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Engineering Controls in Mine Assay Laboratories

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An extensive literature search and professional contacts, who have performed industrial hygiene surveys in mine assay laboratories, suggested that mine assay workers are potentially exposed to a wide variety of chemical hazards, including lead, arsenic, silica, and mercury. As a result, the National Institute for Occupational Safety and Health (NIOSH) has undertaken a study to evaluate and disseminate control technology information for reducing these exposures and protecting worker health in this industry. Mine assay laboratories process and analyze samples from mineral exploration and mineral ore recovery operations. Ore samples are prepared for analysis by drying, crushing, splitting, and mixing samples with lead flux. Walk-through surveys were conducted at five mine assay laboratories where effective engineering controls were identified by the literature search and the professional contacts. Two laboratories appeared to represent good engineering controls in the mine assay laboratory industry and were selected for in-depth evaluations; one was located on a mine site and the other was a commercial laboratory. Both laboratories have the potential to exceed the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 50 $\mu g/m^3$ and the action level of 30 $\mu g/m^3$ for lead. In the commercial laboratory arsenic exposures exceeded the NIOSH recommended exposure limit (REL) of 2 $\mu g/m^3$ (ceiling limit) and have the potential to exceed the OSHA PEL for arsenic of 10 $\mu g/m^3$. Based on our study results, recommendations to reduce worker exposures are as follows: (1) monitor airborne concentrations if evidence from laboratory analytical data indicates increased levels of hazardous metals such as arsenic or cobalt; and (2) require workers to shower and change from work clothes to street clothes before going home. Recommendations to improve ventilation systems in mine assay laboratories are as follows: (1) increase capture velocity on the ventilation hoods in the sample preparation area by increasing the degree of enclosure; (2) use a high efficiency particulate air-filtered vacuum for cleaning in the sample preparation area; and (3) increase exhaust volumes and improve hood design of canopy hoods in fire assay areas to control convection currents generated by furnaces. HALL, R.M.; SHEEHY, J.W.; ZIMMER, A.T.: ENGINEERING CONTROLS IN MINE ASSAY LABORATORIES. APPL. OCCUP. ENVIRON. HYG. 13(9):646–655; 1998. © 1998 AIH.

Mine assay laboratories support mineral exploration, deposit mapping, and mineral ore recovery. Many of the laboratories are in western states where there are active gold and silver mining operations which depend on this service and could not prosper without it. Approximately 2000 mine assay lab workers are employed in Nevada, and up to 5000 mine assay lab workers are employed nationally.[1] Workers in mine assay laboratories are exposed to respirable dust and silica, lead, arsenic, mercury, and other elements in the ore. To help understand the extent of these exposures and the means of controlling them, a study was conducted in the sample preparation and fire assay areas of mine assay laboratories.

Information from the Nevada Division of Occupational Safety and Health[1] indicates total and respirable dust exposures in the sample preparation area up to 20 times the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL). The OSHA PELs for total and respirable dust are 15 and 5 mg/m^3, respectively.[2] Also, lead exposures in excess of 1000 $\mu g/m^3$ were reported while preparing flux.[1] In the fire assay area, time-weighted average (TWA) lead fume and dust exposures have exceeded 300 $\mu g/m^3$. This compares to the OSHA PEL for lead of 50 $\mu g/m^3$.[3] Personal breathing zone (PBZ) samples collected on fire assayers during six health hazard evaluations by National Institute for Occupational Safety and Health (NIOSH) investigators showed TWA exposures to lead ranging from 110 to 850 $\mu g/m^3$ with an arithmetic mean of 340 $\mu g/m^3$.[4]

Mine assay laboratories are located both on mine sites and as separate commercial operations. Because ore bodies encountered at mine site laboratories are from a relatively small area, they are more consistent than ore bodies encountered at commercial laboratories, which analyze ore bodies from mines throughout the world. Laboratories located at mine sites are regulated by the Mine Safety and Health Administration (MSHA), and MSHA PELs apply; on the other hand, commercial laboratories are regulated by OSHA, and OSHA PELs apply. With the stay on the 1991 OSHA PELs, the state of Nevada elected to consider limits for each substance individually.[5] In some cases the Occupational Safety and Health Enforcement Section of Nevada enforces the American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLVs®).[5]

The purpose of this study was to evaluate and document good controls in existing facilities. Two in-depth evaluations were conducted, one at a mine site laboratory and the other at a commercial laboratory.

Process Descriptions

The mine site laboratory employed ten workers. This assay laboratory performs approximately 10,000 determinations per month; 2500 to 3000 are fire assay analyses. Samples analyzed

in the mine assay laboratories are obtained from exploration holes and blast holes as well as from the mineral ore recovery processes. The commercial laboratory presently has a work force of 15 employees. Approximately 130 assay samples were processed in this sample preparation area over the 3 days of this survey. The majority of the assay samples were core samples from the same mine.

Sample Preparation Area

The rock, ore, dirt, and core samples are brought to the sample receiving area of the assay laboratories in individual bags weighing 5 to 10 pounds. Wet samples are dried in an oven at approximately 200°F. Samples are split, crushed, and pulverized. Samples are crushed in either a jaw crusher or a cone crusher and then ground to 85 percent less than 200 mesh size in a pulverizer. This crushed material is then poured into envelopes. Samples from the pulverizers weigh approximately 200 g. Operations such as splitting, crushing, pulverizing, and air hose operations in the sample preparation area are emission sources for silica exposures.

Figure 1 is a diagram of a sample splitter hood, pulverizer hoods, and pour hoods in the sample preparation area of the mine site laboratory. The sample splitter is located in an enclosed ventilated hood (face opening 80 inches wide by 40 inches high) with an exhaust opening in the back of the hood and a downdraft opening near the splitter. Pulverizers are in ventilated hoods (32 inches wide by 41 inches high) with glass doors. To prevent cross-contamination between samples, after each sample is ground, the pulverizer is cleaned with fixed nozzle compressed air jets located in the hood above the pulverizer. Next to each pulverizer hood is another ventilated hood (31 inches wide by 41 inches high) where the crushed samples are poured into envelopes. The worker cleans off the table with a compressed air gun after each sample is poured. The worker spends about 1 hour per shift at the splitter and half the shift (4 hours) at the pulverizer.

