A Guideline to Reducing Inorganic Lead Exposure in Fire Assay Laboratories

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This is the first edition of "A Guideline to Reducing Inorganic Lead Exposure in Fire Assay Laboratories".

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Introduction

Purpose

Fire assay laboratories that use lead oxide (litharge) in their procedures can put the health of laboratory employees at significant risk when lead exposure control measures are inadequate. Engineering controls, administrative controls and personal protective equipment (PPE) are all important components of reducing worker exposure. All laboratory designs are different; each laboratory must conduct regular biological and exposure monitoring to ensure that the controls in place are effective.

The purpose of this document is to provide guidance on controls that can be implemented in fire assay laboratories to reduce worker exposures to inorganic lead and meet the requirements of the Health, Safety and Reclamation Code for Mines in British Columbia (HSR Code).

Sources of Exposure

Lead oxide (litharge) is an important component of the flux material used in the fire assay process to aid in separating target precious metals from the ore. The greatest sources of inorganic lead exposure occur from the release of airborne particulates when mixing flux material and firing cupels. These fine particulates stick to skin, hair, clothing and laboratory surfaces and are easily transferred from one area to another, making exposures to lead a concern throughout the fire assay procedure. Exposure to inorganic lead can cause adverse health effects. Inorganic lead affects a number of body organs and systems, including the nervous and reproductive systems. Lead has the ability to accumulate in the body following repeated exposures, presenting a serious risk for those who work with and/or near lead and lead-containing materials.

Routes of Entry

Inorganic lead most commonly enters the body via ingestion or inhalation. Smaller inhaled particles that reach the lower respiratory tract can be completely absorbed by the body. Larger inhaled lead particles stick to the mucous layer on hair-like fibres called cilia in the upper respiratory tract. The mucous and sweeping motion of the cilia moves lead out of the respiratory tract where it is often swallowed and introduced to the digestive system. Ingestion can also occur due to inadequate hand and face washing before eating, drinking or smoking. Harmful concentrations of lead are not always visible; and no amount of lead accumulation in the body is considered to be safe.

Once lead enters the body, it travels through the bloodstream and is stored in bones and the liver, kidneys, pancreas and lungs. Lead mimics calcium ions, resulting in approximately 94% of the total amount of lead that enters the adult body to be stored in bones. The elimination half-life for lead in bones is approximately 27 years (ATSDR, 2007). Stored lead continues to cause adverse health effects which, given the long elimination half-life, raises significant concerns for workers repeatedly exposed as the total body burden increases with time.

Did You Know?

Blood lead levels have been found to be notably higher in household members sharing homes with workers who have occupational exposures to lead compared to those who do not (Sun et al., 2002).

Lead Poisoning

Symptoms of lead poisoning are non-specific and therefore are difficult to identify. They include abdominal pain and cramping, constipation, diarrhea, anemia, difficulty sleeping, headaches, irritability and muscle weakness. Regular monitoring of fire assay workers' blood lead levels is recommended due to the difficulty in attributing these non-specific symptoms to lead poisoning. Recovering from chronic lead poisoning can take months to years. Full recovery is not always possible, leaving those affected at risk for permanent kidney, muscle, nerve and brain damage.

Exposure Controls

Fire assay laboratories and areas where lead work occurs should be contained and separated from other work areas to ensure that worker exposure is kept as low as possible. Exposures to inorganic lead are best controlled by capturing the lead at the source through engineering controls such as local exhaust ventilation. Administrative controls that can be utilized to limit worker exposures include rotating workers through different jobs, regular cleaning of laboratory surfaces and enforcing proper personal hygiene procedures. Personal protective equipment (PPE) also plays a significant role in reducing worker exposures. It is important to use the appropriate PPE required for each task.

Safe Work Procedures

Safe work procedures must be developed to provide process specific guidance to workers on how to protect themselves from potentially harmful exposures. Safe work procedures for fire assay laboratories should include stipulations for the proper use of lab equipment and PPE. The procedures should detail the required maintenance of lab equipment as well as the target operating parameters for ventilation equipment. Safe work procedures that detail expectations for good housekeeping and personal hygiene should be developed and implemented. Workers must be trained in safe work procedures and informed of the hazards related to working with lead.

