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To cite this article: Michael G. Gressel (1997) An Evaluation of a Local Exhaust Ventilation Control System for a Foundry Casting-Cleaning Operation, American Industrial Hygiene Association Journal, 58:5, 354-358, DOI: [10.1080/15428119791012711](https://doi.org/10.1080/15428119791012711)

To link to this article: <http://dx.doi.org/10.1080/15428119791012711>



Published online: 18 Jun 2010.



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An Evaluation of a Local Exhaust Ventilation Control System for a Foundry Casting-Cleaning Operation

A study was conducted to evaluate the effectiveness of a local exhaust ventilation system for a foundry casting-cleaning operation in which a worker cleaned gray iron castings using a variety of handheld chipping and grinding tools. The operation originally had an exhaust system consisting only of an exhaust duct terminating approximately 1 m (3 ft) above the floor and 2 m (6 ft) from the casting-cleaning workstation. An earlier evaluation of this original control system found time-weighted average exposures to respirable silica ranging from 124 to 160 $\mu\text{g}/\text{m}^3$. The local exhaust ventilation system evaluated in this present study consisted of a downdraft booth outfitted with a turntable for manipulating the castings. The modified local exhaust ventilation system was installed at this facility and connected to the existing plant exhaust ventilation system through the original ductwork. A direct-reading instrument was used to measure the operator's respirable aerosol exposure concentrations during a single day both before and after the installation of the new workstation. The same worker was sampled both times. The operator's activities were recorded on videotape so that the exposures associated with the various tools could be determined. While day-to-day variability could not be accounted for, depending on the type of tool used the local exhaust ventilation system reduced exposures by 59 to 79% during casting cleaning by the sampled worker when compared with the original configuration. These reductions were statistically significant.

Keywords: foundry operations, silica, ventilation

In February of 1992 a Centers for Disease Control and Prevention Health Hazard Evaluation (HHE) was conducted at a foundry in Cincinnati, Ohio, in response to a management request to evaluate worker exposures to airborne contaminants (primarily crystalline silica).⁽¹⁾ This gray and ductile iron foundry, housed in a masonry building, operated one shift with 32 employees. This foundry manufactures small castings, typically less than 100 lbs. The HHE survey evaluated operations throughout the plant, including personal sampling of respirable silica exposure concentrations. The survey results showed high respirable silica exposure concentrations for the workers in a number of areas, including casting-cleaning operations, ranging from 124 to 160 $\mu\text{g}/\text{m}^3$ for an 8-hour time-weighted average (TWA). The results

of this survey, along with the results of other studies,^(2,3) indicated that respirable silica exposure concentrations were not well controlled during casting-cleaning operations. The purpose of the work described in this article was to evaluate the effectiveness of a ventilation control for reducing the silica exposure concentrations during the casting-cleaning operation.

BACKGROUND

Most foundry castings use molds made from a sand and binder system. The binder allows the sand particles to adhere to one another so the molds can be shaped. The facility where this study was conducted used green sand molds (a mixture of silica sand, clay, water, and coal dust). For complicated castings, cores can provide void spaces in the castings.

After the molds are assembled, they are filled with molten metal. The methods for pouring molds vary greatly with the size and type of

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foundry. Following the mold-pouring process, the castings are allowed to cool and then removed from the molds in a process called "shakeout." As with pouring operations, shakeout operations vary greatly with the type and size of the foundry. After shakeout, the casting may be placed in a shot blast machine to remove most of the sand adhering to the new casting. However, some sand will be embedded or burned into the casting. To remove the sand, the castings are cleaned by hand using pneumatic chipping and grinding tools. These same tools are used to remove the sprues and runners from the castings.

The grinding and chipping of the sand produces airborne respirable silica particles, which may present an inhalation health hazard to workers if not adequately controlled. The workers use a variety of tools, including cup grinders, cone grinders, pneumatic chisels, and abrasive wheels to clean the castings. In a study conducted at a stainless steel foundry, work practices—specifically, the direction of the grinding swarf—were found to have a significant impact on the workers' exposure to airborne contaminants.⁽³⁾ Methods for controlling airborne hazards from this operation vary from one foundry to the next. Many plants have no controls or ineffective controls, such as a poorly designed ventilated table.^(2,3)

The employees who cleaned the castings at the Cincinnati facility used National Institute of Occupational Safety and Health/Mine Safety and Health Administration-approved air-purifying respirators with high efficiency particulate air filters. These respirators were incorporated into a helmet with built-in face shields. Safety shoes and safety glasses were required throughout the plant.

