ABSTRACT

SUSAN KAY MITSUYE BUCHANAN. **Respirable Dust Levels During Relining of Foundry Induction Furnaces**. (Under the direction of Dr. Robert L. Harris, Jr.)

Industrial hygiene surveys were conducted to assess employee exposures to respirable silica during induction furnace relining. The operation is performed once every 6 to 12 weeks and takes between 8 to 16 hours to complete. Survey results showed that exposures ranged between 0.87 - 19.90 mg/m^3 during the process and samples contained between 40 - 65% free silica as determined by colorimetric method of analysis. The exposures which occur during the initial lining removal stage include exposures to cristobalite which is formed during furnace use. The health implications of these short-term, high exposures has not been evaluated, however, good industrial hygiene work practices suggest that exposure levels be kept to a minimum and recommendations for dust reduction have been made.

Other potential hazards identified were noise created by pneumatic tools and asbestos present in the preliner fabric. Both require further evaluation to determine the extent of the exposures.

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CONTENTS

INTRODUCTION

-The disease-

Silica exposure has long been known to cause silicosis, a pneumoconiosis resulting from the inhalation of excessive amounts of free silica, most commonly quartz. Development of the disease usually occurs over 20 - 40 years moderate exposure, with symptoms appearing only later in the disease progression (12, 13). Silicosis is preventable by controlling dust levels and exposures, yet it continues to be found throughout those occupationally exposed in industries such as foundries.

-Dusty Trades-

In the foundry industry, silica sand is used in making the molds to cast metal parts. The resulting silica dust exposures during routine operations have been relatively well characterized throughout the years (12, 13). In North Carolina, the Dusty Trades Act was enacted as a part of the Workman's Compensation Act under the Industrial Commission in 1935. This Act recognized silicosis and asbestosis as compensable diseases, and provided for the identification of workplaces with high risk for these diseases (7).

The Division of Health Services' industrial hygiene consultants have had the responsibility to inspect workplaces such as foundries, and have created a data base describing exposures specific to this state's foundry industry.

-Introduction to the project-

One exposure to silica appears to have escaped assessment, possibly due to the unpredictable schedule of the operation in which it is used. This occurs while relining furnaces, which is done only when the lining has been worn beyond repair. Previous sampling (16, 18, colleague experience) indicates that significant silica exposures result from the process but detailed evaluation has not been made.

-The literature-

In a recent study by J. Oudiz, silica exposure data from OSHA inspection records were used to evaluate current silica exposures in foundries. He observed that high levels in the melting areas were a result of ladle and furnace repair (7, 16). Correspondence with Mr. Oudiz indicated the broad and generalized scope to his study, which integrated available data, but did not deal with details of the processes (15).

Another study of foundry exposures was performed in Finland during 1972 - 1975, in response to a condition agreed upon to resolve a labor strike. Although the relining process was again identified as an operation that generates high concentrations of silica (see table), levels corresponding to the individual tasks were not reported (18).

Results of the Finnish Study		
	mean	median
total dust respirable dust ($\leq 5\mu m$)	34 mg/m^3 2.25 mg/m^3	16 mg/m^3 1.13 mg/m^3

* No free silica content specific to the iron foundry relining was cited.

Reports by NIOSH (National Institute for Occupational Safety and Health) comment on the relining operation, but only general remarks on the associated dust levels appear (12, 13).

-The process-

Evaluation of silica dust levels generated during induction furnace relining is the topic of this report. The project was limited to evaluating small to mid-sized foundries in North Carolina that manufacture grey iron and ductile castings. The operation, described later, is a two part process; the old lining is first removed, then a new one is built in. This may be done in one day, over two days, or more gradually depending on the available personnel and the pouring demand. The identified occupational health hazards include not only the silica dust exposures, but also exposures to noise caused by the pneumatic tools and to asbestos, often contained in a fabric used in the lining. This process presents not only the potential for quartz exposures, but also for tridymite and cristobalite exposures (18).

THE OBJECTIVE

From the literature and colleague experience, the dust levels associated with furnace relinings appear to be high, and few measures are being taken to minimize employees' exposures during this process. To address the issue, this operation must be observed and evaluated. The purpose of this project is to identify the tasks in furnace relining and to characterize their associated respirable dust exposures. Once the process is understood, a decision on the necessity for controls can be made. In coordinating this project with the North Carolina Division of Health Services, the data will be added to the Dusty Trades records. Further, should a need to control dust levels be found, this information could be applied to foundries state-wide, through the Division.

Two additional areas may be of concern: noise and asbestos. As previously mentioned, pneumatic tools create high noise levels, and the fabric used in the process has contained asbestos; therefore, a potential for exposure exists if this fabric is still used. These topics will be examined, but not thoroughly evaluated in this report.

STUDY DESIGN

-Choice of foundry-

Two decisions made at the outset of the project limit its scope. The first sets criteria for the foundries sampled. The second restricts the type of samples taken.

The foundries selected were small to medium in size, and have from 25 to 100 employees. They manufacture grey and ductile iron castings and use coreless induction furnaces to melt the metal.