Ventilation

Adequate ventilation in a fire assay laboratory is critical to minimizing worker exposures. Laboratory ventilation systems should be designed by a certified ventilation engineer who can ensure that the system will be appropriate for the specific layout of the laboratory and for handling lead. Dilution ventilation systems are not suitable for controlling worker exposure to lead dust in fire assay labs. Adequate exhaust ventilation must be provided wherever workers:

- mix the flux into ore samples
- operate fusion and cupellation furnaces
- pour samples into slag moulds
- cool samples

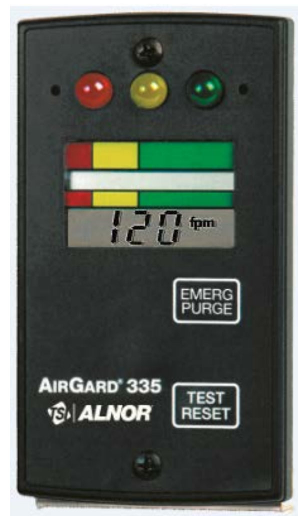

Figure 1: *Example of a flow indicator for a fume hood.*

The potential for worker exposure is greatest when workers are performing the steps listed above as these procedures can generate fumes or airborne particulates. Controlling these exposures at the source minimizes worker exposure and the spread of contamination to other work areas. Every fume hood should be equipped with a flow indicator or alarm to notify workers immediately if flow rates drop below operational requirements (see Figure 1). Exact ventilation requirements will vary depending on the design of and conditions within the lab.

Each lab must be individually assessed to determine the optimum operating parameters for the ventilation system. The most efficient way to capture contaminants and reduce worker exposure is to enclose areas of contaminant generation as much as possible. Reducing the surface area of the hood face opening facilitates contaminant capture at lower flow velocities. Operating parameters specific to containing heavy and toxic contaminants should be considered in the design of the local exhaust ventilation systems. In general, the fire assay laboratory should maintain a slightly negative pressure environment to aid in keeping lead dusts and fumes inside the lab.

The ventilation system of any fire assay laboratory should be balanced by a certified individual anytime an alternation is made. Changes to a ventilation system warrant the need for additional exposure monitoring to confirm the effectiveness of controls.

Mixing the Flux

Automated mixers are preferred when mixing the flux and ore sample (see Figure 2). These mixers improve the consistency of mixing and help to limit lead exposure. Mixing flux and ore by hand must be conducted in a ventilated hood. The speed of mixing and the tool used to stir the flux should be chosen so as to minimize the amount of dust discharged into the air. It is recommended that this task be completed in a side-draft or downdraft capturing hood that is fully enclosed on at least three sides. A side-draft capturing hood should have a baffle system with more than one slotted opening to ensure laminar flow through the open face of the hood. The operational face velocity for this style of hood should not exceed 0.64 metres/second, or 125 feet/minute (ACGIH, 1992) as velocities beyond this create eddies in the air currents that can allow contaminated air to reach the worker's breathing zone. If contaminants cannot be captured sufficiently using a face velocity of 0.64 m/s (125 ft/min) or less, a different style of hood that can capture the contaminants should be employed.

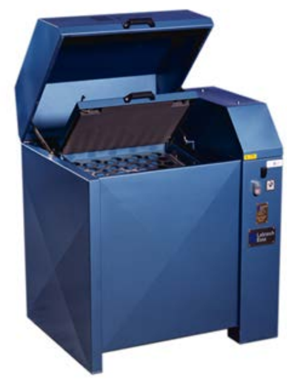

Figure 2: *An automated flux mixer.*

Single-slotted and canopy-style hoods are not appropriate for contaminant capture while mixing the flux due to the nature of the contaminants and the operational capabilities of these hoods. A single-slotted hood, having only one draw point, is designed to pull air uniformly across a single plane; it will not effectively capture lead particulates that are expelled in all directions above and around the crucible while mixing. The single-slotted hood is most effective when the contaminant source flows in a single plane and is placed directly in front of the midline of the slot. Canopy-style hoods can be effective at capturing contaminants released from a hot process where particles are carried into the hood on rising hot air

Did You Know?

Mineral oil can be added to the flux mixture to help suppress dust while mixing.

currents. As indicated by McDermott (1985), effective capture of dusts by a canopy style hood from a mixing process would require a) the hood be placed 1.2 metres (4.0 feet) above the work space and b) an 850% increase of airflow into the hood. This setup would increase sample loss, impede the worker's ability to mix the sample and entail significant operating costs.

