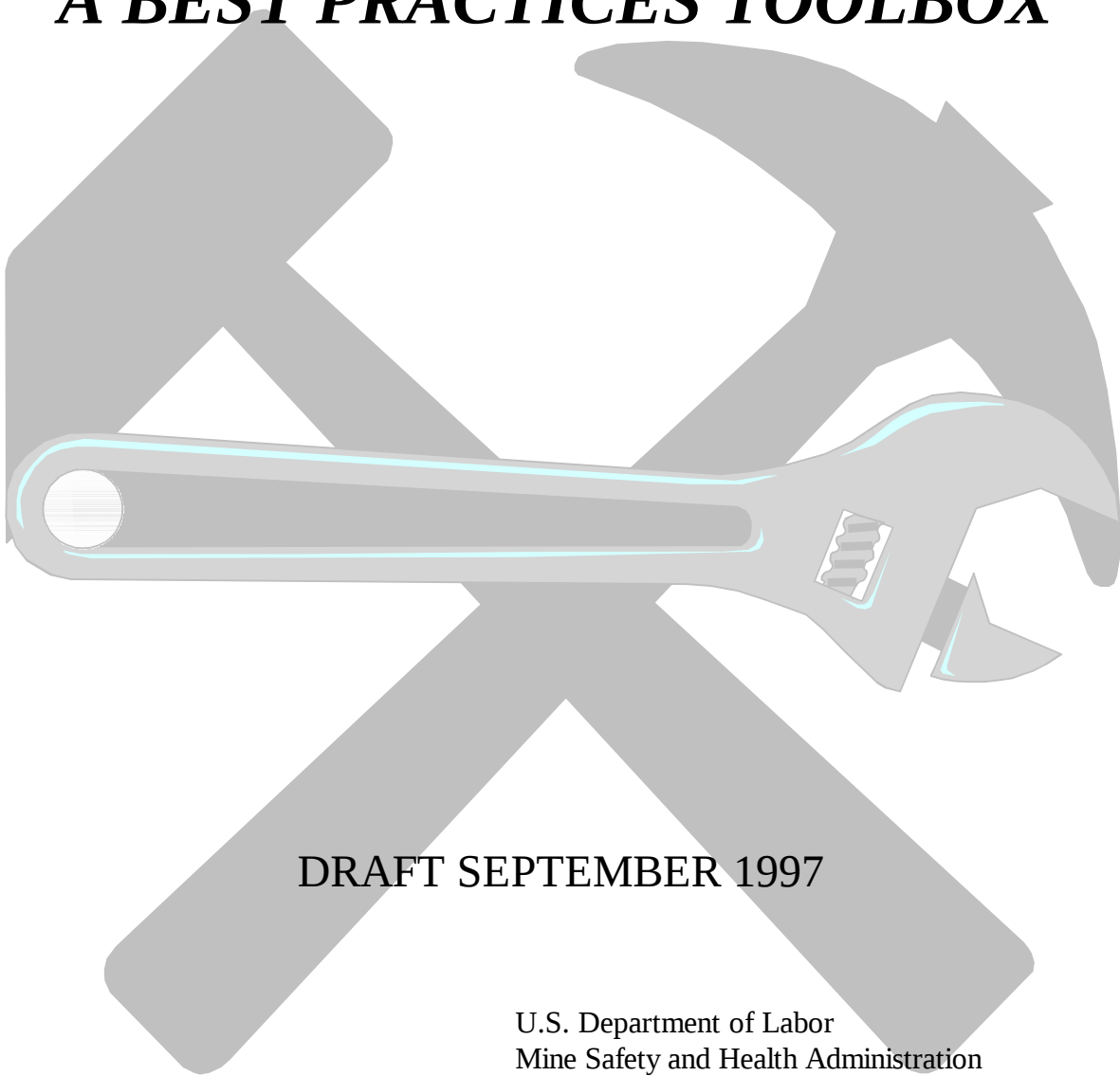


CONTROLLING MERCURY HAZARDS IN GOLD MINING: A BEST PRACTICES TOOLBOX



DRAFT SEPTEMBER 1997

U.S. Department of Labor
Mine Safety and Health Administration

CONTROLLING MERCURY HAZARDS IN GOLD MINING: A BEST PRACTICES TOOLBOX

ABSTRACT

Mercury hazards traditionally have been associated with the gold mining industry in the United States and continue to pose hazards to present day miners. In her 1925 book Industrial Poisons of the United States, Dr. Alice Hamilton recognized the severe hazards of mercury in mining.¹ In 1997, mercury continues to present risks to miners.

Mercury is a cumulative poison which can affect the brain, the central nervous system and the reproductive system. It can be absorbed by inhalation, ingestion and through the skin.^{2 3} If proper care is not taken at the worksite, miners can carry contaminants home and expose their families.⁴ Because it has no warning properties, individuals often underestimate the hazard of exposure to mercury.

The amount of gold produced in the United States has increased tenfold since 1980; employment in gold mining has increased greatly in the same period. In the past six years, the Mine Safety and Health Administration (MSHA) has found many overexposures involving mercury. Because of these overexposures and their corresponding serious potential risks for miners, MSHA has developed this document which discusses mercury hazards and current “Best Practices” to reduce exposure in the gold and silver mining industries. The “Best Practices” section recommends procedures and activities that a mine operator or health and safety professional can use to ensure the miner a healthful worksite.

ACKNOWLEDGMENTS

The Mine Safety and Health Administration has conducted a series of Technical Support assistance visits over the last five years to determine ways of controlling miners' exposures to mercury at gold and silver mining operations. This manual "Controlling Mercury Hazards in Gold Mining: A Best Practices Toolbox," draws upon the experience gained in those visits. The objective of the manual is to limit miners' exposures to mercury by sharing information within the mining community on methods of controlling mercury .

This "Best Practices" manual was conceived and written by Michael Lynham, while an industrial hygienist with MSHA's Toxic Materials Division of the Denver Safety and Health Technology Center. Thanks to the personnel of the Denver Safety and Health Technology Center's Toxic Materials and Physical Agents Divisions for their assistance in composing this document. Special thanks to Galen Trabant, who assisted Michael Lynham in designing many of the suggested control measures, as well as to Steven Kneipple and the Denver Mineral Engineers, Inc., for their design assistance. For illustrative contributions, thanks to Betty Parsons, Richard Duran, and Fred Bigio.

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Andrea Hricko, Deputy Assistant Secretary, provided guidance in finalizing this manual, with legal review provided by Mark Malecki of the Office of the Solicitor (SOL), and other legal assistance provided by SOL's Deborah Green, Jack Powasnik and Robert Aldrich. The report is on the internet thanks to Bill West. Sonya Patterson, Hazel Haycroft, Bria Culp, and Joelle Hoberman assisted with word processing. Coordination of the final document was handled by Jennifer Davis.

MSHA appreciates the willingness of the American Conference of Governmental Industrial Hygienists in allowing us to reprint diagrams from their publications.

Finally, MSHA thanks those mine operators and miners who cooperated with Technical Support staff during these evaluations, as well as the Metal and Nonmetal mine inspectors who accompanied Technical Support staff during the evaluations.