Figures 2 and 3 are ventilation system diagrams for the pulverizer and crusher rooms at the commercial laboratory. Three local exhaust ventilation systems serve the sample preparation area at this laboratory. Ventilation in the crusher room utilized a dust collection system. The jaw crusher and two splitter hoods located in the pulverizer room are served by a separate dust collection system. Air from both systems is filtered prior to being recirculated into a storage room located between these rooms. Twenty high efficiency bag filters are used per system. According to the manufacturer's specifications, these filters are 99.9 percent efficient in removing particles ≥ 1 μm and 98 percent efficient in removing particles ≥ 0.5 μm. The puck and ring mill hood located in the east side of the pulverizing room is served by the third dust collection system. Air from this system is exhausted directly outside of the building.

Fire Assay Area

After samples have been prepared in the sample preparation area, they are taken to the fire assay area, where they are mixed with lead oxide, borax, flour, silica sand, and soda ash under a ventilated mixing hood in a process called fluxing. Fluxing is conducted to help extract the precious metals from the ore in the fire assay process. The fluxing operation is a potential emission source for lead exposures. The mine site laboratory uses a premixed flux that contains mineral oil, which helps control dust during mixing. Mixing in this laboratory is done by hand in an exhaust hood made of transparent plastic on top of a table. The face opening of the hood is 14 inches by 94 inches wide, and a downward exhaust opening in the table is 48 inches by 3.5 inches. A downdraft ventilated hood controls litharge (lead oxide) mixing operations at the commercial laboratory. Figure 4 is a schematic of this hood. Under this hood, large batches of fluxing agents are prepared in a barrel. The barrel is placed inside the litharge mixing hood, where 50 lbs. of litharge is added to approximately 30 lbs. of fluxing agents. The barrel is sealed, removed from the ventilated hood, placed on a roller, and mixed for approximately 30 minutes. The barrel is returned to the ventilated hood, where the seal is removed and a portion of the fluxing material is transferred to a container located inside the hood. The barrel is resealed and moved to a storage area. Fluxing material and pulverized assay samples are then added to crucibles and thoroughly hand-mixed in the ventilated hood. The litharge mixing hood in the commercial laboratory has a face opening of 4.5 by 1.3 ft with a face area of 5.9 ft^2.

In the fire assay room, fluxed samples are placed into fusion furnaces that operate at a temperature of approximately 2000°F. The carbon contained in the flour of the fluxed samples reduces part of the lead oxide to lead, which combines with the precious metals released from the ore.[4] The mine assay laboratories studied during our in-depth evaluations had exhaust hoods located directly over the furnaces. The primary purpose of these hoods is to exhaust fumes when the furnace doors are open.

The exhaust hoods at the mine site laboratory covered the tops of the furnaces and extended 4 to 5.5 inches in front of the furnace doors. Figure 5 is a schematic of these hoods. At the commercial laboratory there was a large canopy hood located over the cupel furnaces and a canopy hood located over the crucible furnace. The canopy over the crucible furnace has an opening of 3.3 by 3.8 ft.

The molten samples are removed from the oven and the lead is separated from the slag by pouring the samples into metal button molds. After cooling, the lead buttons containing precious metals are placed into a bone ash cupel and heated in a cupellation furnace. The difference in melting points of lead and the precious metals is exploited for extraction of the metals. The cupellation furnace at the mine site laboratory has a large hood above the furnace door which extends 17 inches in front of the furnace as well as along both sides. The cupellation furnaces at the commercial laboratory are ventilated by one large canopy hood located directly over the top of both furnaces. This canopy hood has an opening of 8.6 by 3.5 ft. The area under the canopy hood is 30.4 ft^2; however, the opening is blocked by the two furnaces (21 ft^2). Therefore, the actual opening is 9.4 ft^2.

As the button melts, the lead is absorbed by the cupel, leaving the higher melting precious metals at the bottom of the cupel. Sometimes controlled amounts of silver are added to the samples to obtain a visible amount of precious metals in the bottom of the cupel. When cool, the remaining material is taken to the balance room and weighed to determine the amount of precious metal.