Pouring, De-slagging and Hammering

Pouring the molten flux and sample into moulds must be completed in a ventilated enclosure. While slag is cooling in the moulds, a mesh screen should be placed on top to reduce the spread of slag as it cools and cracks. If the fusion process is incomplete, the slag may contain lead. It is good practice to break off slag and hammer the lead button within a hooded enclosure to limit the potential spread of lead-containing particles and to minimize the clean-up required after de-slagging. A side-draft enclosing hood of a similar style to that recommended for mixing flux would be suitable for pouring, de-slagging and hammering the lead button (see Figure 3).

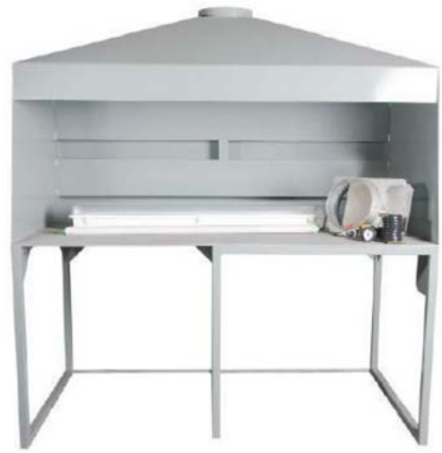

Figure 3: *Hooded work bench for mixing flux and de-slagging moulds.*

Firing Crucibles and Cupels

Furnaces in fire assay laboratories must have hoods to control temperature and capture fumes emitted from the crucibles and cupels. A common problem in fire assay labs is the inability of the furnace hood system to capture the fumes released when removing samples from the furnace. This problem most often occurs due to inadequate exhaust flow and incorrectly configured hoods.

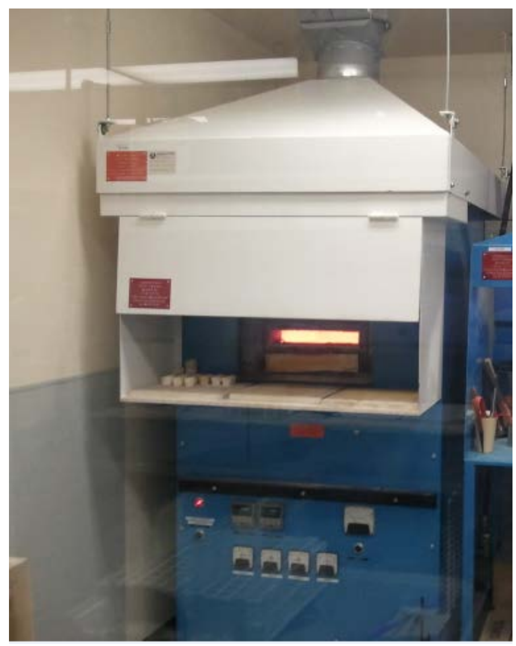

Figure 4: *Cupellation furnace equipped with hood space for hot cupels.*

If using a low-canopy hood over a furnace, contaminant capture can be achieved by extending the edge of the hood 30 cm (12 in.) beyond all sides of the furnace (ACGIH, 1992). A low-canopy hood is defined as being situated at a distance from the hot source that does not exceed either the diameter of the source or 1 m (3 ft) whichever is smaller (ACGIH, 1992). A series of case studies completed by NIOSH have shown, however, that extending the hood 15 – 20 cm (6 – 8 in.) beyond the furnace edges and increasing exhaust air volume can also sufficiently limit worker exposures in fire assay laboratories (Hall et al., 1998; Tharr, 1991). Each situation must be assessed individually to determine the appropriate hood configuration and operating parameters.

The exhaust air volume of the furnace canopy hood must be greater than the convection currents generated when the furnace door is opened. Upward air currents from hot processes are capable of reaching a velocity of 2.0 m/s (400 ft/min) (ACGIH, 1992). Convection currents in fire assay laboratories will differ between furnaces, but have been measured in the range of 0.5 – 0.9 m^3/s (1,100 –2,000 ft^3/min) (Hall *et al.*, 1998). These strong currents are created by the rapid release of heated air when opening the furnace door. Canopy hood systems are also highly susceptible to cross-drafts interfering with contaminant capture. Sources of cross-drafts should be eliminated or reduced to avoid losses in contaminant capture efficiency. In these situations, heat-resistant curtains may be hung from the edges of the canopy hood to limit cross-draft interferences and increase capture velocity and efficiency.