The health effects of silica exposures are well known. Silica may be present in at least three crystalline forms (alpha quartz, cristobalite, and tridymite), as well as amorphous (noncrystalline) forms. Amorphous silica is usually considered to be of low toxicity and, if inhaled, over time may produce X-ray changes in the lung without significant disability.^(4,5) The crystalline forms of silica, the type found at this facility, can cause severe lung disease, known as silicosis, when inhaled. Symptoms such as cough, shortness of breath, chest pain, weakness, wheezing, and nonspecific chest illness often involving cardiac complications, usually develop insidiously. Silicosis usually occurs after years of exposure but may appear in a shorter time if exposures are very high, such as from unprotected sandblasting.

The current Occupational Safety and Health Administration 8-hour TWA permissible exposure limits (PEL)⁽⁶⁾ for respirable dust containing crystalline silica is calculated from Equation 1.

$$PEL = \frac{10 \text{ mg/m}^3}{\%SiO_2 + 2} \quad (1)$$

This PEL depends on the percentage of crystalline silica in the dust. For example, if a dust sample were 100% crystalline silica, the PEL for that dust would be 98 $\mu\text{g}/\text{m}^3$ TWA. For a sample containing no crystalline silica, the PEL would be 5000 $\mu\text{g}/\text{m}^3$.

The National Institute for Occupational Safety and Health has set its recommended exposure limit (REL)⁽⁴⁾ for respirable crystalline silica at 50 $\mu\text{g}/\text{m}^3$ TWA. The standards-setting procedures for the PELs are required to consider the feasibility of controlling exposures; the RELs, by contrast, are based primarily on health concerns relating to the prevention of occupational disease. The American Conference of Governmental Industrial Hygienists has set the threshold limit value (TLV[®]) for respirable quartz at 100 $\mu\text{g}/\text{m}^3$ TWA and for respirable cristobalite and tridymite at 50 $\mu\text{g}/\text{m}^3$ TWA.⁽⁷⁾

The exposure limits are presented to provide a perspective on the exposures associated with the operation studied. Data from the

HHE conducted at this plant suggested that respirable silica exposures from the casting cleaning (124 to 160 $\mu\text{g}/\text{m}^3$) exceeded the exposure limits discussed here. The potential for adverse health effects resulting from these exposures indicated a need for intervention to reduce personal exposures.

STUDY DESIGN

The overall goal of this study was to evaluate the effectiveness of a newly installed control system as compared with the original system. This was accomplished by determining (1) the overall and by-tool exposures for each sampling period and (2) if the differences between the exposures for the sampling periods were statistically significant. The study design consisted of two sampling periods occurring on different days: a preintervention period with the old workstation installed and a postintervention period with the ventilated workstation installed. While this study design does not control for between-day differences, previous studies using similar methods suggest that worker activities have a greater impact on the exposure concentrations than the day the sampling was conducted.^(3,8) In addition, while the mix of tools used varied from one casting to another, the individual tools were used in a similar fashion both between and within visits. Simply stated, the manner in which the tools were used during the two visits was representative of the tool use at this facility. For this evaluation, the same worker operated the tools during both visits. No evaluation of differences between workers was attempted.

The operator used the following four tools when cleaning castings: a 6-inch cup grinder, an in-line cone grinder, a 9-inch cutoff wheel, and a pneumatic chisel. Exposure measurements for each sampling period were analyzed to determine the overall effect of the ventilated workstation. In addition, the exposure measurements for each activity (tool used) were analyzed to compare similar activities between the two sampling periods. This analysis will determine the effects of the ventilated workstation on the exposures associated with the use of the four different tools.