The sampling strategy focused on assessing the respirable dust exposures. Laboratory costs and the time required for sample analyses were important. To keep these to a minimum, a few representative samples were selected from each foundry for free silica analysis and total dust samples were not collected.

-The decision to reline-

Through experience the furnace tender learns to estimate the lining life based on the pounds of iron poured. As the quantity of iron poured approaches the limit characteristic of the furnace, the extent of the wear is determined more accurately with visual inspections and physical measurements. Usually the furnace tender is responsible for these checks and decides whether the lining is still functional, or whether a patch would be adequate to protect the induction coils for a few more weeks.

-Details of the process-

Depending on the foundry and the furnace size, from two to six men perform the relining operation. They tear out the old lining with jack hammers and chisels, and periodically tilt the furnace to empty the debris. After complete removal of the old lining and a final sweep-out, a fabric may be laid in (one foundry still used an asbestos-containing material, one foundry used no fabric at all), covering all the surfaces, and taped with masking tape around the rim (one foundry uses a glue on the seams instead). Once the furnace preparation is complete, relining begins. First, 100-lb bags of silica ramming mix, a 99% free silica powder, are poured into the bottom. An employee stands in the furnace and packs the powder into place with a pneumatic packer and a fork-like tool which minimizes layering. When the bottom is complete, the employees lower a carefully rolled metal form onto the bottom and center it in place. Pouring the powdered silica resumes, a few bags at a time, around the form to make the new wall. Two employees circle the furnace and manually pack the powder in place. Once the silica level has reached the furnace rim, a pneumatic vibrator set inside the form settles the silica further. After completing the walls, an employee may replace the trough (pouring spout) using a wet, brick-shaped silicaalumina material. A hand-held pneumatic tamper presses this into place, to obtain the desired shape. Once metal starter blocks are loaded into the furnace, the curing process begins. This final step involves slowly bringing the furnace up to normal operating temperature. During this time the metal form and starter blocks melt and become a part of the first pour, and the outer powdered silica layer fuses.

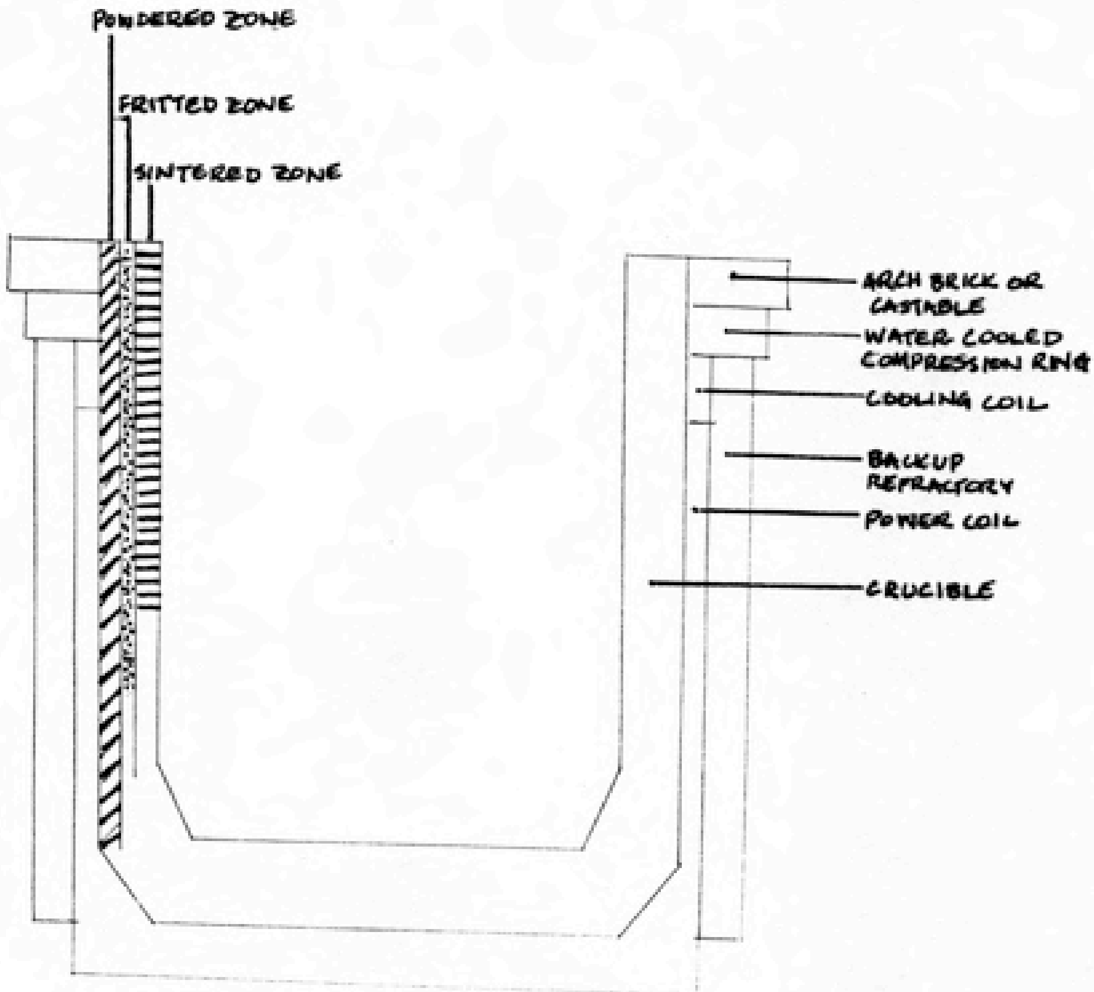
-The tasks identified-

In each of the two parts of the process, tearout and reline, distinct tasks correspond to different exposures. Meeting the project objective requires that these tasks and their associated exposures be identified.