Other options for increasing the effectiveness of a furnace canopy hood system include increasing the fan size and/or speed of the existing system and installing a secondary canopy hood above the furnace door. Using a secondary hood for fume capture has been most successful when the hood extends at least 10 cm (4 in.) beyond the front and sides of the door and maintains a face velocity of at least 1.5 m/s (300 ft/min) (Tharr, 1991).

Quick Tip:

If fumes can be seen rising beyond the edge of the hood when samples exit the furnace, the hood is not configured properly to capture contaminants and must be adjusted by a certified individual.

The largest volume of contaminated fumes produced in the fire assay process arises from cupellation of the lead button. Effective controls must be in place to contain contaminants emitted during this process. To ensure containment of these fumes, it is recommended that the cupellation furnace door be equipped with an enclosed hood that provides shelf space for cupels to cool while the fumes dissipate (see Figure 4). Some laboratories will transfer the cupels from the furnace to a separate hooded workbench to cool; however, this process is not recommended as it allows fumes to enter the work area when the cupels are transferred from the oven to the cooling bench, increasing the risk of worker exposure.

Supply Air

Due to the high flow rates that are required by hood systems, it is important that an adequate supply of make-up air be provided to the lab. The high operating temperatures of the furnace in summer weather and the cold air conditions during winter can create uncomfortable and hazardous working conditions. Provisions must be in place in fire assay laboratories to ensure workers are not exposed to hazardous environments. The supply air for fire assay laboratories should be temperature-controlled to mitigate worker exposures to temperature extremes throughout the year.

Scrubber Systems

All of the air from the fire assay lab must be exhausted out of the building in a manner that prevents entry of contaminants into the building or other nearby areas. It is recommended that the exhaust air be vented to a scrubber system capable of removing fine lead particles from the exhausted air. There are many different options available for scrubber systems. A bag house system similar to the one depicted in Figure 5 can effectively collect lead dusts. Air cannons or vibrating rods shake off dust collected on filter media and enhance the efficiency and longevity of the scrubber system. If the filtering media become clogged, pressure changes can occur in the scrubber system, which may reduce the effectiveness of contaminant capture. Therefore, scrubber systems should be equipped with pressure gauges that can be monitored to ensure the system is functioning as required. The dust shaken from the filtering media must be stored in a sealed container and appropriately labelled to identify it as containing hazardous lead waste. The waste must be collected for disposal by qualified individuals wearing appropriate PPE.

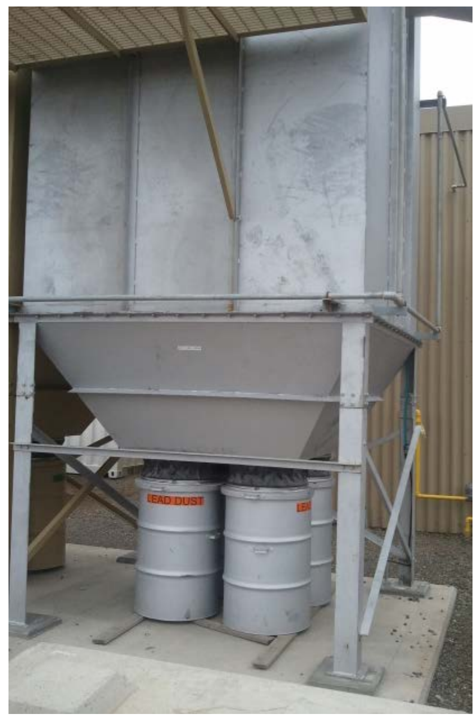

Figure 5: *Lead dust collection barrels of an exhaust filtration system.*

Ventilation Maintenance

Regular testing of the ventilation system must be conducted, including after initial installation and after alterations have been made to an existing system. Over time, parts of the ventilation system (belts, motor, etc.) can become worn, affecting the performance of the fume hoods. The ventilation system should be tested at least every three months or more frequently based on manufacturer recommendations. Measurements of capture and face velocity, duct velocity and/or static pressure of the local exhaust systems in the lab should be completed during testing. Face velocity measurements give a good estimate of performance between regular maintenance checks but should not be relied upon alone to determine the capabilities of the ventilation system. The measurements obtained during regular system assessments should align with the values required to contain contaminants. As a general guideline, fume hoods should operate at face velocities in the range of 0.4 – 0.6 m/s (80–125 ft/min) (ACGIH, 1992); due to the weight and toxicity of lead particles, it is recommended that fume hoods in fire assay laboratories operate at the higher end of this range. Duct velocities should be in the range of 20 – 23 m/s (4,000–4,500 ft/min) (ACGIH, 1992). A log book must be kept for each hood to record the test date and operating performance of the hood. The log book can also be used to record any maintenance or problems that have occurred.