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No specific brand-name product is required to be used under Mine Safety and Health Administration (MSHA) regulations. MSHA provides product information solely as a service to the general public. Reference to any specific product by trade name, trademark, manufacturer, or otherwise in this report does not constitute or imply its endorsement, recommendation, or favoring by MSHA.

INTRODUCTION

The Mine Safety and Health Administration (MSHA) is committed to ensuring that miners are protected from health hazards at the worksite. It accomplishes this through enforcement of health standards and by working with labor, management, and other interested parties to develop and promote solutions to health problems, to share information and to provide health and safety training.

Mercury remains a serious hazard in the mining industry. Although there are no current mercury mines in the United States, mercury can be naturally present in ore and is produced as a by-product of gold and silver mining. The development and growing use of cyanide technology has increased gold and silver production as well as the recovery of other by-products such as mercury. Because mercury has no warning properties, MSHA is concerned that many individuals are not fully cognizant of its hazards and the means necessary to control the risks to miners. In addition, miners may unknowingly take the contamination home and expose their families.⁵

In the past six years, MSHA has taken nearly 700 samples at gold and silver mines. More than 80 overexposures were found to be above MSHA's exposure limit, with 50 percent of the overexposures measuring more than twice the exposure limit.⁶ The exposures ranged as high as 50 times the allowable limit. Many were found in refinery workers. Overexposures to silver have also been found in refinery workers. In addition, MSHA's Technical Support Group has conducted nine studies involving mercury hazards at gold and silver mines in the past five years.⁷

This document has been developed by MSHA solely for the purpose of providing information to the gold mining community on the hazard associated with exposure to mercury. This document is not intended to establish official MSHA policy on all possible methods of compliance at every mining operation. MSHA standards applicable to occupational exposure to mercury may include, but are not limited to those set forth in Appendix D. The purpose of this publication is to present "Best Practices" that can be utilized within the mining industry in controlling employees' exposures to liquid and vapor forms of mercury. This document will:

- C Characterize the problems associated with controlling mercury vapor within cyanidation facilities (facilities using cyanide to extract gold and silver).
- C Discuss good industrial hygiene practices concerning the design and operation of cyanidation plants.
- C Describe the best practices and controls for reducing employees' exposures to mercury.
- C Provide a source list of equipment needed to control mercury vapor within the cyanidation plant and materials required for surface decontamination.

C Provide a list of personal protective equipment to limit employees' exposures to mercury.

A checklist is provided for each section to summarize the key points of the respective chapters. Information from the checklists is not going to be collected; it is not required to be completed; and it will not be used for checking compliance with MSHA regulations. Rather, the checklists are an organizational method for providing information to the public by MSHA for educational purposes.

INDUSTRY OVERVIEW

U.S. gold production has increased tenfold since 1980.⁸ Production has been at historic record levels in the 1990's, with U.S. gold production valued at some \$4.1 billion in 1996.⁹

The rise in U.S. gold production has coincided with a worldwide production increase attributable to rising gold prices since 1980.¹⁰ In the 1990's the United States has become the world's second largest gold-producing nation, after South Africa.^{11 12}

In 1996, U.S. gold mines¹³ produced approximately 325,000 kilograms of gold, a slight increase over 1995 production.¹⁴ From January through April 1997, U.S. mines reportedly produced 104,000 kilograms of gold.¹⁵ After rising over the period 1991 through 1996,¹⁶ gold prices registered a net decline in the first 5 months of 1997.¹⁷ However, the Gold Institute, a trade organization, has projected further production increases through at least 1998.¹⁸

In the United States, there are currently 191 gold mines and 15 silver mines which employ approximately 19,000 miners. They are distributed in twelve states: Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, South Carolina, South Dakota, Utah and Washington. Approximately 40 percent of the mines have an associated mill. There are also 10 free standing mills which process ore from various mines. Many of the mills also have a refinery. Twenty-five percent of the gold mines list silver as a secondary commodity.

Nevada has the largest number of gold and silver mines in the U.S. It has 30 percent of the total operations and 65 percent of the miners employed in gold and silver mining. Fifty-eight percent of its mines have an associated mill. California is a distant second with 19 percent of the operations and 10 percent of the miners. Forty-eight percent of its mines have an associated mill. For 1996, preliminary data indicate that with slightly over 190 operations, the U.S. gold industry employed 17,610 miners.¹⁹

A trend to increased underground gold mining is anticipated by many in the mining community. The U.S. Geological Survey has noted a trend to conversion from surface to underground gold mining as certain near-surface deposits reach depletion.²⁰ Last year, for example, Barrick Gold Corporation opened a major new underground gold mine in Nevada, and further increases in underground gold mining are predicted.²¹

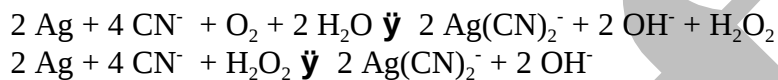
In the past six years, MSHA has taken 690 samples at 72 gold and silver mines and found 86 overexposures at 14 mines. (These 86 overexposures exceeded the exposure limit without considering the sampling error factor). Fifty percent of the overexposures were greater than twice the exposure limit. Many of the overexposures involved refinery workers, some of whom were also overexposed to silver. MSHA believes that these data indicate an ongoing risk to miners, which must be addressed by the mining community.

TECHNICAL REVIEW

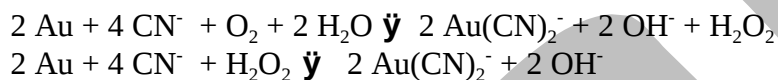
I. Source of Elemental Mercury

In the Western United States, low-grade gold ore deposits containing mercury have been developed and are being processed by cyanidation to recover precious metals. “Cyanidation” uses cyanide solution to extract gold from the ores. These ores usually contain less than 15 parts per million of mercury.²² During the cyanidation process, 10-30 percent of the mercury in the ore is extracted along with the gold and silver. Reactions representing silver, gold, and mercury are shown below:²³

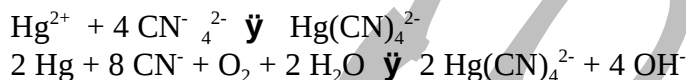
Silver



Gold



Mercury



The small amount of elemental mercury that is extracted from the host ore can pose health risks to employees who work with the gold-bearing solution purification and concentration circuit and in the refinery. The reason is that the cyanidation process involves concentrating the precious metals and the mercury by a factor of 3,000-4,000.²⁴ This is required to produce a small volume of high grade gold solution that is suitable for final gold recovery. Elemental mercury vapor is released when the “pregnant leach” solution undergoes the “Hydro/Pyro”²⁵ recovery process required to produce the dore bars.

A review of the toxicology of elemental mercury will show the importance of limiting miners’ exposures to this contaminant.

II. Toxicology of Elemental Mercury

Symptoms of Exposure

Mercury is a heavy metal that can cause permanent disability and even death in miners unless it is properly controlled. It can also affect the children of miners who may become exposed when their parents bring home mercury through contamination of clothing and other items.²⁶ Exposure to

mercury can affect the nervous system and the kidneys.