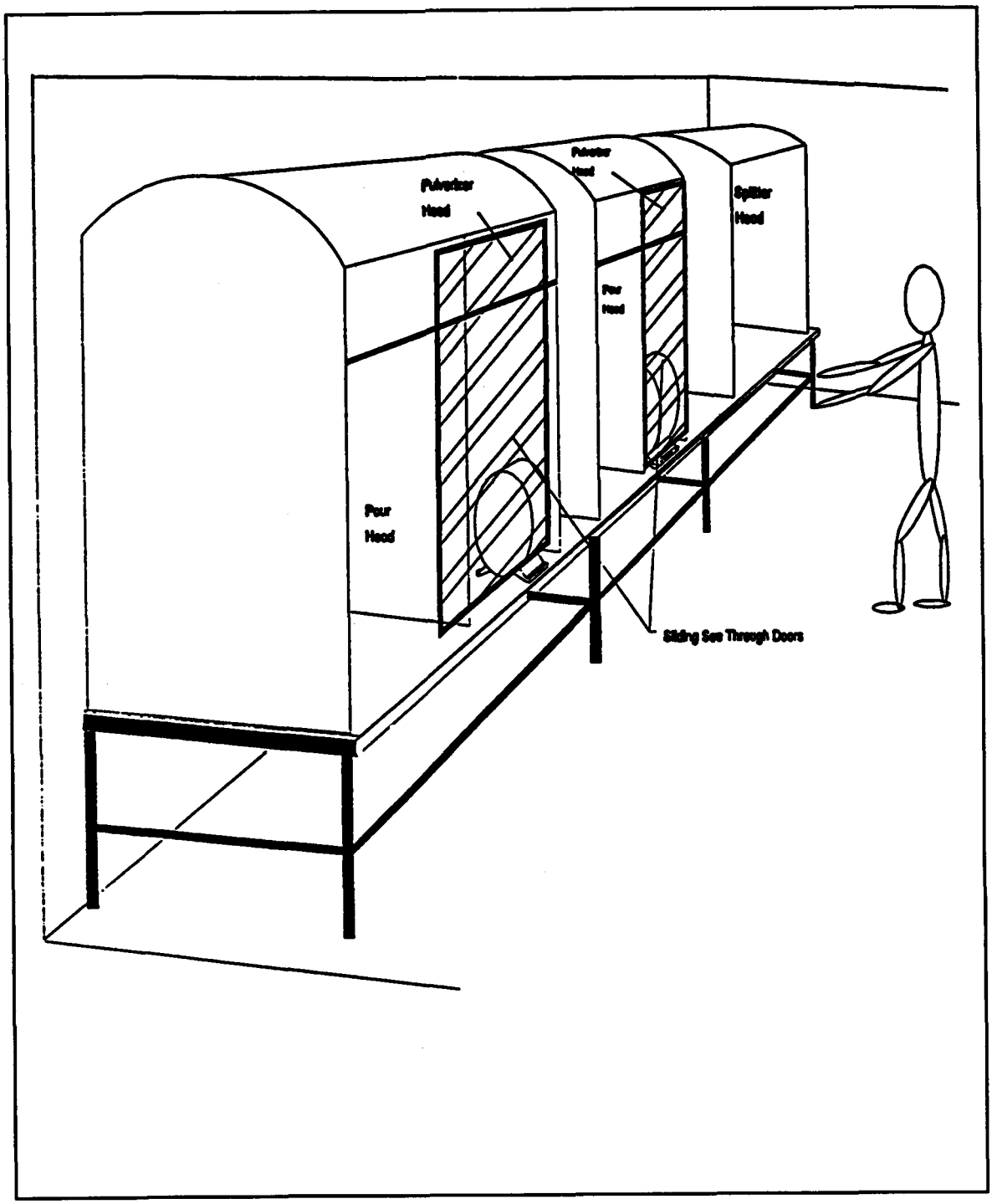

FIGURE 1. Diagram of the splitter hood, pulverizer hoods, and pour hoods in the sample preparation laboratory of the mine site laboratory.

Methodology

During the preliminary stages of this research study, information regarding engineering controls in mine assay laboratories was obtained through an extensive literature search and from professional contacts who have performed industrial hygiene surveys in mine assay laboratories. Walk-through surveys were conducted at five mine assay laboratories where effective engineering controls were identified by the literature search and the professional contacts. After the walk-through surveys were completed, two of these mine assay laboratories were selected for in-depth evaluations; one was located on a mine site and the other was a commercial laboratory. These two laboratories were selected because they appeared to represent good engineering controls in the mine assay laboratory industry.

During the in-depth evaluations, engineering controls were evaluated by performing ventilation assessments (obtaining

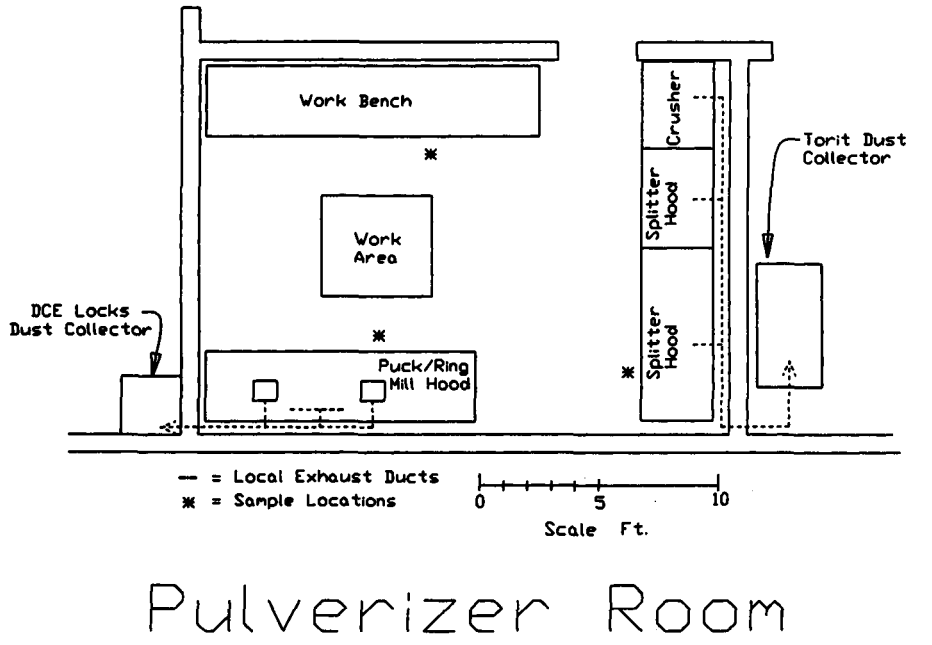

FIGURE 2. Ventilation systems located in the pulverizer room at the commercial assay laboratory.

ventilation measurements and using smoke tubes) and air sampling. Personal and area air samples were collected during the in-depth evaluations.

In the sample preparation areas air samples for respirable quartz were collected and analyzed according to NIOSH analytical method 7500.[6] Samples were collected using battery-operated sampling pumps to draw air through 37-mm diameter, 5-μm pore size polyvinylchloride (PVC) membrane filters, mounted in series with 10-mm nylon cyclones, at a flow rate of 1.7 L/min. Nylon cyclones were used to separate the respirable portion of the airborne dust. The sampling pumps were calibrated before and after sampling. The PVC membrane filters were analyzed for respirable quartz using X-ray powder diffraction.