During tearout, the exposure varies as the employee removes the lining from the furnace rim and works towards the bottom where the space becomes more confined. There are also variations as the different layers of the 4" wall are removed. These layers are a result of three distinct sections - the 'sintered zone', the 'fritted' zone, and the final zone - formed during the curing (23). The outermost layer, or the 'sintered zone', is directly in contact with the molten metal and consists of bonded cristobalite. The 'fritted zone' appears next, in which fused quartz predominates. The final zone is closest to the coils, and is made up of unbonded quartz. Although each of these phases is initially present in a newly packed lining, the sintered layer widens with wear of the furnace walls, as the final zone narrows (see the diagram of the induction furnace). A second exposure results when the furnace is tilted and the employee crawls and/or reaches into the furnace to rake out the loose material.

During lining replacement, the associated tasks are: (1) preparing the furnace to

DIAGRAM OF A TYPICAL CORELESS INDUCTION FURNACE TO SHOW THE LAYERING OF THE WALL



reline by inserting a fabric preliner, grouting cracks around the induction coils and inserting grounding wires, (2) laying the bottom, and (3) building the sides.

In the two tasks associated with lining tearout and during the furnace preparation, the exposure comes from the dust generated during the removal. The bottom and side replacement, however, involves exposures to the new silica powder and may have a different free silica content. Higher exposures are expected while replacing the bottom than during building the sides, because the employee works in a more confined space.

-The forms of silica-

The importance of determining the presence of cristobalite and tridymite lies in their ability to evoke different physiologic responses than quartz. The ACGIH TLVs (American Conference of Governmental Industrial Hygienists Threshold Limit Values) for cristobalite and tridymite recommend limiting exposures to one half the threshold limit value calculated for quartz. These structural changes in silica may be induced by heating, such as during the metal melting process (melting point of pure iron at 1535° C (22), with quartz converted to tridymite at 860° C, and tridymite to cristobalite at 1470° C (5, 17).

-Noise and asbestos-

A general evaluation of noise and asbestos as potential hazards was done, but only to the extent of determining whether further, more detailed assessment is necessary. Particular attention will be paid to the use of pneumatic tools as the primary noise source, and to the content of the fabric and the work practices during insertion where it is used as a preliner.

METHODS

-Personal samples-

The industrial hygiene sampling strategy and procedures used were in accordance with OSHA compliance training as described in the Federal Industrial Hygiene Field Operations Manual (IHFOM) (26, 27, 28). Sampled employees wore MSA personal sampling pumps (Model G) with 10mm nylon cyclones in line for collection of the respirable dust fraction. Each pump was pre- and post-calibrated at 1.7 liters per minute (lpm) using a calibrated 2 liter per minute rotameter. Consecutive sampling continued throughout the process, with the flowrates checked periodically.

-Area samples-

Pre- and post-calibrated high volume (9 lpm) Bendix pumps with steel cyclones in line were used to collect area samples for free silica analysis. Such sampling provided filters with sufficient weight for analysis where personal samples contained inadequate dust loads. Separate groups of samples represented the tearout and the relining and their different free silica contents. When employees relined during routine foundry operation, additional area samples were taken using the MSA pumps to determine the background contribution.

-Bulk samples: lining-

The plant manager at the second foundry was the first to discuss the layering phenomenon in the lining which occurs during the heating process. With this knowledge, bulk samples of the walls were taken in this and subsequent foundries to determine whether cristobalite and tridymite were present.

-Analytical methods-

Three common NIOSH-approved methods for silica analysis are colorimetric analysis, X-ray diffraction (XRD), and infra red (IR) analysis. With analytical support provided by the Division of Health Services, the most feasible method was the colormetric procedure done by the AIHA certified State laboratory (6). Determination of the presence of cristobalite and tridymite in the bulk samples, however, required sending the samples out of state for the XRD technique. To minimize costs, all samples were weighed, but were not analyzed for their free silica content. A few of those with adequate weight which were determined to be representative of the two tasks were then selected for free silica analysis.

-Noise readings-

Sound level meter readings were taken throughout the shift to evaluate the levels and identify sources.

-Bulk samples: asbestos-

Bulk samples of the fabric, both old and new, were taken and submitted for asbestos analysis. In one case where employees stated that the material contained asbestos, one wore a personal sampling pump to assess the exposure while working with the fabric. The pump was pre- and post-calibrated at 2.0 lpm.