VENTILATION CONTROL DESIGN

The ventilation control system evaluated in this study was a down-draft booth. The primary benefit of this design is that it draws the air contaminant (silica) away from the worker's breathing zone. A secondary benefit of the workstation control was that it enclosed the silica dust source and reduced the spread of the airborne contaminant to other areas of the plant.

Figure 1 is a diagram of the newly installed ventilation control system. The system consisted of a booth with exhaust ventilation at the back of the work surface, a design shown in the American Conference of Governmental Industrial Hygienists' *Industrial Ventilation—A Manual of Recommended Practice*.⁽⁹⁾ The table surface was approximately 5 ft long and 2.5 ft deep. A turntable, shown in Figure 2, allowed the worker easy access to the various surfaces of the casting when grinding. A photograph of the workstation with the turntable, as installed at the foundry, is shown in Figure 3.

Another branch of this ventilation system furnished exhaust ventilation to a cutoff saw, located elsewhere in the facility. A damper on this branch was opened when this saw was in use. The original ventilation system consisted of a 12-inch diameter exhaust duct terminating approximately 6 ft from the grinding table. The flow rate through this duct was approximately 5600 ft³/min when

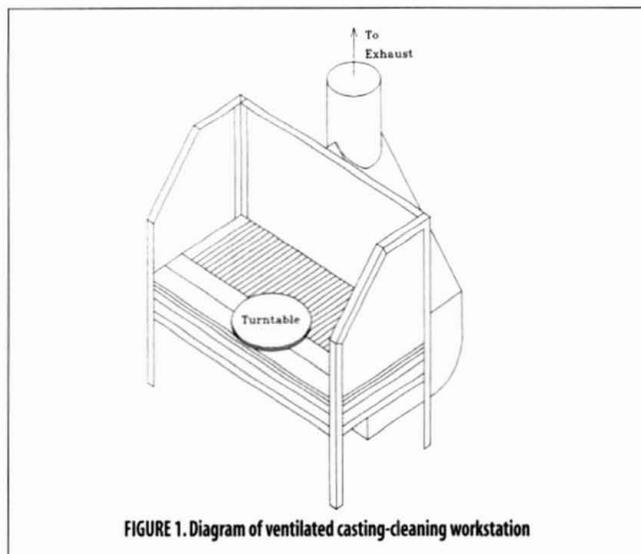


FIGURE 1. Diagram of ventilated casting-cleaning workstation

the damper to the saw branch was closed and 3200 ft³/min with the saw damper opened. Airflow measurements with the new workstation table installed showed that the exhaust volume was

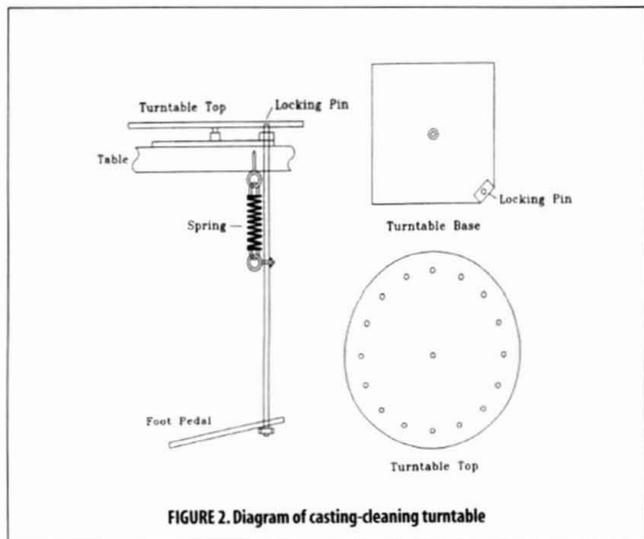


FIGURE 2. Diagram of casting-cleaning turntable

approximately 5400 ft³/min when the damper of the saw branch was closed and approximately 2900 ft³/min when this damper was opened. Both of these flow rates were above the minimum recommended in *Industrial Ventilation*.⁽⁹⁾ All occupational exposure