Acceptable standards for testing fume hoods include *ACGIH Industrial Ventilation: A Manual of Recommended Practice* and ASHRAE Standard 110-1995: *Method of Testing Performance of Laboratory Fume Hoods*. When assessing the average face velocity of a fume hood, a series of velocity measurements should be taken in a grid pattern across the open face of the hood. Each square of the grid should be approximately 0.09 m^2 (1 ft^2) (ASHRAE, 1995). If any measurement taken within a section of the grid pattern fluctuates from the average face velocity by 15% or greater, there may be air turbulence affecting performance, or the fume hood may be poorly designed (ASHRAE 110-1995). If a fume hood is found to have deviated to an average face velocity below 90% or 20% above the required operating parameters, it must not be used until the ventilation system has been restored (ANSI/AIHA Z9.5-2012).

Smoke tube testing can be performed to detect air turbulence that may interfere with hood performance. If smoke is not captured or flows out of the hood, the hood has failed the test and should not be used until corrective actions have been completed. It should be noted that a smoke tube test is not an adequate test on its own to assess the contaminant-capturing abilities of the hood.

Personal Protective Equipment (PPE)

In a fire assay laboratory, having the proper PPE is important for both worker protection and preventing lead contamination outside of the lab. Employees must be provided with the PPE necessary to safeguard their health.

Protective Clothing

At all times in fire assay laboratories, workers must wear the protective clothing necessary to safeguard their health. This includes any clothing required to protect workers from the hazards associated with the furnaces and with pouring molten samples. Protective clothing such as lab coats and coveralls worn in the fire assay laboratory should not leave the lab. It is recommended that any personal clothing worn in the fire assay lab be washed on site to avoid the spread of lead contamination. The mine manager must provide on-site cleaning services suitable for lead contaminated protective clothing or contract these services to an external provider.

To reduce the amount of lead transferred out of the lab, as much of the workers' skin and street clothing should be covered as possible. Coveralls are preferred when fire assaying as they provide full-body protection from settling lead particles. Employees should be provided with more than one lab coat or set of coveralls. Depending on the number of samples being processed, coveralls and lab coats should be replaced with a clean pair at a frequency ranging from daily to weekly. Used coveralls and lab coats should be placed in sealed containers, labelled to identify that they contain a lead hazard while awaiting pick-up for cleaning.

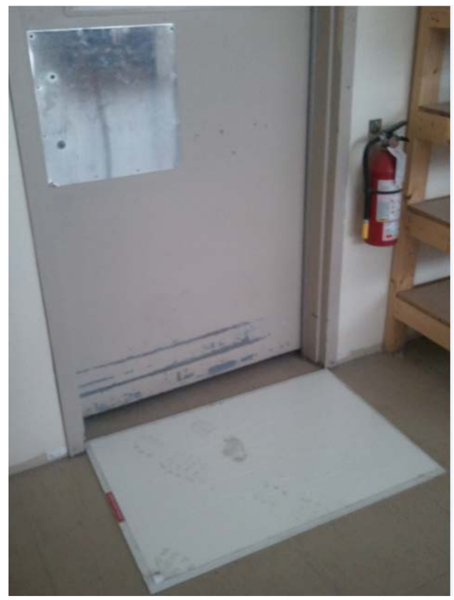

Figure 6: *A sticky door mat placed on the inside of the fire assay lab to capture dust from workers' boots as they exit.*

Boot covers can be used to limit the spread of lead contamination. Boot covers should be removed from boots before leaving the lab. Boot covers may be disposable or made of a cloth material that can be washed and re-used. Sticky mats are also an effective option for preventing the spread of lead from the assay lab. When placed at the entrance/exit to the fire assay lab, the mat's sticky surface captures particles from the bottom of workers' boots. Sticky mats should be regularly maintained to ensure particles are efficiently captured on an ongoing basis.

Respirators

Fire assay laboratory workers must be fit tested and supplied with a respirator that has an appropriate assigned protection factor. Respirator filter cartridges must be able to protect against inhalation of respirable-size dusts. Respirators should be worn at all times in the lab.