RESULTS AND DATA ANALYSIS

-Respirable dust-

Ideally, each task is represented by either a single sample or consecutive samples, depending on the duration of the task. Conditions in the field are not always conducive to this sampling regimen, and samples may overlap two of the tasks. Restrictions on the number of samples to be taken in this study also demanded a conservative strategy. Despite these limitations, estimates of the dust exposures associated with each task remained possible (see Table I).

Table I: Average Respirable Dust Concentrations

Task	Range of Task Duration (mins)	Ave Concentration (mg/m^3)	Range (mg/m^3)	Number of Samples
Tearout: main worker	235 - 305	16.59	1.67 - 19.90	8
Tearout: helper	235 - 305	5.23	0.90 - 16.43	5
Reline preparation	45 - 100	1.20	0 - 3.01	7
Reline (general)	100 - 190	4.97	0.87 - 18.66	14

Note: For individual sample data see Appendix I.

As the ranges indicate, the dust levels are highly variable within each task. A larger number of samples would allow further division of the general task descriptions into more specific tasks, and would reduce the variability. These additional categories are necessary only to the extent that the tasks can be ranked in order of magnitude and duration of exposure, to set priorities for implementing controls if they are determined to be necessary.

Two such modifications to the groupings are adding a furnace cleanout category and having separate categories for relining the bottom and the sides, since the bottom approximates a confined space. The furnace cleanout is visibly a dusty task which lasts 15 - 25 minutes and is performed at least three times during the process, depending on the furnace size. The sample results (n = 2) did not support the presence of high dust levels and further sampling is recommended to identify the exposures, primarily to ensure that if respirators are selected, they provide adequate protection. A few samples were specific to relining the bottom and relining the sides. The levels measured during the work in the furnace, 7.30 and 18.66 mg/m^3 (n = 2), appear to be higher than working around the rim, which ranged from 0.87 - 3.14 mg/m^3 (n = 3). The sample size is too small, however, to determine whether there are two different dust concentration distributions associated with these tasks.

-Percent free silica-

Three to five samples were selected from each foundry to represent the free silica content of the respirable dust. Separate samples were submitted to the laboratory from tearout and reline, to test the assumption that two different compositions exist in the old and new linings. The ranges and averages for each foundry are listed in Table II. The test of the hypothesis that the percent silica in the old and new linings were different was inconclusive (μ of tearout, 47.80%, = μ of relining, 57.40%, $0.10 < p < 0.20$).

Table II Percent Free Silica Associated with the Old and New Linings				
Foundry	Task	Range (%)	Average (%)	No. of samples
1	Tearout	24.92 - 61.32	40.67	3
2	Tearout	48.66	48.66	1
4	Tearout	55.07 - 61.07	58.07	2
1	Reline	55.54 - 57.57	56.56	2
2	Reline	54.09 - 61.29	57.65	2
3	Reline	63.89 - 66.47	65.18	2
4	Reline	42.89 - 58.18	50.54	2

-Cristobalite and tridymite-

X-ray diffraction analysis of pieces of the old lining from each foundry was requested to determine the presence of cristobalite and tridymite. No tridymite was detected, however, cristobalite was found in all the samples, ranging in content from 1.7 - 35%. Because the samples were in a bulk form, no direct correlation to the percent cristobalite in the personal samples can be made. By virtue of the presence of cristobalite however, the ACGIH recommends a TLV of one half the value if the exposure was to pure quartz (1, 14).

$$\text{TLV for cristobalite} = \frac{10\ \text{mg/m}^3}{2\ (\%\ \text{quartz} + 2)}$$

The OSHA Office of Technical Support recommends calculating a standard that incorporates the percent cristobalite (2, 9):

$$\text{PEL, quartz and cristobalite are present} = \frac{10\ \text{mg/m}^3}{\%\ \text{quartz} + 2\ (\%\text{cristobalite}) + 2}$$

If the percent cristobalite is determined on the basis of one sample, this Permissible Exposure Limit (PEL) applies only under the conditions which this sample represents. This is important when evaluating the exposures during tearout because different layers contain different percents cristobalite (23), and the PEL will therefore vary over the period of removal.

-Noise-

Sound level meter measurements indicate that periods of high noise exposure occur, particularly during the use of pneumatic tools. There are periods of exposure below the OSHA action level (the level at which the standard applies) of 85 dBA, however, which may result in an eight-hour time-weighted average below the PEL. In order to accommodate these and other variables, such as extended work shifts, and determine employee exposures, a more comprehensive noise survey is necessary. Some examples of the levels measured in the four foundries are as follows:

- Background - no other foundry operations: less than 70 - 80 dBA.
- Background - other foundry operations such as shakeout: 88 - 89 dBA.
- Jack hammer used during chip out: 94 - 102 dBA.
- Observing vibrating, approximately four feet away: 93 - 94 dBA.
- Adding sand during vibrating: 102 - 104 dBA.