Air samples for lead and other elements were collected in the fire assay areas using battery-operated sampling pumps to draw air through 37-mm diameter, 0.8-μm pore size membrane filters at a flow rate of 3 L/min. The sampling pumps were

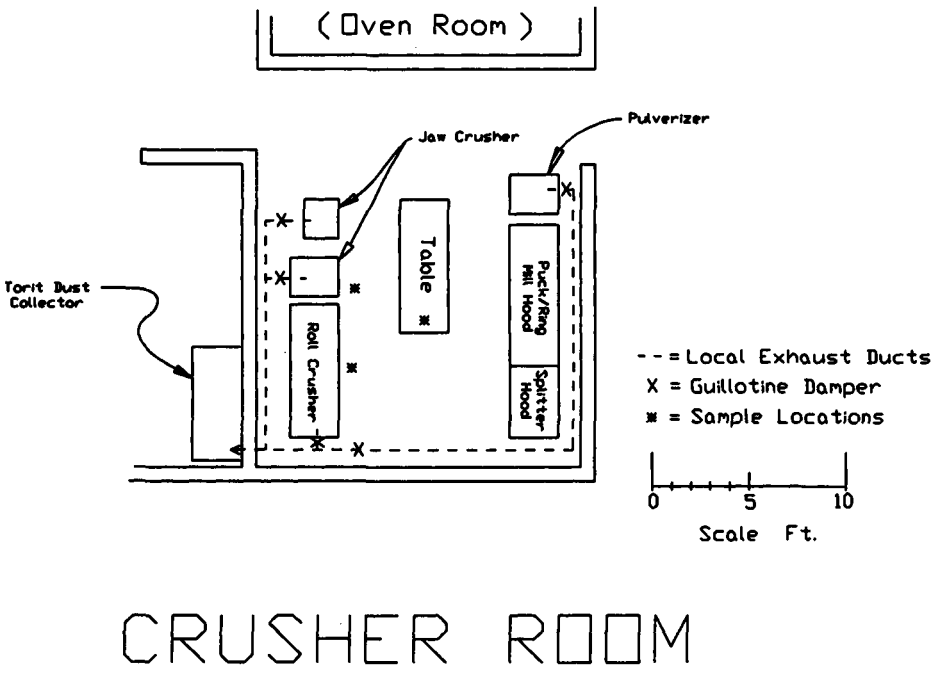

FIGURE 3. Ventilation systems located in the crusher room at the commercial assay laboratory.

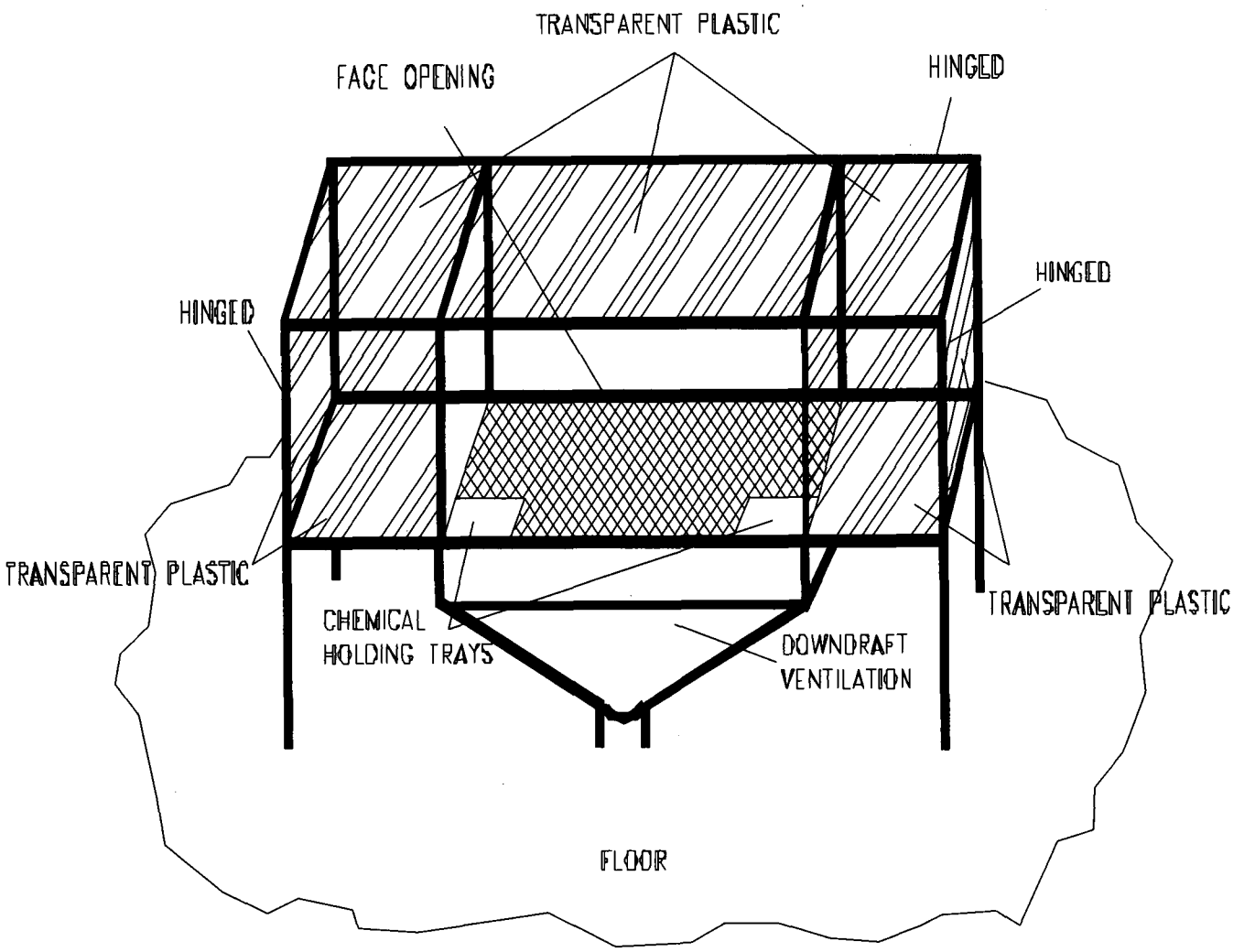

FIGURE 4. Litharge mixing downdraft ventilated hood at the commercial assay laboratory.

