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REDUCING EXPOSURES DURING THE POURING OPERATIONS OF A BRASS FOUNDRY

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The focus of this exposure assessment and control technology study was a brass foundry and the lead exposures of workers involved in the transportation and pouring of metal. Controls in place at the foundry included ventilation systems at the furnace and along the continuous and stationary pouring lines. Real-time measurements were made to determine which tasks were the primary exposure sources, and a hand-held aerosol monitor was used to measure real-time aerosol exposures (as a surrogate for lead) in the workers' breathing zones. Data were collected over two 30-min sampling periods while worker activities were monitored using a video camera. Analysis of the data showed that the greatest aerosol exposures occurred during the transportation of an unventilated, full ladle, resulting in an average concentration of at least twice that of the other tasks. The study concluded that the addition of exhaust ventilation such as a moveable hood and duct system during the ladle transport and pouring tasks, and the implementation of a side draft hood at the pigging area, could result in a reduction of worker exposure to aerosols during the continuous pouring operation by up to 40%. The controls and techniques suggested in this study could be applied to pouring operations throughout the industry to reduce worker exposure to metal fumes.

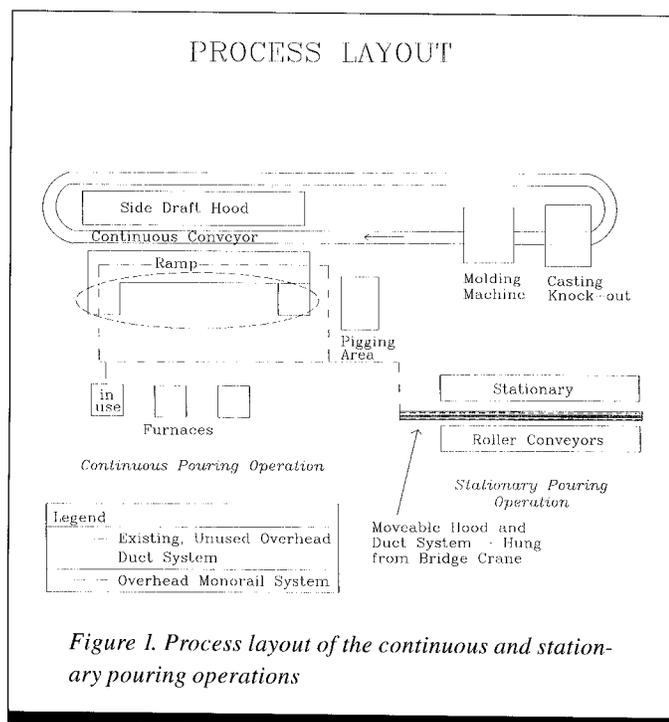
This exposure assessment and control technology study was conducted as part of the SENSOR^(1,2) (Sentinel Event Notification System for Occupational Risks) program that is sponsored by the National Institute for Occupational Safety and Health (NIOSH),

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

Centers for Disease Control. SENSOR, a cooperative state and federal effort, is designed to develop local capability for the recognition, reporting, follow-up, and prevention of selected occupational disorders, including lead poisoning.

In this instance, the state of Ohio participated in the SENSOR program for the reporting of occupational lead poisoning. Specifically, a borderline blood-lead level of 39 $\mu\text{g}/\text{dL}$ of blood was reported to the state in a worker at this foundry. A Health Hazard Evaluation (HHE) conducted by NIOSH researchers⁽³⁾ showed that of seven personal samples gathered for various on-site operations, three samples exceeded the OSHA Permissible Exposure Limit (PEL) of 50 $\mu\text{g}/\text{m}^3$ for lead, three samples were below the PEL, and one sample had no lead detected. Of the three samples in excess of the PEL, one was collected on a cut-off saw operator and two were collected on pouring operators. The 8-hr time-weighted average (TWA) of the cut-off saw sample measured 61 $\mu\text{g}/\text{m}^3$ of lead, accounting for 7% of the total accumulated metal fumes on the sample. The 8-hr TWAs of the pouring samples measured 78 $\mu\text{g}/\text{m}^3$ and 172 $\mu\text{g}/\text{m}^3$ of lead, accounting for 17% and 20% of the total accumulated metal fumes on the samples.