-Asbestos-

Of the four foundries sampled, only one continues to use an asbestos-containing material as a pre-liner in the furnace. The others use either no fabric at all, or a fiberglass substitute. Bulk samples of the asbestos-containing material had 30 - 40% chrysotile in the new lining and 20 - 30% chrysotile in the old lining. One employee's exposure during cutting and inserting the fabric was 3.5 fibers/cc for the 45 minutes sampled.

-Assessment of error in personal samples-

NIOSH has published a coefficient of variation (CV_t) of 0.09 for the field sampling and weighing of respirable dust samples collected according to procedures described in the Federal IHFOM. This figure was calculated by combining coefficient of variations for the field error, primarily that of the pump, and for the filter weighing (10). Although sampling was performed according to the federal protocol, a separate calculation of the precision yielded higher CV_t values, ranging from 0.173 - 0.202 (see Appendix II for the calculations). Since this CV_t is derived from the actual techniques used, it is considered to be more accurate for the data collected. The equation used was taken from (21)

$$\frac{\sigma_M}{C_M} = \sqrt{\frac{\sigma_M^2 + \sigma_B^2}{(M-B)^2} + \frac{\sigma_V^2}{V^2}}$$

where: M = weight of sample
B = weight of blank
V = volume
C = concentration

Sources of error included in the calculation were:

(1) Field sampling:
time (watch) = 0.5 mins

flowrate = 0.3 lpm

(2) Lab weighing = 0.005 mg

The total coefficient of variation represents the quantifiable error associated with the sampling and weighing of each filter, and is an approximation of the inherent error, at best. Some of the less easily estimated sources of error include flowrate variations over time, individual cyclone efficiencies, and filter loading.

In addition to the error associated with field sampling and weighing, error is introduced during the analytical procedure. The published value for the NIOSH Analytical Method for percent free silica, colorimetric analysis P&CAM 106, is a relative standard deviation, or coefficient of variation, of 9.25% (0.0925).

Other nonquantifiable variables that influence determining the employee's true exposure are the changes in percent free silica with time and space, and the presence of cristobalite. The percent respirable free silica collected on a filter depends on the time and spatial changes in the particle concentration and size distribution, as well as on the nature of the task being performed (e.g. which layer of the old lining is being removed). The percent cristobalite, as a component of the percent free silica, is affected in the manner described for percent free silica, above. It is also a quantity that is difficult to determine accurately due to the detection technique precision of ± 25 (reported with the results by the laboratory). This precludes its use in calculating exposures or TLVs precisely.

-Exposure calculations-

The ACGIH recommends a standard for respirable silica that is based on the percent respirable free silica present.

$$\text{TLV} - 8\text{ hour} = \frac{10\text{ mg/m}^3}{\%\text{ quartz} + 2}$$

OSHA has adopted this recommmendation from the 1968 TLVs as their standard, the Permissible Exposure Limit (PEL). In calculating the TLVs to compare to the task exposures, an average of the percent free silica was used.

Table III Calculated Threshold Limit Values

Foundry	Task	Average % silica	TLV (mg/m^3)
1	Tearout	40.67	0.234
2	Tearout	48.66	0.197
4	Tearout	58.07	0.166
1	Reline	56.56	0.171
2	Reline	57.65	0.168
3	Reline	65.18	0.149
4	Reline	50.54	0.193

Note: % cristobalite is not included because only bulk analysis was requested.

The objective of the study was to identify the exposures for each task; however, comparison to the OSHA eight-hour standard sets these levels in perspective with other foundry operations. For each employee a time-weighted average based on the length of time he was sampled (TWA) is computed (see Table IV). The concentrations of the consecutive samples (Appendix I) are entered into the following general equation (1, 14), where Σt_n is the sampling time in minutes.

$$\text{Time-weighted average (TWA) for the time period } \sum t_n = \frac{c_1 t_1 + c_2 t_2 + \cdots + c_n t_n}{\sum t_n}$$

where c_n = concentration in mg/m^3
t_n = time in minutes

Because the test of hypothesis to determine whether the average percent silicas differed was inconclusive, each standard in Table IV is time-weighted using the TLVs for the tearout and the reline for each foundry (Table III).

Table IV Employee time-weighted average exposures during relining

Fdry	Employee	Approx. Process Duration (mins)	Sample Time (mins)	TWA (mg/m^3)	TLV (mg/m^3)	Ratio of TWA to TLV	Comments
1	A	825	455	7.13	0.2344	30.42	Remove lining.
	B	825	237	9.75	0.1708	57.08	Replace lining.
	C	825	777	8.70	0.2033	42.79	
	D	825	759	5.69	0.2027	28.07	
2	A	540	228	3.71	0.1801	20.60	
	B	540	519	5.13	0.1834	27.97	
	C	540	452	3.64	0.1858	19.59	
3	A	255	119	0.87	0.1489	5.84	Replace lining.
	B	255	39	4.67	0.1489	31.36	Replace lining.
	C	255	125	1.51	0.1489	10.14	Replace lining.
4	A	220	210	10.56	0.1903	55.49	Remove lining.
	B	300	290	2.75	0.1665	16.52	Replace lining.
	C	300	288	6.74	0.1665	40.48	Replace lining.