calibrated before and after sampling. Air samples for lead were analyzed by graphite furnace atomic absorption spectroscopy using NIOSH analytical sampling method 7105.[7] Air samples for elements were analyzed using an inductively coupled plasma emission spectrometer according to NIOSH analytical method 7300.[8] Air samples for arsenic that were below the limit of detection (LOD), using NIOSH analytical method 7300, were rerun using NIOSH analytical method 7901.[9] These samples were analyzed using a graphite furnace AA spectrometer.

A Jerome® model 411 Mercury vapor analyzer was used to measure mercury levels at the mine site laboratory. Ventilation measurements were made with hot-wire anemometers. Smoke tubes were used to observe air movement in front of and in the enclosures. The capacity and dimensions of the local exhaust ventilation controls were obtained.

Results and Discussion

Sample Preparation Area

RESPIRABLE DUST AND RESPIRABLE QUARTZ. PBZ samples for respirable dust and respirable quartz exposures were collected

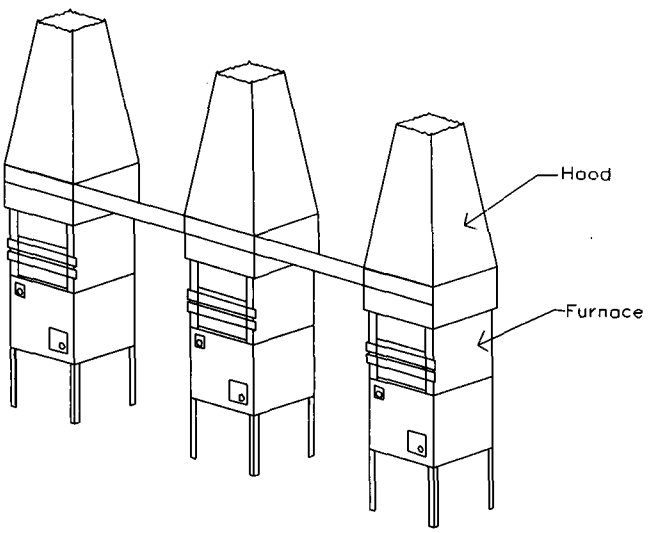

FIGURE 5. Diagram of exhaust hoods located directly over the fire assay furnaces at the mine site laboratory.

TABLE 1. Ventilation Measurements in Sample Prep Area and Fire Assay Area of Mine Site Laboratory

Location	Average Face Velocity (ft/min)	Air Volume (ft^3/min)
Splitter hood[A]	120	2600
Crusher[A]	830	70
Right pulverizer hood[A]	1060	840
Right pour hood[A]	270	2500
Left pulverizer hood[A]	1730	1540
Left pour hood[A]	300	2600
Flux mixing hood	30	290
Fusion furnace (left)	1340	430
Fusion furnace (center)	740	320
Fusion furnace (right)	480	240
Cupellation furnace	270	1050

[A]The *ACGIH Industrial Ventilation Manual* recommends capture velocities from 100 to 500 ft/min for these operations.[13]

in the sample preparation area at both laboratories. PBZ samples for respirable dust averaged 0.2 mg/m^3, which is well below the MSHA and OSHA PELs for respirable dust.[2,10] At the mine site laboratory PBZ samples for respirable quartz averaged 0.03 mg/m^3, which is less than the MSHA PEL, OSHA PEL, NIOSH recommended exposure limit (REL), and ACGIH TLV for respirable quartz.[2,10–12] Area samples for respirable dust and respirable quartz were collected in front of the splitter hood, pulverizer hood, and pouring hood at about head height. The respirable dust concentrations averaged 0.2 mg/m^3, while respirable quartz concentrations averaged 0.02 mg/m^3. PBZ and area sample results show that the ventilated hoods and work practices used in the sample preparation operations were effective in controlling respirable dust and quartz exposures at both laboratories. Full-day background samples collected inside the laboratory office and outdoor ambient samples collected near the sample preparation area showed respirable quartz levels of less than 0.01 mg/m^3. These data indicate that respirable quartz did not escape from the sample preparation area into other rooms inside the building and that outside respirable quartz levels were negligible.

At the commercial laboratory, two representative bulk samples were obtained. One random bulk sample was taken to represent the majority of the core samples processed during the survey. This sample contained 26 percent quartz and no cristobalite. Another bulk sample was taken of an assay sample representing approximately 5 percent of the samples processed over this period. This sample contained 91 percent quartz and no cristobalite.

VENTILATION. The average face velocity and air flow into the sample splitter hood, jaw crusher, pulverizer hoods, and pour hoods in the sample preparation area at the mine site laboratory are shown in Table 1. Ventilation measurements for the pulverizer hoods were taken with the glass doors closed and averaged 1060 and 1730 ft/min. The average face velocities on the pour hoods were 270 and 300 ft/min. These face velocities are within the guidelines recommended in the *ACGIH Industrial Ventilation Manual*.[13] The splitter hood at the mine site laboratory averaged 120 ft/min. ACGIH recommends capture velocities of 200 to 500 ft/min when compressed air is used. Therefore, the splitter hood capture velocity at the mine site laboratory should be increased from 120 to >200 ft/min.