Mercury poisoning can result from both acute and chronic exposures. **It is critical to recognize that exposure to mercury can be without warning, thus, workers may not know the extent to which they have been contaminated. It is essential that personal, environmental, and biological monitoring be done to determine the exposure hazard and evaluate symptoms, as necessary.**

The symptoms of acute mercury exposure generally involve the lung and central nervous system. The early symptoms include tremors, nausea, shortness of breath, chest pain, progressive pulmonary failure, and pneumonitis. Nervous system damage including hallucinations has also been reported. The symptoms can progress and deaths have resulted from severe acute poisonings within days of exposure.²⁷

The symptoms of chronic mercury poisoning are nonspecific, making early detection of poisoning difficult. Early signs of chronic mercury poisoning are mild central nervous system dysfunction, including increased irritability, loss of memory, reduced self-confidence, insomnia, anorexia, and slight hand tremor. Chronic mercury poisoning can cause kidney damage resulting in proteinuria, which is the appearance of protein in the urine. Mercury can also adversely affect both male and female reproductive systems; in one study, following a single acute exposure, several men developed chronic and irreversibly impaired sexual functions.²⁸ If excessive exposure to mercury is not controlled, the symptoms can become severe, resulting in permanent disability and loss of function. At any stage with symptoms, removal from exposure may not result in improvement. The symptoms of chronic mercury poisoning do not vary by route of exposure.²⁹

Routes of Exposure

Mercury can be absorbed via the lungs, skin and gastrointestinal tract.

Although the absorption rate varies for each route, it is critical for the protection of the worker that each route of exposure be controlled. Uncontrolled routes of exposure will lessen the overall protection given the worker by the controls in place. The following is a brief discussion of each absorption and elimination pathway.³⁰

Pulmonary Route of Exposure

Vapor inhalation is the main route of entry into the body. Mercury vapor diffuses across the alveolar membranes of the lungs and it is estimated that between 74 and 80 percent of the inhaled mercury is retained in the body.³¹ After absorption, the elemental mercury continues to exist for a short time in the metallic form, thereby enabling it to cross the blood-brain barrier or placenta. Metallic mercury is oxidized by hydrogen peroxide-catalase to divalent ionic mercury (Hg^{2+}) which fixes to proteins. Oxidation of mercury to the ionic form, which is less likely to cross barriers, can trap it in the brain and the placenta.³²

Dermal Route of Exposure

Mercury vapor is absorbed through the human skin. The dermal uptake at whole-body exposure is estimated to be 2.2 percent of the pulmonary uptake.³³ Dermal contact with liquid mercury could significantly increase biological levels. Metallic mercury may also cause allergic contact eczema. In addition to percutaneous exposure, contact with mercury by unprotected skin or porous work clothing can result in enhanced risk of pulmonary uptake due to the vaporization of the mercury

Gastrointestinal Route of Exposure

Metallic mercury is not well absorbed when ingested unless a gastrointestinal (GI) fistula (lesion) or other GI inflammatory disease is present. The oral absorption of elemental mercury is limited and is less than 0.01 percent.³⁴

Elimination of Metallic Mercury

Excretion of elemental and divalent mercury occurs primarily in the urine and feces. Mercury has a half-life of 40 to 60 days. The highest concentrations of absorbed mercury are found in the gray matter of the brain, in the kidney and in the liver.

III. Mercury Exposure Limits

MSHA standards at 30 CFR §§ 56/57.5001, for metal and nonmetal mines, incorporate by reference the 1973 edition of the American Conference of Governmental Industrial Hygienists publication “TLV’s Threshold Limit Values for Chemical Substances in Workroom Air Adopted by ACGIH for 1973.” The standards require that exposure to airborne contaminants not exceed, on the basis of a time weighted average, the 1973 threshold limit values adopted by ACGIH. As a result, MSHA’s current TLV-TWA (8-hour shift) for mercury (all forms except alkyl) is 0.050 mg/m³.

The following is a list of other exposure limits for metallic mercury vapor established by various safety and health organizations. These limits are designed to prevent adverse central nervous system and kidney effects resulting from exposure to metallic mercury vapor. Currently, no unequivocally safe level has been ascertained to protect the reproductive functions of males and females. The ACGIH recommends that women of childbearing age should not be exposed to air concentrations of metallic mercury vapor greater than 0.010 mg/m³.³⁵

American Conference of Governmental Industrial Hygienists³⁶

Mercury, inorganic forms including metallic mercury (skin)
C TLV-TWA (8-hour shift): 0.025 mg/m³

The ACGIH has also assigned a “skin” designation to certain forms of mercury. This refers to the

potential for significant contribution to an individual's overall exposure to mercury by the cutaneous route. This includes mucous membranes and the eyes, either by contact with vapors or by direct contact with the mercury. The amount of mercury an individual may safely contact is not specified by the ACGIH.

National Institute for Occupational Safety and Health³⁷

Mercury, compounds [except (organo) alkyls] (skin)

C REL (8-hour shift): 0.050 mg/m³

C IDLH: 10 mg/m³

Occupational Safety and Health Administration³⁸

C PEL: Ceiling - 0.100 mg/m³

World Health Organization³⁹

C TLV-TWA (8-hour shift): 0.050 mg/m³

IV. General Cyanidation Process

The run-of-mine ore is crushed and ground to an optimum particle size to make the ore amenable to gold extraction. An oxidative process may be required as a pretreatment for sulphidic and carbonaceous ores that will permit the precious metals to be extracted by standard hydrometallurgical techniques.

The next step of the cyanidation process is to leach the precious metals from the gold-bearing ore with a weak cyanide solution. In this step, the precious metals and mercury are solubilized into the cyanide solution as cyanide-metal complexes. This phase can be accomplished through heap leaching or tank agitation leaching. The “pregnant leach” solution is pumped to carbon columns where the precious metals undergo further purification and concentration. There are two standard techniques by which this phase can be accomplished and they are “carbon-in-pulp” and “carbon-in-leach”. Each technique involves mixing the “pregnant leach” solution with activated carbon in carbon columns or tanks. The metal cyanide complexes are adsorbed onto the activated carbon. The difference between the two techniques is that in the “carbon-in-leach” method, the leaching and carbon adsorption phases are done simultaneously within the same vessel. With the other technique, the leaching and carbon adsorption phases are two distinct steps.

The next step involves acid washing the loaded carbon to remove inorganic fouling agents to improve the efficiency of the metals desorption process. The carbon is washed using either a weak hydrochloric acid solution or a nitric acid solution.

The acid-washed carbon is then sent to a carbon elution vessel where the precious metals are stripped from the carbon. The elution systems are operated at elevated temperatures and pressures. The stripped carbon is transferred to a rotary kiln for regeneration. The carbon is

regenerated by heating it in the rotary kiln at approximately 700°C in a reducing atmosphere, such as steam. The re-activated carbon is returned to the carbon adsorption circuit. The carbon strip solution is pumped to the refinery to recover the precious metals.

