

FIGURE 3. Particle size distributions from the downdraft grinding benches. Bench A had filters installed with no visible signs of leakage. Booth B had some secondary filters missing.

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