Within a week of the HHE, a more detailed exposure assessment and control technology study was performed to supplement it. Since lead exposures to the two pouring operators exceeded the OSHA PEL, and since the worker with the borderline blood-lead level had periodically performed the pouring operation, this activity was chosen as the focus of the exposure assessment and control technology study. The goal of this study was to identify and prioritize the aerosol exposures encountered by workers engaged in the pouring operation so that effective engineering controls could be implemented by this foundry. A secondary goal was to develop the controls so they would be useful to other similar operations.



This study also was seen as a follow-up to another study conducted by researchers at The Kettering Laboratory, Institute of Environmental Health, University of Cincinnati Medical Center in 1976.⁽⁴⁾ The Kettering Laboratory study focused on lead exposures during the ladling cycle at a nonferrous foundry. It concluded that while engineering controls for the pouring operation were essential, the necessary direct-reading technology was not yet available to investigate the exposures in-depth. The researchers indicated that "application of segmental and real-time analysis may allow definition of chemical exposure or physical routines . . . once the crucial segment(s) are pinpointed, the degree of control or remedial action can be assessed . . . control measures can then be employed." With the advancements in real-time sampling techniques, the present study was able to identify the crucial tasks of the pouring operation and assess the priority of the necessary controls.

PROCESS DESCRIPTION

The pouring operation has long been associated with overexposure to lead fumes in nonferrous foundries.⁽⁴⁻⁷⁾ During this study a stationary pouring operation and a continuous pouring operation were observed and are diagrammed in Figure 1. For the stationary operation, sand molds were placed on a stationary roller conveyor. A moveable hood and duct system (variation of Figure VS-65-03 in the American Conference of Governmental Industrial Hygienists publication *Industrial Ventilation*)⁽⁸⁾ controlled aerosol emissions when the worker poured the molds and transported the ladle along the stationary roller conveyor. For the continuous operation the sand molds were placed on a slow-moving conveyor. The continuous operation did not use the moveable hood to control emissions, but instead used a side draft hood

approximately 12 m (40 ft) long, located along the continuous conveyor where the worker poured the molds.

Three induction furnaces were located in the plant; however, only one furnace was operating during this study. A close-capture ventilation hood (Hawley Mob-L-Vent, Vulcan Engineering, Birmingham, AL) was used at the furnace to control the worker's exposure to metal fumes while melting and pouring the molten metal. A ladle (200 pound capacity) used during both operations was suspended from an overhead monorail system during the entire continuous operation and certain tasks of the stationary operation and was manually maneuvered into position.

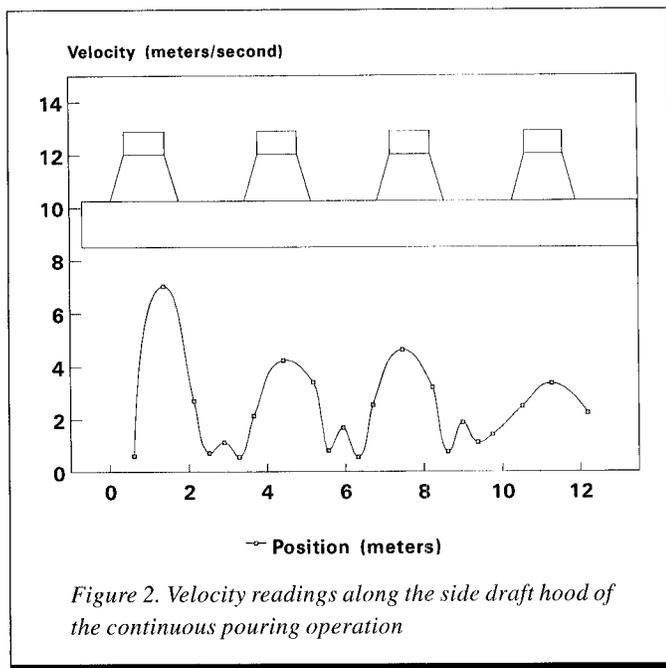
The process flow for the stationary operation was as follows:

- (1) The empty ladle was filled at the furnace after removing the ladle lid and swinging aside the moveable hood positioned over the ladle.
- (2) After slagging the ladle (skimming off any nonmetallic impurities formed on the surface of the molten metal), the lid was replaced and the moveable hood was repositioned over the ladle.
- (3) The full ladle was transported to the stationary roller conveyor via the overhead monorail system.
- (4) The moveable hood on the ladle was then connected to the duct system, which was suspended from a bridge crane.
- (5) The worker walked up and down the length of the roller conveyor pouring molds until the ladle was empty.
- (6) The duct system was removed from the moveable hood.
- (7) The ladle was transported back to the furnace via the overhead monorail system.

The stationary operation was performed periodically between runs on the continuous operation.

The process flow for the continuous operation was somewhat similar to the stationary operation:

- (1) The empty ladle was filled at the furnace after removing the ladle lid.
- (2) After slagging the ladle, the lid was replaced.
- (3) The full ladle was transported up a ramp to the continuous conveyor.
- (4) The worker moved the ladle along the continuous conveyor, filling molds until the ladle was nearly empty.
- (5) The ladle was transported to the pigging area.



- (6) Excess metal was poured into small ingots, the ladle lid was removed, and the ladle liner was scraped clean of any remaining material.
- (7) The lid was replaced on the empty ladle.
- (8) The ladle was transported back to the furnace.

METHODOLOGY

Video exposure-monitoring techniques were employed in this study to identify exposure sources during the pouring operations.⁽⁹⁾ A direct-reading instrument monitored personal aerosol exposures of one worker who performed both the stationary and continuous operations. Also, a video recording of the work activity was made for a detailed task analysis. Data were collected for two sampling periods of approximately 30 min each. In addition to the video exposure monitoring, face velocities were measured at the side draft hood to determine if high aerosol exposures were associated with low air-flow velocities.

Real-time measurements

A hand-held aerosol monitor (HAM) (PPM, Inc., Knoxville, TN) measured the total aerosol concentrations during the pouring operations. The response of this light-scattering instrument is dependent on the optical characteristics of the aerosol being measured. The HAM responds to respirable aerosols but does not differentiate between lead and other aerosols.⁽¹⁰⁾ For this reason, the concentrations were reported as relative concentrations rather than as absolute levels. The pouring operations were far removed from other dust-producing operations in the plant. Therefore, the

pourers were not exposed to inhalable dusts containing lead during the pouring operation.

The HAM was attached to the worker using a belt and harness with the sensor monitor positioned on the chest near the worker's breathing zone. The analog output of the HAM was recorded by a data logger (Rustrak Ranger, Gulton, Inc., East Greenwich, RI) attached to the belt of the worker. After each sampling period, the data logger was downloaded to an IBM compatible computer for storage and analysis.

Side Draft Hood

The side-draft ventilation system is diagrammed in Figure 2 and consisted of a slot hood approximately 12 m (40 ft) in length, with four exhaust takeoffs separated by a distance of about 1.5 m (5 ft). The hood was angled over the molds on the conveyor at about 30° from vertical. The face velocity of the side draft hood was evaluated using a hot wire anemometer (Kurz Digital Air Velocity Meter 1440-4, Carmel Valley, CA). Velocity readings were made at 22 points along the face of the hood.

RESULTS

Real-time Measurements

By reviewing the real-time video recordings, the individual tasks of the stationary and continuous pouring operations were identified and coded into the data set so that each task's contribution to the worker's cumulative aerosol exposure could be calculated. The stationary operation was divided into six tasks: working at the furnace (ventilated), transporting a full ladle without the duct attached (unventilated), transporting a full ladle with the duct attached (ventilated), pouring with the duct attached (ventilated), transporting an empty ladle with the duct attached (ventilated), and transporting an empty ladle without the duct attached (unventilated). The continuous operation was divided into five tasks: working at the furnace (ventilated), transporting a full ladle (unventilated), pouring along the continuous conveyor (ventilated), scraping the ladle at the pigging area (unventilated), and transporting an empty ladle (unventilated).