The gold and silver are recovered using either the Merrill-Crowe zinc precipitation method or through electrowinning. The silver content of the ore body usually dictates the gold recovery method that will be utilized at any one mine. Mines having an ore body containing a high percentage of silver will tend to use the Merrill-Crowe technique while others will use electrowinning. The Merrill-Crowe method involves using elemental zinc to reduce the metal cyanide complexes, such as gold and silver to their respective elemental forms. The solution is drawn through a filter press where the precipitate is collected. Electrowinning involves reducing the metal cyanide complexes to their elemental form by applying a voltage across a pair of electrodes immersed in the carbon strip solution. In each method, the neutral mercury cyanide complex will also be reduced to its elemental form. Therefore, both the zinc precipitate and the electrowon sponge must be retorted prior to smelting of the concentrate.

The retorted concentrate is mixed with slag-forming fluxes and smelted in a furnace. Once smelting is completed, the slag is poured off and the precious metal alloy is poured into dore bars. A general cyanidation process flow sheet is depicted in Figure 1.

V. Sources of Mercury Exposure

The primary sources of mercury exposure connected with the cyanidation process stem from the following:

- C Carbon Adsorption Columns.
- C Carbon Elution Vessels & Feed Bins.
- C Carbon Regeneration Kiln & Feed Bins.
- C Regenerated Carbon Screens.
- C Zinc Precipitate Filter Presses.
- C Electrowinning Cells and Cathodes.
- C Mercury Retort and associated Equipment.
- C Local Exhaust Ventilation System Components (scrubbers, fans and duct work).
- C Recirculation of Contaminated Air from Poorly Maintained HVAC Units.

Secondary sources of mercury exposure are:

- C Mercury Contaminated Work Clothes & Equipment.
- C Mercury Contaminated Clothes Lockers.
- C Poor Housekeeping Practices.
- C Poor Personal Hygiene Practices.

Each of these sources must be examined with respect to reducing employees' exposures to both liquid and vapor forms of mercury.

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BEST PRACTICES:

EMPLOYEE HYGIENE FACILITY

I. Introduction

Clothing worn by employees who work with or near mercury-contaminated equipment and work surfaces can become contaminated with mercury. This potentially contaminated clothing should never be worn home for laundering or stored in the same lockers used to hold employees' street clothes. MSHA has identified situations in which employees' personal motor vehicles and their homes have been contaminated with mercury because good industrial hygiene practices were not followed. The purpose of the employee hygiene facility is to limit employees' exposures to mercury and to prevent mercury from being transported from the employee's work environment to their autos, homes and personal belongings. This is accomplished by providing a place to shower and by isolating street clothes from sources of mercury such as contaminated work clothes and tools.

II. Building Materials

Building materials that have a porous surface can, over time, become contaminated with mercury vapor. These contaminated surfaces will be a secondary exposure source if they are not properly cleaned or treated. Since most construction products are porous, it is best to select a material that provides a smooth finished surface that can be easily sealed and cleaned. The following considerations should be given when selecting building materials for the portions of the cyanidation plant containing mercury:

- C Wood, carpeting, wallboard or any other material which are not suitable for making a continuous crack-free, non-absorptive surface should not be used in the construction of any structure that will be exposed to elemental mercury.
- C Walls should be constructed of either cinder block or concrete and sealed with an epoxy paint.
- C The floor should be concrete and treated with a non-slip epoxy paint. Cracks between floor sections should be filled with an epoxy compound containing a fine aggregate. The epoxy compound should have enough elasticity so that cracks will not form due to movement of the concrete slab.
- C The same epoxy compound can be used as a coping against the walls of the building. This will create a 1-inch lip where the floor meets the walls, thereby minimizing seepage of mercury between these two surfaces.

III. Location and Interior Layout

A general layout of a hygiene facility is depicted in Figure 2. It consists of four separate areas:

- C A clean (mercury-free) locker room where personnel can remove and store their street clothes and personal belongings.
- C A shower area where personnel can shower after work.
- C A “dirty”⁴⁰ locker room where personnel can change into their work clothes prior to the start of their shift and wash and store them after work.
- C A clean lunch and/or break room where personnel can eat.

The hygiene facility location should be such that employees enter the clean side of the facility from the parking lot. They should not be required to walk through any process area where there is potential for mercury contamination. The general flow of foot traffic for the facility is shown in Figure 2. Employees should enter directly into the work area from the “dirty” side of the hygiene facility and not go through the lunch room. It is suggested that a “lunch bay”, for transferring lunches to the lunch room be located in the interior wall separating the clean locker room and the lunch room. Such an arrangement is depicted in Figure 3.

The clean side should be equipped with clothes lockers, and toilet facilities. Visitors and employees should remove their street clothes and store them in a locker at this location. Attention should be paid to the physical arrangement and equipment (including towels or robes) to ensure privacy. It is recommended that all jewelry be removed prior to entering the work areas.

Next, employees should proceed to the “dirty” room to don their work clothes. Showers should be located between the “dirty” and clean locker rooms. This arrangement serves two purposes: (1) employees exit the shower directly into the clean locker room and (2) it separates the clean locker room from the “dirty” one. Soap and towels should be provided.

The “dirty” side of the facility should also be equipped with a bathroom, clothes lockers and benches. Employees don their work clothes and enter directly into their work areas from this location. The “dirty” locker room exit can be provided with an air-lock to isolate it from the adjacent work area. This will help prevent mercury vapor from infiltrating from the plant. At the end of the work shift, employees should clean their rubber boots in a wash solution containing a mercury complexing agent. Also, employees should remove their coveralls prior to entering the “dirty” locker room. After entering the locker room, they should remove and store their work clothes and shower. Again, provision should be made to ensure privacy. After showering, employees should proceed to the clean room, dress, and exit directly to the parking lot.

A floor drain should be installed in each area of the hygiene facility. This will permit the use of a hose to wash down each location of the facility. The floor should slope toward the drain to assist

drainage. The floor drains for the clean room can be connected to the same drainage system used for the bathrooms. It would be preferable for the “dirty” locker floor and shower drainage to be recycled back into the cyanidation process to prevent inadvertently introducing metallic mercury into the environment. The drains should be cleaned and treated with a mercury complexing agent to prevent the accumulation of mercury.

Employees’ work clothes and reusable coveralls should be laundered either on-site or by a laundry service. Clothes wash rooms should be located in the “dirty” locker room. The dryer exhaust should be vented to the outside of the building and connected to a mercury vapor collection system (local exhaust ventilation). Drainage from the clothes washer should be returned to the process sump to prevent spread of contamination. Clothing should be washed on a daily basis. A mercury vapor analyzer should be used to scan employees’ work clothes to avoid donning mercury contaminated clothing. If an outside laundry service is utilized, they should be informed that the clothing is contaminated with metallic mercury. This will allow them to take necessary precautions to protect their work force and to comply with State and Federal environmental regulations.

IV. Visitors

A policy should be established that requires all visitors to follow the entry and exiting procedures outlined above. Personal protective equipment such as respirators, boots, gloves and coveralls should be made available for use by visitors. Visitors should not be allowed to leave the property with contaminated equipment or clothing.