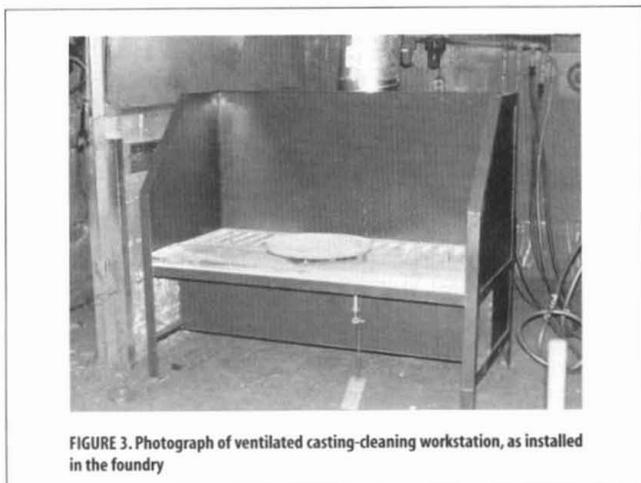


FIGURE 3. Photograph of ventilated casting-cleaning workstation, as installed in the foundry

measurements were made at the higher flow setting with the saw branch damper fully closed.

SAMPLING METHODS

A direct-reading instrument was used to measure respirable dust as a surrogate for respirable silica. This instrument, the Hand-Held Aerosol Monitor (HAM) (PPM Inc., Knoxville, Tenn.), is a light-scattering device that responds to any dust of respirable size. The response, however, depends on the nature of the contaminant (particle shape, refractive index, etc.). Measurements taken during the earlier HHE evaluation showed that the workers performing this operation were overexposed to silica. The concern of this study was the differences between the workstation configurations. Therefore, the data from the HAM was used as a relative measure of the worker's respirable silica exposure. However, it was assumed that both the percentage concentration of silica and the particle size distribution in the airborne dust remained relatively constant over all sampling runs.

When sampling, the optics probe of the HAM was placed near the worker's breathing zone. To improve the instrument response, the HAM was operated in an active mode, using a sampling pump (calibrated to 2 L/min) to draw air through the sensing chamber. The active mode improved the response since the instrument did not have to rely on ambient air currents to transport the airborne contaminant into the instrument.

The output from the HAM was connected to a Rustrak Ranger I data logger (Rustrak, East Greenwich, R.I.) for data collection and storage. The data were recorded and stored at 1-sec intervals. The data logger was downloaded to a personal computer, where the data were subsequently analyzed.

The sampling operation was recorded on videotape to document tool usage during the sampling periods. The camera clock was synchronized with the clock of the data logger so that the activities recorded on tape could be matched with the exposure data. Following sampling, the video recordings were reviewed and tool usage variables were entered into the exposure data file.

RESULTS AND DATA ANALYSIS

The preintervention sampling period yielded over 8500 measurements during casting cleaning. (The operator spent over 8500 sec using any one of four grinding tools during this period.) The postintervention period resulted in over 3100 readings. In the postintervention sampling period, the worker used two different pneumatic chisels, one of which was not used in the first sampling period. Exposure data collected during the use of this additional chisel were excluded from the analysis of the other chisel data.

Since a nonspecific direct-reading instrument was used to measure exposure concentrations, exposures listed are not actual concentrations but are concentrations relative to other measurements made in this study. Because of instrument and environmental response issues, the data were adjusted for a transportation lag of 5 sec.⁽¹⁰⁾ By reviewing the video recording, casting variables (casting number) and activity variables (tool usage) were coded and entered into the data set. Exposure measurements for each tool were averaged for each casting cleaned (i.e., measurements for cup grinder on the first casting were averaged, cone grinder on the second casting, etc.). This reduced the original data set to 49

measurements before and 15 measurements after the installation of the workstation. These data were then log-transformed, and the geometric mean and geometric standard deviation were determined for the overall exposures and by-tool exposures for each sampling period. These results are given in Table I. In addition, Table I also gives the percentage reduction in the operator's dust concentration due to the ventilated workstation.

TABLE I. Geometric Means and Geometric Standard Deviations for Preintervention and Postintervention Relative Exposures

	Preintervention			Postintervention			% Reduction Pre-versus Post-
	n ^A	GM ^B	GSD ^C	n	GM	GSD	
Overall grinding	49	0.14	3.04	15	0.039	4.77	72%
Cup grinder	21	0.23	2.34	3	0.052	1.20	77%
Cone grinder	21	0.066	1.71	5	0.027	1.38	59%
Cutoff wheel	5	0.78	2.12	3	0.20	1.72	75%
Pneumatic chisel	2	0.027	1.60	4	0.015	13.6	46%

Note: Differences for the pneumatic chisel were not statistically significant.