To find how each task affected the cumulative exposure, the real-time data were assembled into a spreadsheet format (Lotus® 1-2-3®, Release 2.2, Lotus Development Corp., Cambridge, MA). The data set consisted of total aerosol concentration measurements and the time the measurements were taken. The interval between concentration measurements was one second. Codes were added to the spreadsheet to identify the specific task being performed at the time of the concentration measurements. By coding each data point, the average concentration, cumulative time, and cumulative exposure (the product of the average concentration and cumulative time) for each of the tasks of the stationary and continuous pouring operations could be calculated.

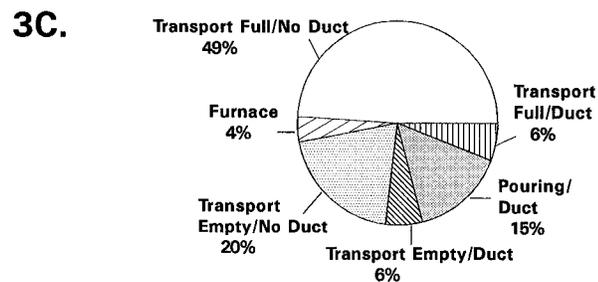
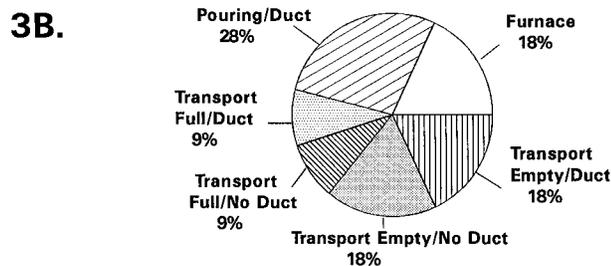
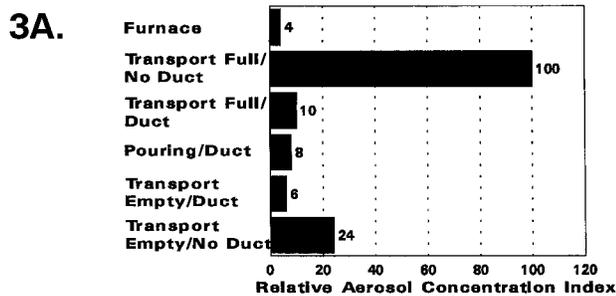


Figure 3. Contribution of the individual tasks of the stationary pouring operation to the (A) total aerosol concentration, (B) activity time, and (C) cumulative exposure

$$\text{Cumulative Exposure} = \frac{\sum \text{Concentration}}{\text{Number of Measurements}} \times \sum \text{Task Length}$$

It was determined that transporting a full ladle without the duct attached (unventilated) resulted in the highest average concentration. This concentration was arbitrarily assigned a relative concentration index of 100. The relative concentration indices for all other concentration measurements were calculated as follows:

$$\text{Relative Concentration} = \frac{\text{Average Concentration}}{\text{Highest Average Concentration}} \times 100$$

Figure 3A shows the relative aerosol concentrations of each of the six stationary operation tasks. Figures 3B and 3C summarize the contribution of the individual tasks of the stationary operation to the total activity time and cumulative exposure, respectively. While it accounted for less than a tenth