In estimating a particular foundry's exposures, the first consideration is whether the relining is done as a part of the regular shift, as with small furnaces (4,000 - 5,000 lbs. in this study), or whether a weekend is devoted to reline, as with larger furnaces

(18,000 lbs.). If the relining occurs during the daily workshift, exposures from routine duties in addition to relining tasks must be included in the estimate. If the relining occurs over a weekend where tearout and reline last between 9 - 15 hours on Saturday, the TLVs must be adjusted for the extended workshift (greater that eight hours). The modifier applied is based on a simplified model for silica removal from the lung, which assumes a long retention time for silica (8, 11, 19) and is proportional to the number of hours of exposure (11, 29). For the single-day extended workshift, this modifier is the ratio of the time for a standard workshift, 480 minutes, to the time for the workshift, and is multiplied by the TLV to give an adjusted TLV value.

$$\text{Adjusted TLV} = \frac{\text{480 minutes}}{\text{Work shift duration (minutes)}} \times \text{TLV}$$

The TLVs used are weighted TLVs for this study (Table IV).

Table V Relining Exposures with TLVs Adjusted for Extended Workshifts

Foundry	Employee	Time Sampled (minutes)	TWA (mg/m^3)	Weighted TLV	Ratio of TWA to TLV
1	C	777	8.70	0.1183	69.27
	D	759	5.69	0.1179	44.42
2	B	519	5.13	0.1630	30.25

Other sampling conditions must be recognized before the exposure levels identified in this project are applied industry-wide. A list of some of the more important conditions that affect dust levels follows.

- Employee work practices.

- The number of employees on the job.
- The use of patch material to gain a longer lining life.
- Furnace size.
- The temperature of the furnace during relining (convection currents keep the small particulate airborne).
- Background levels of dust produced by other operations.

The reported values modified according to the presence or absence of similar and additional variables during the operation will provide the best estimates.

CONCLUSIONS AND RECOMMENDATIONS

-Respirable dust-

Percent free silica

The range of percent free silicas for the four foundries was 24.92 - 61.32%, an average of 47.80% during tearout, and 42.89 - 66.47%, an average of 57.40% during reline. A test of hypothesis to determine whether the percent silicas of the two tasks was different was inconclusive, primarily as a result of too small a sample size (n of tearout = 6, n of reline = 8).

Exposures

Despite the differences in environments in the four foundries sampled, the pooled results demonstrate that high dust concentrations are generated during each task. One measure of the degree of exposure is the ratio of the eight-hour time-weighted average exposure to the TLV, listed in Table IV. The comparisons in Table

IV may be summarized as follows:

Small furnaces:
-Employee removing the lining = TWA is 55 times the TLV
-Employees replacing the lining = TWA range is 6 - 40 times the TLV

Large furnaces:
-Employee removing the lining = TWA is 30 times the TLV
-Employee replacing the lining = TWA is 57 times the TLV
-Combined tasks = TWA range is 19 - 43 times the TLV

Alternatively, an example using the average respirable dust concentrations and the shortest task durations from Table I shows a similar degree of exposure.

Estimated TWA - main worker on tearout	=	11.80 mg/m^3
Estimated TWA - helper during tearout	=	4.78 mg/m^3
TLV using average percent silicas for tearout, 47.80%, and reline, 57.40%	=	0.1911 mg/m^3

Ratio of TWA to TLV:
-Main worker on tearout = 62 times the TLV
-Helper on tearout = 25 times the TLV

The significance of the relining exposures in developing silicosis is not easily determined, and was not addressed in this study. This operation is only one source of exposure during a foundryman's working lifetime and further literature review and research are necessary before any hypotheses are proposed. One effect, however, may be postulated.

The likelihood of developing silicosis depends on both the frequency and duration, as well as on the level of the exposure (8). The potential for developing chronic silicosis in a shorter time increases with increasing daily dose, and acute silicosis is associated with exposure to high dust levels such as those found in sandblasting and abrasive soap manufacturing (a silica powder is used as the abrasive) industries (4, 20, 25, 26). Relining represents a combination of both these conditions. Employees involved in relining experience both moderate exposures during daily duties as well as high periodic exposures during relining; therefore, this process may increase their risk of developing the disease.

Recommendations

This study has not quantitatively identified the contribution of the exposures to the development of silicosis; therefore, without further assessment of the significance of the exposures, the process cannot be considered to constitute a health hazard that requires immediate measures to reduce the dust levels. If one accepts the reasoning above, however, then good industrial hygiene practice encourages voluntary abatement, and it is for this reason the following recommendations are presented.

The first steps in reducing employee exposures are to establish a respirator program, in accordance with the OSHA standard 1910.134, and a program of medical monitoring. Respirators are a temporary solution, used only while engineering controls are being installed, unless state-of-the-art technology fails to reduce the levels to safe exposures. Medical monitoring such as annual chest x-rays and work histories are already provided in North Carolina under the Dusty Trades Program.