^An = number of measurements

^BGM = geometric mean

^CGSD = geometric standard deviation

The data were analyzed to determine if the differences between the geometric means were significant using the Multivariate analysis of variance (ANOVA) function in Statgraphics[®] Plus for Windows,™ Version 1.4 (Manugistics, Inc., Rockville Md.), a statistical analysis program. The analyses were conducted in two different steps. First, the ANOVA was run to look at the difference between the preintervention and postintervention measurements regardless of the tools used. The second series of analyses looked at the differences by tool and was run by repeating the first analysis excluding the data for all but the tool of interest. This was repeated for each of the four tools used.

The results of these analyses show that, overall, the new ventilated workstation significantly reduced the worker's exposure ($p < 0.0008$). In addition, statistically significant reductions were determined for the cup grinder ($p < 0.0073$), the cone grinder ($p < 0.0017$), and the cutoff wheel ($p < 0.0001$). Exposures were reduced for the pneumatic chisel at the ventilated workstation, but the difference was not statistically significant ($p < 0.3334$).

CONCLUSIONS AND RECOMMENDATIONS

The results of the sampling in this facility indicate that the installation of the ventilated workstation produced a statistically significant decrease in the airborne dust concentrations. On a tool-by-tool basis, the ventilated workstation significantly reduced measured dust exposures when the worker used the cup grinder, the cone grinder, and the cutoff wheel. The percentage reduction by tool ranged between 59 and 77% (see Table I). There was no statistically significant difference in the exposures when the pneumatic chisel was in use. These concentrations were also among the lowest of all the exposures, indicating that little dust was generated by this tool. The TWA exposures for workers using this ventilated workstation are also expected to decrease correspondingly, since tool operation was the primary source of silica exposure. The magnitude of the exposure reduction will depend on tool usage.

The tool-by-tool evaluation of the workstation was a better measure of the effectiveness of the workstation than the overall comparison. The overall comparison depended on the tools used

during the cleaning of the castings, and hence, on the mix of castings cleaned on any given day. The tool-by-tool evaluation resulted in a direct comparison of each tool with and without the new ventilation control. The same worker cleaned the castings for both evaluations; work practices for both evaluations were also similar.

The results of this study, along with the findings of a study conducted in a stainless steel foundry,⁽³⁾ indicate that tool usage affects workers' silica exposure. In the case of this study the percentage reduction in exposure varied with the tool used and will likely vary among workers. The addition of the turntable to the workstation in this study should help the worker to position the casting to direct the grinding swarf into the grinding booth, away from his breathing zone. This work practice should help to reduce exposures.

The effectiveness of the ventilated workstation shows how a well-designed local exhaust ventilation system can reduce worker exposure. The original simple exhaust duct configuration did not provide efficient control of the airborne silica dust created by the grinding operation. Installation of the ventilated workstation significantly reduced the operator's exposure without a need to increase the exhaust flow rate. Standard long-term integrated air sampling should be conducted to confirm the reductions in TWA silica exposure. Further reduction in worker exposures could be achieved by the use of more complex and costly controls, such as tool mounted high-velocity low-volume exhaust systems. However, as an economical first step, installation of similar workstations at other casting-cleaning operations is an effective means to reduce workers' exposures to airborne dust.

ACKNOWLEDGMENTS

The following persons are recognized for their assistance in conducting this project: Daniel S. Watkins, for his skill in constructing the ventilated workstation evaluated in this study; Daniel R. Farwick, for his assistance in preparing the equipment survey used in the two surveys; James P. Agee for his assistance in installing the workstation and collecting the survey data; Ronald J. Kovein and Charles S. Hayden, for their assistance in collecting the survey data; Thomas J. Fischbach and Ruiquang Song for their assistance in conducting the statistical analysis of the survey data; and Anne Votaw for her assistance in editing this manuscript.

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