TABLE 2. Lead Exposures for Workers

Date	Worker	Sample Time (min)	Lead Concentration ($\mu g/m^3$)
Mine site laboratory			
3/9/93	A	412	41
3/10/93	B	411	33
3/11/93	B	190	30
Commercial assay laboratory			
12/14/93	A	484	4
12/15/93	A	465	7
12/16/93	A	419	8
12/15/93	B	430	20
12/16/93	B	317	49

At the commercial laboratory, smoke tube observations in the sample preparation area revealed no unusual air flow patterns. Face velocities were measured at the ventilation openings to the crusher equipment and the face of the splitter and puck and ring pulverizer hoods. All measurements were taken with the ventilation system configured as the employees used them (i.e., maximum capture velocities). The face velocities of the crusher equipment hood ranged from 350 to 460 ft/min, as recommended in the *ACGIH Industrial Ventilation Manual*.[13] However, the face velocities at the hood opening for both the splitter and puck and ring mill hoods ranged from 20 to 54 ft/min.

Fire Assay Area

LEAD. PBZ samples for lead were taken on the fire assayer working in the litharge mixing and fire assay furnace room. PBZ sample results for lead, as TWAs, are shown in Table 2. The lead exposures, ranging from 4 to 49 $\mu g/m^3$, were all less than the MSHA and OSHA PELs for lead; however, four samples were above the OSHA action level of 30 $\mu g/m^3$.[3] [Assay laboratories located at mine sites fall under the jurisdiction of MSHA, and the PELs for MSHA apply.[10] Mine assay laboratories are legally required to meet only those levels specified by the MSHA PELs. Some current MSHA PELs are: 150 $\mu g/m^3$ for lead; 10 mg/m^3/(% respirable quartz + 2) for silica; 500 $\mu g/m^3$ for inorganic arsenic; and 0.05 mg/m^3 for mercury.]

Short-term PBZ samples collected at the commercial laboratory while 50 lbs. of litharge was mixed with fluxing agents under the downdraft ventilated litharge hood showed lead exposure to be less than 2 $\mu g/m^3$. This indicates that this litharge hood does control worker exposures during litharge mixing operations.

Area lead concentrations measured in the litharge mixing and fire assay room at the mine site laboratory are presented in Table 3. Statistical analyses were performed on log-transformed data.[14] Analysis of variance (ANOVA) showed that sampling location had a significant effect on concentration

TABLE 3. Area Lead Concentrations (Mine Site Laboratory)

Location	Number of Samples	Geometric Mean ($\mu g/m^3$)	Multiple Comparison Test Code[A]	Range ($\mu g/m^3$)
Fusion furnaces	7	14	A	6–55
Cupel furnace	3	18	A	16–22
Pouring station	4	13	A	8–20
Flux mixing hood	8	8	AB	5–14
Drying oven in sample prep	8	4	BCD	1–13
Drying oven in wet lab	3	3	CD	2–6
Background levels				
Indoor (office)	3	2	DE	2
Outdoor (near laboratory)	3	1	E	0.5–2

[A]LSD method: geometric means with different letters differ significantly.

($p > F < 0.0001$).[15] A multiple comparison test, least significant difference (LSD), was used to examine the concentration differences between the locations. The concentration differences are shown in Table 3. A significance level of 0.05 is the basis for the following discussion. Concentrations at the pouring station (pouring molten metal into cone molds) and furnace operations (both fusion and cupellation furnaces) were significantly higher than at the drying ovens and background locations (both inside and outside). These results indicate that the pouring station and furnace operations are the major sources of lead emissions at the mine site laboratory. Indoor ambient lead concentrations indicate little buildup of lead in the laboratory building and represent less than one-tenth the fire assay workers' average lead exposure. Full-shift (8 hours) outdoor ambient area samples for lead averaged 1 $\mu g/m^3$.

A summary of area and background (ambient) lead concentrations measured during the commercial laboratory survey is presented in Table 4. During this survey 49 area samples were collected in the fire assay area. Most samples were collected for a half day (approximately 220 to 240 minutes). Figure 6 shows the area sample locations in the fire assay area. After log-transforming the data, an ANOVA showed that sampling location had a significant effect on lead concentration. A multiple comparison test, LSD, showed the concentration differences in Table 4.

TABLE 4. Summary of Lead Area Sample Concentrations in Fire Assay Area (Commercial Assay Laboratory)

Location	Number of Samples	Geometric Mean ($\mu g/m^3$)	Multiple Comparison Test Code[A]	Range ($\mu g/m^3$)
Cupel furnace[B]	4	49	A	1–200
Crucible furnace	6	16	AB	8–30
Pouring station	12	10	BC	1–34
Litharge hood (left)	6	4	C	1–10
Litharge hood (right)	6	4	C	1–10
Background samples				
Background (in office)	6	0.1	D	0.03–0.2
Background (near laboratory)	6	0.08	D	0.02–0.3

[A]LSD method: geometric means with different letters differ significantly.
[B]Area samples taken on the second day of survey when the cupel furnace was not in operation were omitted in this summary.

At the commercial laboratory, concentrations at the cupellation furnace were significantly higher than at the pouring station, litharge hood, and background locations (both indoor and outdoor). Concentrations at the crucible furnace were significantly higher than at the litharge hood and background locations. These results indicate that the cupellation and crucible furnaces are the major sources of lead emissions at the commercial laboratory.

The personal sample results along with the area sample results at the mine site laboratory indicate that the ventilation system satisfactorily controls lead exposures in the litharge/furnace room to below the MSHA and OSHA PELs. Nevertheless, the one half-day area sample, which exceeded 50 $\mu g/m^3$, suggests the potential for lead levels to occasionally exceed the OSHA PEL. Area samples taken at the commercial laboratory indicate that the ventilation system over the furnaces is not functioning satisfactorily to control lead emissions.