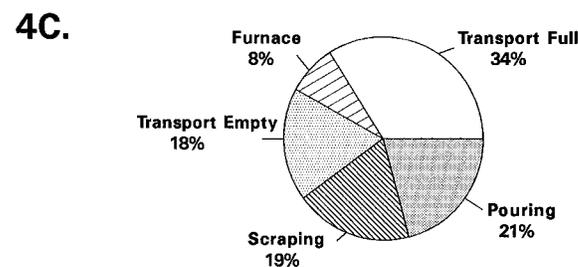
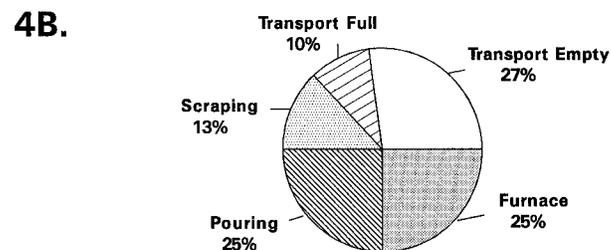
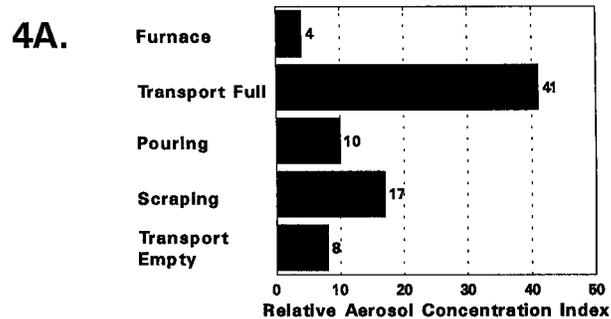


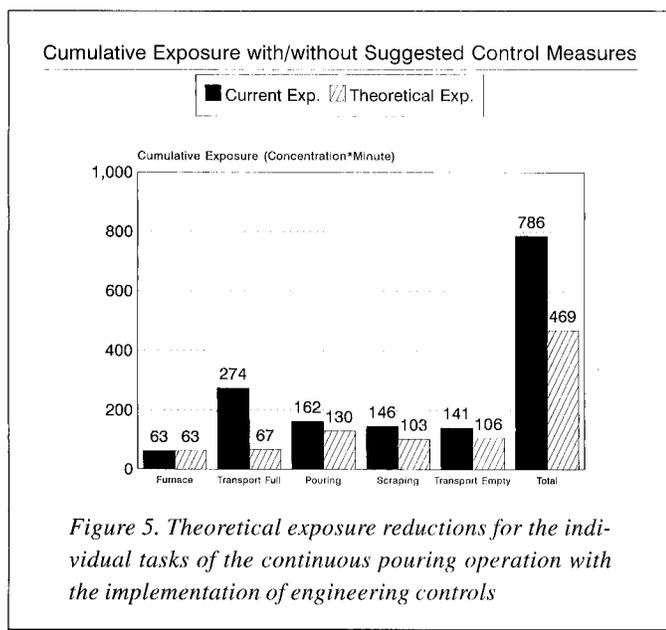
Figure 4. Contribution of the individual tasks of the continuous pouring operation to the (A) total aerosol concentration, (B) activity time, and (C) cumulative exposure

of the total activity time, transporting a full ladle without the duct attached (unventilated) was responsible for almost half the cumulative exposure for the stationary operation.

Figure 4A shows the relative aerosol concentrations for each of the five continuous operation tasks. Transporting a full ladle (unventilated) resulted in the highest concentration with a concentration index of 41. Figures 4B and 4C summarize the contribution of the individual tasks of the continuous operation to the total activity time and cumulative exposure, respectively. Transporting a full ladle (unventilated) contributed more than one-third of the cumulative exposure during the continuous operation, but only one-tenth of the total activity time.

Side Draft Hood

The face velocity readings obtained along the length of the side draft hood indicated that the highest velocities, from 2–8 m/sec (390–1575 feet/min), were found at the midpoint



of each exhaust takeoff. Figure 2 shows all the measured velocities at the respective positions along the hood, with a smooth curve fitted to the data points. The average flow rate for the side draft hood (measured 700 feet³/min/linear foot of hood or 1.1 m³/sec/m of hood) was more than double the flow rate recommended (200–300 feet³/min/linear foot of hood or 0.3–0.5 m³/sec/m of hood) for a “partial side enclosure with small molds” in *Industrial Ventilation*.⁽⁸⁾

DISCUSSION

As reflected in the data, the highest concentrations for both the stationary and continuous operations occurred during the transport of the unventilated full ladle. Also, the cumulative exposures from the continuous operation’s tasks were far greater than those from the stationary operation due to the greater time the worker spent on the continuous operation. Additionally, the controls on the stationary operation were more effective than the controls on the continuous operation.