Listing the tasks in order of increasing dust level concentration, the employee in the furnace during tearout receives the highest dose, average = 16.59 mg/m^3, followed by those replacing the lining, average = 5.32 mg/m^3, and those helping with the tearout, average = 5.23 mg/m^3. The lowest exposures occur during the preparation for relining, average = 1.20 mg/m^3.

Tearout, as the highest source of exposure, should be considered for controls first. The recommendations presented are two variations of local exhaust. The first would be designed to provide capture at the point of dust generation with flexible duct during chip-out. The second involves a small diameter hose (duct) run along the pneumatic hose on the jack hammer which provides exhaust in the immediate area of dust generation, at a velocity to capture the respirable dust fraction. In both cases, the volume of air removed should be such that makeup air is required and flows from the furnace rim towards the bottom, helping to keep the dust below the breathing zone, down in the capture region. Any systems, however, must be designed to maintain sufficient visibility to avoid damaging the coils with the jack hammer.

A different lining removal method that has been developed in the past two years is a process known as the Quick Lining Removal, patented by BBC Brown Boveri, Inc.. The process takes advantage of the lining's shrinkage as the furnace cools, the presence of the third layer ('final zone') in the lining which remains unfused and in a powder form, and the special characteristic of their furnace walls which have a smooth formica-composite surface. The properties of the lining and the furnace create a slip plane and the lining can be pushed out from the bottom. According to the representative (3), retrofitting both Brown Boveri and Lindberg furnaces is possible, but is recommended only for furnaces with larger than a two-ton capacity.

Currently, the common engineering controls for dust, local exhaust systems, apply only to tearout. Other means of reducing the dust levels require individual foundry evaluation of the process. For example, in the foundries surveyed, employees helping with the tearout are often unnecessarily exposed, between 0.90 mg/m^3, 100 minutes and 2.39 mg/m^3, 157 minutes (see Appendix I). Although lining removal in the large furnaces (9 ton) requires more than one employee, anyone not needed immediately as a relief person should not stay in the immediate area. The fatigue element may be used instead to the employee's advantage. Through a schedule of rotations out of the furnace (an administrative control) fatigue may be avoided or delayed and the exposure to any one worker may be minimized. Again, the decision must be on a case by case basis; some foundries feel there is a degree of skill required to help in the operation, while others do not have extra personnel available.

Two potential dust control methods are the use of water and of local exhaust while replacing the lining. In this study, all the foundries were hesitant to use water, and very rarely did so. The problem arises when dampness persists beyond the curing stage. Water collecting on the outside of the induction coils must be avoided because any drops that form and fall to a lower coil create a potential for short circuiting of the current and a possible sparking or overheating of that area of the furnace.

Before designing a local exhaust system for the powder-packing task, the importance of the particle size distribution in the sand mixture must be understood. The porosity of the lining once the silica is fused depends on the ratio of large and small particle sizes in the sand, and the relining protocol attempts to preserve the composition. Any local exhaust must be designed so that the smaller particles are not removed by the system before they have time to settle onto the layer being packed.

-Noise and asbestos-

The screening measurements for noise and the bulk samples for asbestos document exposure to these potential hazards. Both require further evaluation to determine the extent of the exposures. Immediate measures should be taken in the case of asbestos, in view of its carcinogenic properties (1).

-Further work-

The project leaves several additional areas open for study. Both asbestos and noise require additional assessment; the effect of implementing dust controls needs evaluation; the development of new controls demands exploration. Further, as indicated, the significance of the relining exposures has not been determined. A first approach may be to look at the incidence of silicosis in furnace operators who reline and have been in the same job category for more than ten to fifteen years, using the Dusty Trades files.

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APPENDICES

I. Respirable Dust Concentrations for Each Filter

Tearout						
Filter #	Conc. (mg/m^3)	Sample Time (mins)	Time to Complete Task (mins)	% Free silica	Calc PEL (mg/m^3)	Comments
31286-49*	14.68	103	103	58.07±3.0	0.1665	Primary, 46.6% of sample time.
31286-45*	6.27	107	app 115	"	"	Primary, 29.0% of sample time.
32086-146*	10.63	85	app 340	40.67±18.69	0.2344	Primary, 41.2% of sample time. Use of patch material.
32086-141	1.67	82	"	"	"	Primary, 24.4% of sample time.
32086-148	19.90	134	"	"	"	Primary, 73.9% of sample time.
32086-164*	15.95	159	"	"	"	Primary, 67.9% of sample time.
42886-38	4.96	295	app 300	48.66	0.1974	Primary, 4.41% of sample time.
42886-35*	7.12	294	"	"	"	Primary, 19.3% of sample time.
32086-150*	1.52	124	app 340	40.67±18.69	0.2344	Only helping.
32086-161	0.90	100	"	"	"	Only helping.
32086-158	2.39	157	"	"	"	Only helping.
32086-165	1.20	80	"	"	"	Helping and cleanout once (17 min) using supplied air.
32086-153	16.43	169	"	"	"	Helping and cleanout twice (34 min) using supplied air. Blow out furnace with compressed air the last time.
32086-139	0.41	15	app 20	"	"	Sample represents cleanout once, using supplied air.
42886-13	0.60	41	"	48.66	0.1974	Sample represents cleanout twice, using a disposable dust mask.