V. Heating, Ventilation and Air Conditioning System

The hygiene facility should have its own heating, ventilation, and air conditioning (HVAC) system. The building should be kept under a slight positive static pressure with respect to the outside work areas (0.5 inches of water). The static pressure within the structure should be greatest inside the clean room and lowest inside the “dirty” room. This will cause the air to flow from the clean room through the shower area to the “dirty” room. Figure 4 shows the static pressure gradient and the general airflow for the hygiene facility. The intake air vents for the HVAC system should be located in a mercury vapor-free zone. If this is not feasible, the HVAC unit should be equipped with a mercury vapor removal system. The duct work should be doubled walled so that the duct insulation is not exposed to the intake air stream. It is recommended that the space between the acoustical ceiling tiles and the concrete ceiling not be used as a return airway for the ventilation system. This could lead to contamination of the ceiling tiles. The ventilation system should be well maintained and the air quality entering the facility should be checked for contamination using a mercury vapor analyzer.

VI. Maintenance Practices

The hygiene facility should be used only for the purpose stated above and not as an equipment storage area. The street clothes lockers should not be used to store hand tools or other equipment. The hygiene facility and its equipment, such as the clothes washer and dryer should be cleaned on a regularly scheduled basis. At a minimum, the facility should be cleaned once a shift. Showers should also be treated to prevent the growth of bacteria and fungi. It is suggested that cloth curtains, rugs, and cloth upholstered furniture not be used in the hygiene facility, since these items can absorb mercury and cannot be satisfactorily cleaned. A mercury vapor analyzer should be used to monitor the effectiveness of clean-up procedures. Sources pinpointed by the instrument should be cleaned with a mercury complexing agent. If linoleum is laid over a concrete floor, a continuous sheet should be used in lieu of 12-inch tiles in order to minimize the number of seams in the floor.

Cracks and crevices at corners and joints should be sealed with epoxy, and be flush with the surface. Chemical smoke tubes should be used to indicate the static pressure relationships with respect to the three locations within the hygiene facility. Ensure that the air movement always flows from the clean locker room towards the “dirty” locker room. Test the airflow with doors and windows in both the open and closed positions.

EMPLOYEE HYGIENE FACILITY CHECKLIST

I. Building Materials

YES NO

- | | | |
|---|---|---|
| “ | “ | Are concrete or cinder block walls sealed with an epoxy paint? |
| “ | “ | Are concrete floors sealed with a non-slip epoxy paint? |
| “ | “ | Are the joints between floor sections filled with an epoxy compound? |
| “ | “ | Are the joints between the walls and floor sealed with an epoxy coping agent? |
| “ | “ | Have carpeting, cloth curtains, and cloth upholstered furniture been removed from the hygiene facility? |
| “ | “ | Are wood surfaces and wallboard intact and sealed with an epoxy paint? |

II. Location and Interior Layout

YES NO

- | | | |
|---|---|---|
| “ | “ | Have provisions been made for both male and female employees? |
| “ | “ | Have privacy considerations been included in location and provision of equipment and facility? |
| “ | “ | Does the facility have separate areas where personnel can remove and store their street clothes, don and remove their work clothes, and shower? |
| “ | “ | Is the entrance to the building suitably located to avoid personnel walking through process areas? |
| “ | “ | Is the clean locker room equipped with lockers, benches and a lavatory? |
| “ | “ | Is there a means of transferring lunches from the clean locker room to the lunchroom? |
| “ | “ | Is the shower room equipped with hot and cold water, soap and towels? |
| “ | “ | Is the “dirty” locker room equipped with lockers, benches, and a lavatory? |

- “ “ Is the “dirty” room egress area to and from the work locations provided with an air-lock doorway to isolate the hygiene facility from the process areas?
- “ “ Does drainage from the “dirty” locker room and shower flow to a process sump in lieu of sharing the same drainage system for the bathrooms?
- “ “ Will employees’ work clothes be laundered on-site? If so, has someone been assigned the responsibility for performing this task?
- “ “ Is the clothes dryer vented to the outside of the building into an exhaust ventilation hood?
- “ “ Is drainage from the clothes washer returned to a process sump?
- “ “ Are receptacles available to dispose of contaminated coveralls? Is there a company policy that dictates how the contaminated coveralls will be disposed?
- “ “ Are boot washes provided at the entrance to the “dirty” locker room?
- “ “ Has a written policy been developed and implemented requiring all persons to use the hygiene facility?

III. Heating, Ventilation and Air Conditioning System

YES NO

- “ “ Does the facility have its own HVAC system?
- “ “ Are the intake air vents located in a mercury-free zone?
- “ “ Is the ductwork double-walled to protect the insulation from contamination?
- “ “ Will the ventilation system require a mercury vapor removal system?
- “ “ Has a maintenance program been developed for the HVAC system?
- “ “ Is the hygiene facility kept under a positive pressure relative to the outside of the building and process work areas?
- “ “ Is the airflow within the building being monitored to ensure that it flows from the clean locker room to the “dirty” locker room?
- “ “ Have you avoided using the space between the acoustical ceiling tiles and the

permanent concrete ceiling as a return airway for the ventilation system?

IV. Maintenance Practices

YES NO

- | | | |
|---|---|--|
| “ | “ | Are you sure the hygiene facility is not used as an equipment storage area? |
| “ | “ | Is linoleum going to be laid over the concrete floor? If so, use a continuous sheet instead of 12-inch tiles. |
| “ | “ | Are all cracks and crevices at corners and joints sealed flushed with the surface? |
| “ | “ | Has a cleaning and maintenance schedule been developed for the facility? |
| “ | “ | Is air monitoring for mercury vapor being done and logged to determine the effectiveness of clean-up procedures? |
| “ | “ | Are wipe samples being taken on sealed eating surfaces to determine surface contamination? |
| “ | “ | Are employees' work clothes being scanned for mercury contamination? |
| “ | “ | Are there adequate supplies of clean towels, soap, and other items? |

LUNCH ROOM

I. General Guidelines

The lunch room should consist of a wash room (change area with wash facilities) and eating area. If the lunch room is located adjacent to the process area, an air-lock entrance is recommended to isolate the wash room from the eating area. A sketch of a lunch room is depicted in Figure 4. The HVAC system used to provide contaminant-free air to the hygiene facility can be used to supply tempered air to the lunch room. If the lunch room is going to have its own HVAC system, ensure that the air intake is situated in a mercury vapor-free area. The lunch room should be under a positive static pressure with respect to the outside work areas and slightly negative when compared with the hygiene facility. Employees should wash their rubber boots in a mercury complexing solution, remove their coveralls, and wash their hands prior to entering the eating area. Consideration should be given to having the employees remove their boots and use disposable slippers prior to entering the eating area. The same basic principles should be applied (except the air-lock entrance) to a trailer that is going to be used as a lunch facility.

II. Maintenance Practices

The lunch room should be used only for this purpose and not as a process control room, office or equipment storage area. This will minimize the amount of mercury transported into this room. At a minimum, the lunch room should be cleaned after each shift. After cleaning, a mercury vapor analyzer should be used to check surface areas for mercury contamination. Wipe samples can also be used to ascertain the effectiveness of clean-up procedures. It is recommended that a sign stressing the importance of good personal hygiene be posted inside the lunch room. For reasons stated above, no curtains, rugs, and cloth upholstered furniture should be used in the lunch room. The static pressure relationships with respect to the eating area and the wash room should be monitored to ensure that the air movement is always toward the wash room.