In the continuous operation, transporting a full ladle (unventilated) had the shortest task duration, at only 10% of the total time. Even with this short activity time, transporting a full ladle (unventilated) produced the largest exposure for the operation due to the magnitude of the average concentration measured for this task. Controlling this task was thus identified as the main priority for controlling aerosol exposures to the worker during the continuous operation.

The aerosol concentrations for the ladle transport tasks (empty and full) of the stationary operation were well controlled when using the moveable hood and duct system. However, when a ladle was transported without the duct attached, the exposure to the worker increased substantially. The moveable hood and duct system was able to reduce the aerosol concentration by about a factor of 10 during full ladle transport and a factor of 4 during empty ladle transport.

The effectiveness of the moveable hood and duct system on the stationary operation led to an initial conclusion that similar additional exhaust ventilation on the continuous operation could result in reduced concentrations. By substituting the concentration data of the stationary operation’s ventilated ladle transport tasks for the concentration data of the continuous operation’s unventilated ladle transport tasks, potential exposure reductions could be calculated for the continuous operation. Specifically, the concentration index of the stationary operation’s task “Transport Full/Duct” was substituted for the concentration index of the continuous operation’s task “Transport Full,” and the concentration index of “Transport Empty/Duct” was substituted for the concentration index of “Transport Empty.” The theoretical exposures for the ladle transport tasks of the continuous operation were then calculated.

Figure 5 contrasts the current exposure data for the continuous ladle transport tasks with the theoretical values for the same tasks using controls. The data show that by using a moveable hood and duct system during the ladle transport tasks of the continuous operation, the worker’s cumulative exposure to aerosols theoretically could be reduced by up to 76% for the full ladle transport task, and up to 25% for the empty ladle transport task.

Three alternatives for reducing the exposure from the pouring task of the continuous operation were considered. The first was to substitute a moveable hood and duct system for the existing side draft hood located along the continuous conveyor. The second was to modify the existing side draft hood to improve the efficiency of aerosol capture during the pouring task. The third was to use a moveable hood and duct system in addition to the side draft hood.

The first alternative was analyzed for its potential control effectiveness during the pouring tasks. The pouring task of the stationary operation was performed with the moveable hood and duct system attached at all times. It was assumed that without the control of the moveable hood and duct system, the average concentration during this task would have been greater. Therefore, it was concluded that the use of a moveable hood and duct system during the pouring task of the continuous operation also could result in reduced concentrations. To determine the potential exposure reduction from using this control, the concentration index of the controlled, stationary operation’s task (Pouring/Duct) was substituted in the spreadsheet for the continuous operation’s task (Pouring). The theoretical exposure for the pouring task of the continuous operation was then calculated. Figure 5 contrasts the current exposure data for the continuous pouring task with the theoretical value for the same task using controls. The data show that by using this alternative the worker’s cumulative exposure to aerosols theoretically could be reduced by up to 20%.

For the second alternative, the side draft hood was analyzed to find where the ventilation was least efficient. It appeared that the fluctuations in the measured face velocities were caused by a shallow plenum. To determine the effect the pouring location had on the cumulative exposure, the pouring task was divided into two categories: pouring within

the length of the takeoff and pouring in-between the takeoffs. (Data collected when pouring only partly within the exhaust takeoff were not included in this analysis.) The aerosol concentration index, cumulative time, and cumulative exposure were then calculated for both pouring locations. If the hood was modified so that a uniform face velocity was obtained, the worker's cumulative aerosol exposure from the pouring task theoretically could be reduced about 12%.

Although no data were available for analysis of the third alternative, it was expected that the combined effectiveness of the moveable hood and duct system and the side draft hood would be greater than the effectiveness of either of the control components individually. Fumes given off during the actual pouring would immediately be captured by the moveable hood and duct system, and any further fumes would be captured by the side draft hood as the molds continued along the continuous conveyor.

The scraping task at the pigging area was the third highest cumulative exposure source of the continuous operation. A side draft hood similar to the one used during the pouring task of the continuous operation was proposed to control this operation. A conservative estimate expected for the scraping task exposure could be derived by substituting the concentration index obtained when using limited ventilation (pouring in-between the exhaust takeoffs of the side draft hood during the pouring task of the continuous operation) for the current concentration index of the scraping task. Figure 5 contrasts the current exposure data for the scraping task with the theoretical value for the same task using controls. The theoretical data show that the implementation of a side draft hood at the pigging area conservatively could be expected to reduce the cumulative exposure from the scraping task by up to 30%.