ARSENIC. At the mine site laboratory, arsenic levels on the filters were all less than the LOD (0.2 $\mu g/m^3$). Personal samples, collected on workers in the fire assay area, showed that arsenic exposures were all less than 0.2 $\mu g/m^3$ at the mine site laboratory. These exposures are well below the MSHA PEL (500 $\mu g/m^3$) and OSHA PEL (10 $\mu g/m^3$) for arsenic.[10,16] Area samples for arsenic collected in the sample preparation area, in the wet chemistry laboratory, and by the fire assay furnaces were 0.2 $\mu g/m^3$ or less at the mine site laboratory. Background samples for arsenic taken both inside and outside the mine site laboratory were all less than 0.1 $\mu g/m^3$.

Some of the ore bodies received by the commercial laboratory are high in arsenic. At this laboratory, six personal air samples were collected and analyzed for elements over the 3-day sampling period in the fire assay area. The results of the personal air sampling for arsenic at the commercial laboratory are summarized in Table 5. Arsenic (TWA) exposures ranged from 0.2 to 8 $\mu g/m^3$, which is less than the OSHA PEL.[16] However, the NIOSH REL of 2 $\mu g/m^3$ (ceiling limit) was exceeded.[11]

Area samples for arsenic were collected at the pouring station and furnaces in the commercial laboratory. All concentrations of arsenic were below 3.5 $\mu g/m^3$ at the pouring station and less than 1.3 $\mu g/m^3$ at the furnaces.

OTHER METALS. Personal exposure concentrations for various metals and minerals (including beryllium, cadmium, chromium, cobalt, copper, manganese, molybdenum, nickel, selenium, silver, tellurium, thallium, tin, vanadium, and zirconium) collected on workers in the fire assay areas of both laboratories were all below their respective NIOSH RELs, MSHA PELs, OSHA PELs, and ACGIH TLVs. Nevertheless, there is the potential for increased exposure to hazardous

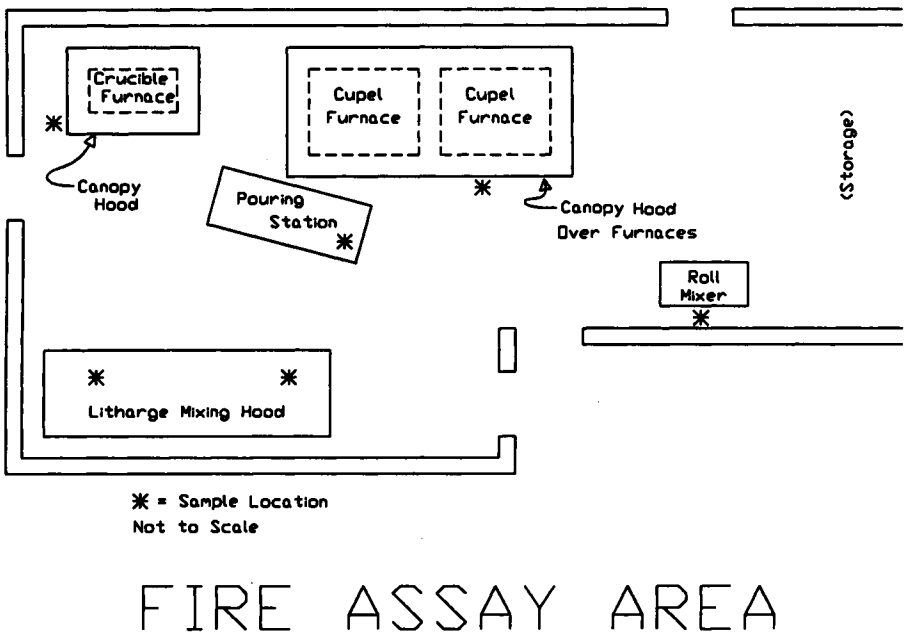

FIGURE 6. Sample locations in the fire assay area at the commercial assay laboratory.

metals for the mine assay laboratory workers when a different ore body is encountered. The specific level of exposure varies with the composition of the ore body. For example, oxide ore bodies tend to be lower in arsenic and mercury than refractory ore bodies. Additional air sampling should be conducted whenever a different ore body is encountered or evidence from laboratory analytical data indicates increased levels of hazardous metals such as cobalt or arsenic.

MERCURY. In the mine site laboratory, spot mercury measurements were made in the wet chemistry lab, at the drying oven in the sample preparation area, next to the furnaces in the fire assay room, and while pouring molten samples into the metal cone molds. All mercury levels were less than the sensitivity of the instrument, which was 0.003 mg/m^3.

VENTILATION. In the fire assay area of the mine site laboratory, the average face velocity and air flow into the flux mixing hood are shown in Table 1. The face velocity to the flux mixing hood at this laboratory was 30 ft/min. The mine site laboratory also utilized an automatic mixer to mix the flux with the samples. This operation helps reduce the workers' exposure compared with hand mixing. The face velocity at the litharge hood in the commercial laboratory averaged 160 ft/min with an air volume of 950 ft^3/min. The ACGIH industrial ventilation manual recommends a 100 to 200 ft/min capture velcoity (Table 3-1 in the ACGIH industrial ventilation manual) for intermittent container filling operations.[13] This hood operates within these guidelines.

The average face velocity and air flow into the fusion furnace hoods and the cupellation furnace hood at the mine site laboratory are presented in Table 1. Exhaust air flow for the left fusion furnace hood was nearly twice that for the right fusion hood at this laboratory. This inconsistency is not surprising since the hood for the left furnace was nearest to the exhaust fan. During the mine site laboratory survey, the operating temperatures for fusion furnaces 1, 2, and 3 were 1950°, 1950°, and 1770°F, respectively. The cupellation exhaust hood at this laboratory had its own fan. Exhaust air from all the furnaces is discharged directly outside.

Smoke tubes were used to visualize the air currents in the fire assay area at the commercial laboratory. The smoke tube findings indicated that the canopy hoods located over the furnaces in the fire assay area did not extend out far enough in front of the furnaces or have adequate air volume to capture the smoke. Smoke escaped the capture of the canopy hoods and rose to the ceiling, where it exited through an opening located around the exhaust ventilation duct, causing the high lead concentrations noted in Table 4.