LUNCH ROOM CHECKLIST

I. General Considerations

YES NO

- | | | |
|---|---|--|
| “ | “ | Is there a wash room where employees can wash their boots, remove their coveralls and wash their hands prior to entering the lunch room? |
| “ | “ | Is the lunch room being maintained under a positive static pressure relative to the work areas and slightly negative static pressure compared to the hygiene facility? |
| “ | “ | Are the intake air vents for the HVAC system located in a mercury vapor-free zone? |
| “ | “ | Is the lunch room being used only for this purpose or is it being used for other purposes such as an office, control room or equipment storage area? |
| “ | “ | Do persons inside the lunch room have access to a lavatory? |
| “ | “ | Has a cleaning schedule been developed for the lunch room? |
| “ | “ | Are mercury vapor and wipe samples being collected and logged to determine the effectiveness of clean-up procedures? |
| “ | “ | Have rugs, cloth curtains, and cloth upholstered furniture been removed from inside the lunch room? |
| “ | “ | Is the static pressure relationship between the lunch room and the wash room being monitored? |

CARBON ADSORPTION and REACTIVATION

I. Introduction

The carbon adsorption and reactivation processes are designed to: (1) produce a concentrated gold-bearing solution from which the precious metals can be recovered using either zinc precipitation or electrowinning and (2) reactivate and recycle the carbon back into the carbon adsorption circuit. The carbon adsorption circuit involves adsorbing the metal cyanide complexes onto activated carbon. The general order of preference of carbon adsorption for gold, silver and mercury cyanide complexes is as follows:⁴¹



The neutral mercury cyanide complex competes directly with the gold cyanide complex for adsorption sites on the activated carbon. The loaded activated carbon undergoes an elution step where the metals are desorbed from the carbon. The stripped carbon is sent to a rotary kiln for reactivation. The electrolyte is pumped to the refinery where the precious metals are recovered.

II. Mercury Sources and Control Techniques

Carbon Adsorption Circuit

The following locations within the carbon adsorption circuit are potential sources of mercury vapor:

- C Carbon Adsorption Columns.
- C Loaded Carbon Surge Bins.
- C Carbon Elution Vessels.
- C Sumps.

The loaded carbon surge bins should be covered and maintained under a negative pressure using local exhaust ventilation. The air from the bins should be exhausted through an activated carbon pack prior to being discharged to the atmosphere. The carbon elution vessel should also be vented through a carbon pack. The sumps should be cleaned on a regular basis and treated with a mercury complexing agent.

Carbon Reactivation Circuit

The following locations within the carbon reactivation circuit are potential sources of mercury vapor as well as liquid mercury:

- C Rotary Kiln Feed Bins
- C Rotary Kiln
- C Rotary Kiln Exhaust Ventilation System

- C Carbon Screens
- C Carbon Fines Tanks & Push Water Tanks

Since the elution step is not 100 percent efficient, the stripped carbon will contain residual amounts of mercury and precious metals. Mercury vapor can express itself when the carbon is transferred from the elution vessel to the rotary kiln feed bins. This is due to the high operating temperature of the strip vessel. If a push water system is used to move the stripped carbon to the kiln feed bins, the push water tank and the carbon fines tank can be significant sources of mercury vapor. This is primarily due to having fine carbon, that contains mercury, becoming entrained in the push water system. The kiln feed bins are sources of mercury vapor due to residual mercury contained on the carbon. The kiln is an obvious source of mercury vapor due to the heating of the carbon. The kiln exhaust ventilation system is a point source of mercury. Employees who maintain the ventilation unit can be exposed to high concentrations of mercury. The carbon is usually screened to remove the fines prior to being recycled back to the carbon adsorption circuit. These screens are significant sources of mercury vapor. A filter press is used to dewater the carbon fines that are separated out from the reactivated carbon. After dewatering, air is forced through the filter press to reduce the moisture content of the fines. This may be a source of mercury depending on the mercury content of the fines and the temperature of the compressed air.

The tanks and screens connected with the carbon reactivation system should be covered and maintained under a negative pressure using a local exhaust ventilation system. The air exhausted from these pieces of equipment should pass through a carbon pack prior to being discharged to the atmosphere. The rotary kiln should also be equipped with an exhaust ventilation system to capture emissions from the kiln. The airstream should be scrubbed by passing it through a mercury removal system. The design of the exhaust ventilation system for the kiln and maintenance procedures will dictate the severity of employees's exposures to mercury when operating and maintaining the ventilation unit. Design and maintenance procedures will be discussed later in this document. A mercury vapor analyzer should be used to determine if the filter press blow-down procedure is a significant source of mercury vapor. If so, the air should be exhausted through a mercury scrubbing device. This can consist of bubbling the air into a tank that contains a mercury complexing agent or using a carbon pack impregnated with either sulfur or iodine used in conjunction with a demister.

CARBON ADSORPTION and REACTIVATION CHECKLIST

Mercury Sources and Control Techniques

YES NO

“ “ Are the following locations under the influence of local exhaust ventilation?

- C Loaded Carbon Surge Bins
- C Carbon Elution Vessel
- C Rotary Kiln Feed Bins
- C Rotary Kiln
- C Carbon Screens
- C Carbon Fines Tanks & Push Water Tanks

“ “ Has the carbon fines filter press blow-down procedure been checked for mercury vapor?

“ “ Are sumps being cleaned with a mercury complexing agent to prevent the accumulation of mercury contaminated material inside the sumps?

REFINERY

I. Introduction

Once the precious metals are stripped from the loaded carbon, the strip solution is pumped to the refinery where precious metals are recovered. When mercury is present in the ore, the following processes are performed sequentially to recover the precious metals:

- C Electrowinning or Merrill-Crowe Zinc Precipitation,
- C Mercury Distillation (Retorting), and
- C Smelting and Pouring of the Dore Bars.

Each process presents mercury exposure problems to employees who are directly involved with them. The following is a discussion of each process and recommended approaches to controlling mercury vapor emitted during these operations.

II. Location and Interior Layout

The refinery should be located in a building separate from the carbon adsorption and reactivation processes. If a two-story building is used, mercury distillation equipment should be located on the lower floor. A refinery layout is depicted in Figure 5. It is suggested that all process equipment be aligned along an outside wall. This will simplify the installation of exhaust ventilation systems that will be required to remove gases, vapors, and fumes from the various processes. The process equipment should be laid out so that the process flows from one end of the building to the other. The mercury retort and related equipment should be isolated from the rest of the refinery.

A sump system should be installed in the middle of the refinery to allow washing down of the floor and process equipment. It is recommended that a mercury trap be installed just below the drain opening to catch any droplets of mercury. A sketch of a gravity trap is depicted in Figure 6. Drainage from the refinery is funneled into a container. A grate is placed in the bottom of the container that allows the mercury to fall through and protect it from being washed out. The water overflows the bucket and falls to the bottom of the sump. The container should be checked and periodically emptied. This device will help minimize the amount of liquid mercury entering the sump. As always around water and molten metal, extreme care should be taken so there is no chance for a steam explosion.