Furnace Preparation						
Filter #	Conc. (mg/m^3)	Sample Time (mins)	Time to Complete Task (mins)	% Free silica	Calc PEL (mg/m^3)	Comments
31286-54*	0.85	42	app 60	58.07±3.0	0.1665	Prepare and lay fabric.
32086-144	0.52	49	app 50	40.67±18.69	0.2344	"
32086-140	0.32	38	"	"	"	"
32086-155	0	41	"	"	"	"
31286-35*	3.01	55	app 60	58.07±3.0	0.1665	Hand sweep furnace, repair trough, and lay fabric.
32086-145*	1.57	96	app 96	40.67±18.69	0.2344	Grounding wires put in, grout cracks and lay fabric.
42886-16	2.14	43	43	"	0.1974	Grounding wires put in.

Reline						
Filter #	Conc. (mg/m^3)	Sample Time (mins)	Time to Complete Task (mins)	% Free silica	Calc PEL (mg/m^3)	Comments
31286-44*	7.30	19	app 27	65.18±1.28	0.1489	Reline the bottom.
31286-147*	18.66	128	app 60	56.56±1.02	"	"
31286-16*	0.87	121	app 120	65.18±1.28	0.1489	Reline sides.
31286-59*	1.51	126	"	"	"	"
32086-47*	3.14	105	app 100	56.56±1.02	0.1708	"
42886-23*	2.51	225	app 120 "	57.65±3.64	0.1675	Reline sides and bottom: app 30 min = bottom, 40 min = sides, vibrating at the end.
42886-31*	3.71	228	"	"	"	"
31286-53	4.76	196	app 100	56.56±1.02	0.1708	123 min = bottom, 93 min = sides pouring.
31286-17	6.21	127	"	"	"	43 min = bottom, 84 min = sides packing.
31286-48*	7.74	286	app 120	50.54±7.65	0.1903	55 min = bottom.
31286-37*	2.69	235	"	"	"	Smoothing bottom w/ trowel, app 15 min.
31286-13*	3.31	80	app 80	56.56±1.02	0.1708	Vibrating and final cleanup.
31286-39	3.35	118	"	"	"	Sides = 37 min, vibrating, filling w/ starter blocks.
31286-31	3.84	110	"	"	"	Sides = 28 min, vibrating, filling w/ starter blocks.
31286-25*	2.18	20	20	65.18±1.28	0.1489	Trough buildup as the final job after lunch.

* Indicates that these samples were submitted for free silica analysis.

II. Relative Precision of the Sample Concentration

General equation:

$$\frac{\sigma_M}{C_M} = \sqrt{\frac{\sigma_M^2 + \sigma_B^2}{(M-B)^2} + \frac{\sigma_V^2}{V^2}}$$

where M = sample weight
B = blank weight
C = sample concentration
V = volume

Relative precision of the volume, V, is based on the flowrate, F, and the sampling time, T, and will vary from sample to sample. The formula becomes:

$$\frac{\sigma_M}{C_M} = \sqrt{\frac{\sigma_M^2 + \sigma_B^2}{(M-B)^2} + \frac{\sigma_F^2}{F^2} + \frac{\sigma_T^2}{T^2}}$$

An approximation can be made by maximizing each of the terms under the square-root sign. Substituting in the error associated with the weighing, flowrate and time, and the smallest values for weight, flowrate and time used in this study, where the values for precision are as follows:

σ_M, σ_B = 0.005 mg
σ_F = 0.3 liters
σ_T = 0.5 minutes

$$\frac{\sigma_M}{C_M} = \sqrt{\frac{0.005^2 + 0.005^2}{0.03^2} + \frac{0.3^2}{1.477^2} + \frac{0.5^2}{15^2}}$$

$$= \sqrt{0.056 + 0.041 + 0.001}$$

$$= 0.313$$

The term for relative precision of the sample time is negligible and therefore may be dropped from the equation. To estimate the range of precision associated with the samples in this study, values for the lowest weight and flowrate and for the highest weight and flowrate are substituted into the equation to obtain the upper and lower limits. These are 0.03 mg, 1.48 lpm and 4.48 mg, 1.92 lpm, and yield a range of 0.155 - 0.313.

For conditions recommended by the Federal IHFOM of 2 mg maximum dust load, 499 - 800 liters maximum volume (equal to 294 - 470 minutes at 1.7 lpm):

$$\frac{\sigma_M}{C_M} = \sqrt{\frac{0.005^2 + 0.005^2}{2^2} + \frac{0.32^2}{1.7^2} + \frac{0.5^2}{294^2}}$$

$$= \sqrt{1.25\times10^{-5} + 0.031 + 2.89\times10^{-6}}$$

$$= 0.176$$

The concentrations assigned to each task are average concentration of a widely varying range of concentrations (see Table I). As a result, the imprecision does not affect these values, which themselves are only estimates of the dust levels encountered.