The large canopy hood in the commercial laboratory (located over the two cupellation furnaces) had an average face velocity of 110 ft/min with an air volume of 1030 ft^3/min. The hood exhaust volume of 1030 ft^3/min was less than the convection currents of approximately 2000 ft^3/min generated

TABLE 5. Personal Sample Concentrations of Arsenic in Fire Assay Area (Commercial Assay Laboratory)

Worker	Date	Average Sample Time (min)	Number of Samples	Arithmetic Mean (μg/m^3)	Range (μg/m^3)
A	12/14/93	243	2	8	0.1–15
A	12/15/93	234	2	0.3	0.2–0.5
A	12/16/93	212	2	0.2	0.2–0.3
B	12/15/93	215	2	3	0.2–5.6
B	12/16/93	160	2	0.4	0.3–0.5

OSHA PEL = 10 μg/m^3; NIOSH REL = 2 μg/m^3 ceiling.

by the two furnaces. The convection currents were calculated using the formula

$$q_0 = 29[(H')(Ap^2)(m)]^{1/3}$$ (17)

where:

q_0 = air induction rate at upper limits of hot source (cubic foot/minute)
Ap = cross-sectional area of air stream
m = height of column receiving heat
H' = convection heat transfer rate, BTU per minute

The canopy hood extends 3 inches in front of the two furnace doors. The hood should extend approximately 6 to 8 inches in front of the furnaces to capture the plume which expands at about a 5° angle from the heat source.[17]

The average face velocity into the canopy hood (located over the crucible furnace at the commercial laboratory) was 60 ft/min with an air exhaust volume of 750 ft^3/min. This exhaust volume was less than the convection currents of approximately 1100 ft^3/min calculated to be generated by this furnace.[17] The canopy hood on the crucible furnace should also extend 6 to 8 inches from all sides of the furnace.[17]

During our surveys, employees at both laboratories wore high efficiency particulate air (HEPA)-filtered half-mask respirators in the fire assay area and during flux mixing operations. HEPA-filtered half-mask or half-mask dust and mist respirators were worn in the sample preparation areas. The mine site laboratory also rotated employees through the fire assay and sample preparation areas to help minimize exposures. The workers at the mine site laboratory were provided with clean uniforms daily, and shower facilities were available.

Conclusions

Sample Preparation Area

In the mine site laboratory, the combination of partial enclosures, local exhaust ventilation, and the use of an enclosed pulverizer with fixed nozzle compressed air jets effectively controlled respirable dust and respirable quartz levels in the sample preparation area. For example, all respirable quartz exposures were less than the NIOSH REL of 0.05 mg/m^3 as well as the MSHA PEL, OSHA PEL, and ACGIH TLV. Area samples taken in the sample preparation area on top of the drying oven showed lead and arsenic levels to be well below their respective NIOSH RELs, MSHA PELs, and OSHA PELs.

The local ventilation systems in the sample preparation area of the commercial assay laboratory also appear to control exposures. No area or personal air samples were above the NIOSH REL, OSHA PEL, MSHA PEL, or ACGIH TLV for respirable quartz. These results appear to be related to several factors, including: (1) small quantities of material processed; (2) good ventilation of the crusher equipment; (3) enclosure of the puck and ring mills; and (4) conscientious work practices.

The following recommendations are offered for controlling respirable quartz exposures.

1. The risk of exposure to respirable quartz is greatly increased through the use of compressed air for cleaning. A portable HEPA filter vacuum system or a vacuum system connected to the local ventilation system is recommended for cleaning this area to prevent unnecessary silica exposures and to reduce the risk of cross-contamination between assay samples.
2. Where compressed air is used, significant turbulence is created within the hoods. The ACGIH industrial ventilation manual recommends capture velocities of 200 to 500 ft/min for conditions when compressed air is used.[13] If vacuuming is used, reduced capture velocities may be used to effectively control exposures.
3. The face velocities for hoods can be increased by increasing the degree of enclosure. This can be accomplished economically by adding Plexiglass® to the existing hoods to decrease the face area, while still maintaining sufficient visibility so that the employees can effectively perform their duties. Some laboratory managers have expressed concern that when capture velocities exceed 150 ft/min, entrainment of sample fines may occur and thereby compromise the validity of the analysis.[5] Important factors that need to be considered before increasing the capture velocities include hood design, restricting the use of compressed air, and work practices. Proper protection with lower exhaust volumes may be achieved by limiting the use of compressed air.

Fire Assay Area

Good practices and controls observed at the mine site laboratory included the use of: (1) premixed flux that contains a mineral oil which helps control lead dust during flux mixing; (2) a partial enclosure and exhaust ventilation for the litharge mixing table; and (3) local exhaust ventilation hoods over the fusion and cupellation furnace doors. Nonetheless, three personal samples for lead were above the OSHA action level of 30 $\mu g/m^3$. Exceeding the action level triggers a number of requirements under the OSHA lead standard.[3] With lead exposures above the action level, the fire assayers should wear respiratory protection while working in the litharge/furnace room. Airborne concentrations should be monitored if evidence from laboratory analytical data indicates increased levels of hazardous metals such as arsenic or cobalt.

As demonstrated by air sampling results in the commercial assay laboratory, the enclosed downdraft ventilation litharge hood does appear to control worker exposures to lead during litharge mixing operations in the fire assay area. Smoke tube tests and air sampling results in the fire assay area of the commercial assay laboratory indicated that the ventilation systems on the furnaces are undersized. To control fume exposure, hoods and exhaust flows need to be properly sized to capture convection currents completely.

Smoking and eating in the laboratory work areas should not be permitted. Workers exposed to lead, arsenic, or other toxic metals should shower and change from work clothes to street clothes after their tour of duty. Such measures should help reduce the possibility of taking lead home to the family.

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Disclaimer

Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

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