III. Heating, Ventilation and Air Conditioning System

The ventilation system that supplies make-up air to the refinery should deliver a minimum of ten percent more air to the interior of the building than is removed by local exhaust ventilation systems. This will ensure that the local exhaust ventilation systems will operate as designed. The supply air plenum and diffusers should be located near the ceiling, along the wall opposite the process equipment. This will cause the air to sweep across the refinery toward the process equipment. The intake air vents should be located away from sources of mercury vapor. Avoid

placing the intake air vents where mercury vapor from other processes can be entrained and introduced into the refinery. The fresh make-up air ventilation system should be properly maintained and checked for contamination using a mercury vapor analyzer.

Temperature plays a key role in controlling the level of mercury within the refinery. Temperature in the refinery should be kept at or below 65°F. If evaporative coolers are used in addition to the primary HVAC system, they should also be properly maintained and monitored for mercury contamination.

IV. Electrowinning

Electrowinning is used to recover gold from concentrated solutions generated by the elution of gold from loaded carbon. Generally, precious metals are plated onto either a carbon steel wool cathode or a stainless steel mesh cathode housed in a polypropylene basket. In addition, expanded metal sheets are also used, in lieu of the polypropylene baskets, to sandwich and hold the stainless steel mesh in place. Mercury will be plated onto the cathodes as well as the gold and silver. The elevated temperature of the electrowinning cell solution raises the vapor pressure of the plated mercury. The refiners are exposed to this vapor when they remove the cathodes from the electrowinning cells. It should be noted that there is also potential for dermal contact when performing this task.

Mercury Sources and Control Techniques

(A) Removing the cathodes from the electrowinning cells

Standard electrowinning tanks are equipped with an air plenum that is maintained under a negative pressure by connecting the plenum to an exhaust fan. Its primary purpose is to remove by-product gases, such as ammonia and hydrogen from the tank. An explosion proof fan should be used to exhaust air from the electrowinning cells due to the potential generation of hydrogen gas at the cell's cathodes if a malfunction was to occur. However, the refiner is exposed to a plume of mercury vapor when the cell is initially opened. This occurs because the exhaust system is ineffective in capturing mercury vapor from the cathode as it is being pulled from the cell. This problem can be addressed by quenching the cathodes inside the electrowinning cell prior to their removal from the cell, which can be accomplished by taking the cell temporarily out of service and draining the hot solution from the tank. Introducing cool water into the tank reduces the temperature of the cathodes inside the cell. This will reduce the vapor pressure of the mercury plated on the cathode, thereby reducing the mercury vapor concentration. Effects of thermal stress on the electrowinning cells due to repeated temperature changes should be considered prior to implementation. Stainless steel electrowinning cells are recommended.

When the electrowinning cells cannot be taken out of service, the lid of the cell can be converted into an air plenum and connected to an exhaust fan. Air is drawn through the plenum to the back of the cell away from a person lifting the lid. A sketch of the cell is shown in Figure 7. In

addition, the cathode can be placed immediately into a quench tank located next to the electrowinning cell which will reduce the vapor pressure of the mercury plated on the cathodes.

(B) Stripping the electrowon sponge from the cathodes

When a carbon steel wool cathode is used, the wool must be removed from the polypropylene basket and placed in a mercury retort pan. This is a major source of mercury exposure for refiners and should be done on an epoxy-coated table that is under the influence of local exhaust ventilation. A sketch of a downdraft hood and work bench is shown in Figure 8.⁴² Any material that has fallen into the clean-out doors should be placed into the retort pan.

When stainless steel mesh cathodes are used, they are placed in a wash tank where the plated material is removed with a high pressure water hose. The sludge is dewatered by drawing it through a filter press. The water exiting the filter press is either returned to an electrowinning cell or drained into a sump. This procedure requires the refiner to be in close proximity to the cathode. It is important to cool the cathode prior to moving it to the wash tank. The wash tank should be located adjacent to the electrowinning cells and designed to minimize handling of the cathode by refiners. A wash tank is depicted in Figure 9.

(C) Placing the electrowon sponge into the mercury retort

It is a common practice to store the sponge in a 5-gallon bucket or other container inside the retort room prior to placing it into the mercury retort. Water is poured into the container to cover the sponge and is intended to act as a barrier to prevent mercury vapor from escaping into the room. Water is not an effective mercury vapor barrier.⁴³ It is the temperature of the water that controls the amount of mercury vapor being emitted from the container. As the water gets warmer, its ability to act as a “vapor barrier” decreases. This source of mercury vapor can be eliminated by placing the electrowon sponge directly into the mercury retort.

V. Merrill-Crowe zinc precipitation

The Merrill-Crowe zinc precipitation gold recovery method involves using elemental zinc to reduce gold to its elemental form. As with electrowinning, mercury is reduced and co-precipitated with the silver and gold. Refiners are exposed to mercury vapor when the filter press leaves are separated and while the precipitate is being scraped into the retort pans, which requires the refiner to work directly with the precipitate. The best approach to controlling exposures to mercury vapor is to cool the precipitate with water prior to pulling the filter presses. It is important to place the precipitate directly into the mercury retort after it is recovered from the filter presses.

When directly handling steel wool or zinc precipitate cathodes, refiners are also at risk of dermal exposure to mercury in addition to inhalation exposure. The appropriate personal protective equipment should be worn by employees when handling the sponge or precipitate.

VI. Mercury Retort

Materials containing significant concentrations of mercury must be treated for its removal prior to smelting. In order to minimize the release of vapor during smelting, the following general work practices should be followed when operating a mercury retort.

Retort Room

The mercury retort should be isolated from the rest of the refinery by placing it in a separate room. The room should be kept under a negative pressure with respect to the rest of the refinery, which can be accomplished by using either wall fans or local exhaust ventilation. A pressure differential of at least 0.5 inches of water should be maintained between the retort room and the interior of the refinery. The make-up air vents for the room's exhaust ventilation system should be located on the wall opposite the refinery's fresh air supply plenum.

It is preferable to use local exhaust ventilation to keep the retort room under a negative pressure. The primary reason is that mercury vapor that is drawn to a wall fan will be exhausted directly to the outside of the building. This will contaminate the ground with metallic mercury in the immediate vicinity of the fan's exhaust. In addition, the potential exists for the vented mercury to be vapor entrained in the make-up air system and introduced back into the refinery. The exhaust ventilation opening should be located near the floor of the retort room due to the density of the mercury vapor. Locating exhaust openings near the ceiling causes a portion of the "captured" mercury vapor to condense inside the room before it can be collected by the exhaust system. The exhaust ventilation system should be equipped with a mercury vapor removal unit and the retort room should be cleaned daily. The following clean-up procedure is recommended:

- C Vacuum contaminated debris and beads of elemental mercury from equipment and floor using a mercury vacuum.
- C Wash floors with a mercury complexing solution. Avoid washing liquid mercury or contaminated materials into sumps.
- C Re-epoxy the walls and floor where needed.
- C Use a mercury vapor analyzer to check for sources of mercury vapor, if found, re-clean contaminated surfaces.