Fit testing for respirators must be performed by trained individuals. After the initial fit test, workers must be fit tested at least every two years, or more frequently if required (e.g. after a weight change, facial injury, etc.). Best practice is for workers to be fit tested at least annually. Workers must not have any facial hair that may interfere with a complete seal. Workers must be trained in the use and limitations of respirators, as well as proper care and storage. Respirators should be stored in a manner that will not allow them to become contaminated, such as in a designated storage locker or in specially designed sealed bags. Respirators should be cleaned after use.

Gloves

Disposable gloves should be worn while mixing flux and handling samples that have been mixed with flux. Fine lead particles stick easily to skin and can be difficult to remove (Esswein *et al.*, 2011). Disposable gloves should also be worn while cleaning lead contaminated areas and when handling lead contaminated equipment. Controls must also be in place to mitigate the risk of thermal burns when working at the fusion and cupellation furnaces and with hot samples. Hand and arm protection used for this purpose should be rated to protect against the amount of radiant heat emitted from the furnace and against splashes of molten materials.

Face and Eye Protection

Safety glasses should be worn at all times in the fire assay lab. When de-slagging the lead buttons, a face shield should be worn to protect the face and eyes. In accordance with CAN/CSA Z94.3, as updated from time to time, Class 6 protection (face shields) must be worn in conjunction with either Class 1 (spectacles) or Class 2 (goggles) protection. When choosing eye and face protection, consideration shall be given to impact resistance, flame resistance and protection from non-ionizing radiation, as required by the CAN/CSA Z94.3 standard. Protection from non-ionizing radiation becomes a concern when working with fusion and cupellation furnaces.

Figure 7: *A fire assay worker wearing full PPE while de-slagging samples.*

Personal Hygiene

Maintaining good personal hygiene is the final defence against lead exposure. Lead easily sticks to skin, clothing and hair, making it important for workers to shower and change their clothing at the end of a shift. The site must support good personal hygiene habits by providing workers with appropriate training and facilities. Personal hygiene procedures should be clearly explained to workers and provided in a written safe work procedure.

Face and Hand Washing

Fire assay laboratory workers must wash their hands and faces before eating, drinking or smoking. Hand-washing stations should include nail brushes to remove lead from underneath fingernails. Some studies have shown that common decontamination procedures using generic soap and water alone are not successful at removing lead from the skin (Esswein *et al.*, 2011; Virji *et al.*, 2009). A study conducted by Esswein *et al.* (2011) determined that some soaps specializing in the removal of heavy metals such as lead performed better than regular soap and water alone. The effectiveness of lead removal has also been shown to increase when scrubbing with a textured surface or wipe, as suggested by Esswein *et al.* (2011). The amount of lead remaining on workers' hands after hand washing has been correlated to levels of lead found in workers' blood, indicating the importance of hand washing in reducing exposure to lead (Sun *et al*., 2002).

> ### Did You Know?
>
> *Lead doesn't just stick to workers' hands. Workers sampled from 13 construction sites had an average skin lead contamination level of 814μg on their hands at break time and 373μg on their faces at the end of shift (Virji* et al.*, 2009).*

As lead is easily transferred from one surface to another, the wash station provided to fire assay employees should not be used for any purpose other than lead removal unless faucets and soap dispensers are automatic or operated by a foot pedal. If the faucet and soap dispenser are manually operated, the procedure for hand washing should include a provision to turn off the faucet with the use of a disposable wipe or paper towel so as to avoid contact with a contaminated surface.

To monitor the effectiveness of hand washing, lead test kits can be used, as a training tool or otherwise, to indicate where lead remains on skin after hand washing. These test kits are capable of producing immediate results at a sensitivity level below lead exposure limits.

Mine Dry Facilities

Part 2.4.2 of the HSR Code requires that fire assay lab workers have access to showering facilities and separate storage areas for street and work clothing. A person exposed to contaminants shall not leave the mine at the end of their shift until all affected areas of skin have been cleansed of contamination. The site must ensure workers are provided with the resources required to sufficiently decontaminate, such as washing supplies and allotted time at the end of their shifts to properly decontaminate themselves. Similar to hand washing, specialized soaps that remove heavy metals from the hair and body are available. Due to the ability for lead contamination to spread easily to other areas, the showering facilities must be designed to ensure that lead contamination is contained. The showering facility should be designed so that there is a "clean" side and a "dirty" side, with separate entrances and exits for each side. The two sides should be separated by the shower room. A locker for each employee should be provided on each side so that clothing worn in the assay lab, including boots, remains on the contaminated side. Laundry collection bins should be provided for used work attire. Anything that may have been contaminated in the fire assay lab should not enter the clean side of the dry.