The close-capture system used at the furnace appeared to contain visible smoke and fumes, and the concentration measured was the lowest of all the tasks of both the continuous and stationary operations. Therefore, no further controls were suggested for work at the furnace.

From the data analysis discussed above, the following improvements could be made in the continuous operation:

- (1) Additional exhaust ventilation such as a moveable hood and duct system could be used when transporting an empty or a full ladle. This control could reduce the cumulative exposure from the entire continuous operation by up to 30%.
- (2) Ventilation controls could be added along the pouring line, such as a moveable hood and duct system, or the existing side draft hood could be modified. The combination of a moveable hood and duct system with the side draft hood also would be appropriate. Using the moveable hood and duct system alone, the cumulative exposure from the entire continuous operation could be reduced by up to 4%.
- (3) A side draft hood could be implemented in the pigging area for ingot pouring and ladle scraping. This control

could reduce the cumulative exposure from the entire continuous operation by up to 5%.

The stationary operation could be improved by implementing and using additional exhaust ventilation, such as a moveable hood and duct system, throughout all of the ladle transport tasks. Although data was not obtained on theoretical exposure reduction values for this control, it is assumed that the constant use of a moveable hood and duct system while transporting the ladle could further reduce worker exposure to aerosols during the stationary operation.

CONCLUSIONS

The brass foundry in this study is typical of other nonferrous foundries, and the conclusions reached on the necessary engineering controls for the pouring operation can be applied throughout the industry. The implementation of additional exhaust ventilation during the transport and pouring tasks of the continuous operation and the installation of a side draft hood at the pigging area would result in substantial reductions in the cumulative aerosol exposure to the worker. For instance, a moveable hood and duct system could be utilized during the full ladle transport, empty ladle transport, and pouring tasks of the continuous operation. When working at the furnace, the duct could be disconnected, as the control at the furnace appears to be adequate. When performing the scraping task at the pigging area, the moveable hood and duct could be disconnected and the side draft hood used to control aerosol emissions. The total exposure to the worker during the continuous operation potentially could be reduced by approximately 40% with the implementation of these engineering controls. During the HHE,⁽³⁾ the lead exposures measured for the two pouring operators were $78 \mu\text{g}/\text{m}^3$ and $172 \mu\text{g}/\text{m}^3$. The estimated percent reduction in total aerosol exposure could bring these workers' exposure levels within or closer to the PEL of $50 \mu\text{g}/\text{m}^3$ for lead.

It should be noted that this foundry did have an existing loop of the moveable hood and duct system set up for use during the continuous operation. However, this system was not used due to various mechanical problems that greatly reduced the ability of the worker to maneuver the ladle. If the system could be redesigned to eliminate these mechanical problems, use of this existing control would be possible for the continuous operation. Also, the stationary operation could be improved further by implementing exhaust ventilation controls during all the ladle transport tasks, such as by keeping the moveable hood and duct system attached to the ladle at all times. This would reduce aerosol exposures during the stationary operation in addition to the continuous operation.

Finally, the limitations of this study should be addressed. The major limitation of the video exposure-monitoring technique is the use of real-time aerosol measurements as a surrogate for an actual measurement of lead. The basic assumption is that the composition and size distribution of the aerosol remain constant over the sampling periods. Since

the workers sampled were engaged in only one operation (the pouring and transportation of hot metal), and were exposed to only metal fumes and not metal dust, this assumption would appear to be met. In fact, traditional sampling performed on the two pourers indicated that their exposure was to aerosols that contained 17% and 20% lead, which indicates that the assumption of constant composition was met. (The actual metal composition was 5% lead.) Other workers, in nonfume producing operations, had lead exposures representing only 5%–9.5% of the total metals. Also, an obvious limitation of this study is that the calculated reductions in exposure would need to be validated by installation of the suggested controls.

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