Did You Know?

Elevated lead levels are often found in personal vehicles of workers who do not use or have access to showering facilities (Virji et al., *2009).*

Employees should be provided with clean towels to use when exiting the showers. Once on the clean side, employees can change back into their street clothes and should not cross back to the contaminated side. When arriving for a shift, employees should store all clothing on the clean side and cross through the shower area to change into work clothes. Clean coveralls/lab coats should be stored on the clean side. Employees should not leave the site with any contaminated equipment or clothing.

Good Housekeeping

Frequent and regular cleaning of the assay lab prevents lead dust from accumulating on laboratory surfaces. Fire assay laboratories with daily cleaning procedures can see significant reductions in lead contamination of shared laboratory and work spaces (e.g. wet assay laboratories, scale rooms, lunchrooms, etc.). Surface swab and personal exposure monitoring results should be reviewed to determine an optimal cleaning frequency. Dust accumulation can represent a significant source of secondary contamination when it is disturbed. Dry sweeping should be avoided, especially when cleaning the assay lab floor. In addition, compressed air guns should not be used to clean up areas that could be contaminated with lead dust. Local exhaust ventilation systems designed to capture contaminants in laboratory work areas are rarely designed to contain the air currents generated by compressed air, causing lead particles to become airborne, escaping the local exhaust ventilation system and contaminating the work environment.

A vacuum system that is connected directly to the ventilation system should be used to contain the dust. This type of system eliminates the need to change filters and handle collected dust for disposal. A portable vacuum suitable for an industrial setting with a high-efficiency particulate arrestance (HEPA) filter is another option. Vacuums should be emptied in a manner that limits employee exposure and does not allow lead to re-enter the area. Any collected dust and used vacuum filters must be stored in an appropriately labelled, sealed container while awaiting disposal. After vacuuming has been completed, surfaces should be wiped down with soap and water. Soaps designed to remove heavy metals from surfaces may be more efficient than using generic soaps. Once cleaning is completed, care must be taken to ensure that equipment used during cleaning is handled and stored in a manner that does not spread contamination outside of the lab.

Exposure Monitoring

The HSR Code requires monitoring of workplace exposures be conducted to assess personal exposure levels. Exposure assessment should be done under the direction of a certified industrial hygienist. In addition, monitoring should be conducted to ensure lead contamination does not spread beyond the assay laboratory. For example, swabs of surfaces outside of the laboratory should be collected and analyzed to verify containment. It is recommended that floor surfaces for laboratories (other than fire assay laboratories) not exceed 2.2 mg/m^2 (200 $\mu g/ft^2$) and surfaces in eating areas not exceed 0.43 mg/m^2 (40 $\mu g/ft^2$) (WorkSafeBC, 2011).

A medical surveillance program is required by Part 2.12 of the HSR Code. Accordingly, employees must be made aware of the importance of regular biological monitoring and that a medical surveillance program is available. Employee participation in the program must be on a voluntary basis. A person participating in the medical surveillance program may attend the doctor of his/her choice to undergo any examinations and tests stipulated within the program. A blood sample is often taken to assess a worker’s exposure to lead. An occupational health physician should be consulted to determine the recommended tests, frequency of testing and to interpret the test results. Regular testing is needed as symptoms of lead poisoning are non-specific and develop over time as overexposures occur. It should be noted that blood lead levels are not synonymous with lead poisoning. While the elimination half-life for lead in the blood stream is approximately 30 days, lead most often accumulates in the bones where it has an elimination half-life of approximately 27 years (ATSDR, 2007). This retention and accumulation of lead can result in lead poisoning.

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Figure 1. Example of a flow indicator for a fume hood. Photo courtesy of TSI Inc. [Received on Sept.19, 2014].

Figure 2. An example of an automated flux mixer. Photo courtesy of FLSmidth. [Received on August 4, 2014].

Figure 3. Hooded work bench for mixing flux and de-slagging moulds. Photo courtesy of Anachemia Science. [Received on October 2, 2014].

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