Retort

The retort should be operated and maintained in accordance with the manufacturer's recommendations. Tests should be conducted to determine the retort's optimum operating parameters prior to placing it into service. Once a baseline has been determined, the above tests can be performed periodically to monitor the operating efficiency of the retort. This will minimize the potential of sending mercury contaminated concentrate to the flux mixing station and furnace.

The retort should be kept under a vacuum during operation and the air exiting the water

condensation system should be scrubbed with a mercury vapor removal system (usually charcoal impregnated with a sulfur compound) prior to being introduced into the vacuum pump. The scrubber system is required because the water condensation unit is not 100 percent efficient. Mercury vapor losses usually vary between 0.2 percent and 0.4 percent for each distillation cycle.⁴⁴ It is also recommended that the treated air be discharged to the outside of the refinery. The air should be monitored for mercury vapor to determine if the charcoal scrubber unit has become saturated with mercury vapor. This measure should be implemented for two reasons: (1) mercury vapor will not be introduced into the retort room from the condensation unit if the mercury scrubber unit becomes saturated and (2) monitoring will enable the refiners to replace the activated carbon prior to it becoming saturated with mercury vapor. The spent charcoal from the scrubber unit should be disposed by retorting. Records should be kept to determine the life expectancy of the charcoal scrubber. This will also assist the refiners in determining when the charcoal should be replaced.

The doors to the mercury retort should only be open while the concentrate is being placed into or removed from the retort. Leaving the doors open needlessly allows residual mercury vapor to enter the room.

Condensed mercury vapor is trapped in a condensation pot. It is a common practice to remove the liquid mercury from the pot by opening a ball valve and draining it into a container such as a 5-gallon bucket. The mercury is then poured into a flask. This procedure is messy and contributes to exposures to mercury vapor. The best means of accomplishing this task is to transfer the mercury from the condensation pot directly to the mercury flask by using water. The water used to transfer the elemental mercury to the flask should be filtered using a mercury removal system. An alternate method is depicted in Figure 10. The mercury is transferred directly into a flask under the influence of exhaust ventilation.

The chances of over-filling the mercury flasks are reduced by:

- C Determining the exact volume of the flask.
- C Connecting a permanent translucent separatory funnel having a larger volume than the flask to the retort condensation pot. The container should be marked to indicate the same volume as the flask.
- C Opening the ball valve on the condensation pot and filling to the line marked on the funnel.
- C Opening the funnel stopcock and filling the flask.
- C Using personal protective equipment to prevent skin contact with the mercury.

A mercury vacuum cleaner can be used as the source of exhaust ventilation or a stationary hood connected to a ventilation system can be constructed for this purpose. If a mercury vacuum cleaner is to be used, a semi-circle exhaust hood can be constructed to be used with the vacuum unit. It is suggested that the mercury flask be set in a plastic pan to catch any spillage that may occur. The outside of the flask should be cleaned with a mercury complexing agent prior to storage. This will remove any residual mercury that may be present on the outside of the flasks

and reduce the chances of contaminating other areas of the refinery. The flasks should be stored in a cool and well ventilated area.

Retort equipment and other items connected with the gold recovery process should be cleaned prior to storage. This should be done with a mercury complexing agent. A parts cleaning tank containing a mercury-complexing agent can be used to clean small parts and tools. The equipment should be stored inside the retort room.

VII. Smelting

The concentrate obtained from the filter presses and electrowinning cells is heated in a furnace in the presence of slag-forming fluxes at temperatures in excess of the melting point of all the components of the charge, typically between 1200°C and 1400°C. This is done for approximately 1.5 hours to ensure complete separation of impurities from the gold and silver. The molten gold and silver form an alloy that is heavier than the slag and sinks to the bottom of the furnace. Once the smelting is completed, the slag is poured off and the precious metal alloy is removed from the furnace.

Furnace Charge Preparation

Flux is added to the concentrate to remove base metals and other impurities from the precious metal alloy. The mixing of the fluxes and the concentrate should be done under the influence of local exhaust ventilation. The best approach to performing this task is to vacuum the flux materials and concentrate from the retort pans either directly into the furnace or into a hopper that will automatically feed the material into the furnace. This will limit the refiners' exposures to the flux chemicals, silver dust and any residual mercury that may be present after retorting. An alternative approach is to mix the concentrate and the fluxes at a flux mixing table that is maintained under a negative pressure using exhaust ventilation. A flux mixing table is shown in Figure 11.

Smelting of the Concentrate

Any residual mercury contained in the concentrate will be volatilized in the initial stages of the smelting process. An exhaust hood should be placed over the furnace to capture any mercury vapor and fumes that are generated during the smelting process. There are two types of hood design that can be used to control contaminants generated at the furnace. An annular hood mounted on top of the furnace can be used to capture emission during smelting. A cover that can be hydraulically moved can be placed over the top of the furnace to enhance the performance of the hood. A hatch can be installed in the hood to facilitate loading the concentrate into the furnace. The other design is to construct an enclosure around the furnace. An exhaust enclosure for a gas furnace is depicted in Figure 12. The furnace should be enclosed on three sides. The front of the enclosure should extend down past the furnace pour spout and protrude outward to contain fumes that are forced out of the spout. An opening should be left in the lower portion of

the front of the enclosure for combustion air. A similar enclosure can be used for an electric furnace (Figure 12a). The only changes would be to extend the front of the enclosure to within 12 inches of the floor and eliminate the protrusion.

Pouring of the dore bars

Pouring of dore bars can be a source of mercury vapor. Depending on the silver content of the concentrate, this process can also be a significant source of silver fume. MSHA's exposure limit for silver fumes and dust is 0.010 mg/m^3 . The dore bars should be allowed to cool in the molds well below the melting point of silver, which is 962°C . A graphite compound can be used to coat the molds to facilitate removal of the bars after they have cooled. An exhaust hood should be constructed so that silver fumes will be captured during the pour. The molds should be allowed to cool under the hood prior to removing the dore bars from them.

Cooling of the slag pots

Slag pots should be allowed to cool under an exhaust hood to capture fumes.

Chipping and storage of the dore bars

Dore bars are quenched in a water bath after they are poured and then chipped to remove slag. This process is accomplished using either a pneumatic chipping gun or automatic descaler which is a source of silver dust. Depending on the number of bars that need to be scaled, an automatic scaler is considered to be the best method for removing slag from dore bars. Descalers should be equipped with local exhaust ventilation. Compressed air has been used to remove moisture and steel pellets from dore bars prior to weighing them. This activity must be done in an exhaust hood. Experimentation should be performed to determine the minimum air pressure required to obtain the desired results. Lowering the air pressure will enhance the performance of the exhaust hood. If a hand-held chipping gun is to be used, the chipping process should be done at a table equipped with local exhaust ventilation. Another method is to chip the dore bar in a container of water. Either of these methods should reduce exposure to silver dust.

The dore bars should be checked to determine if they are a source of metallic mercury vapor, which can be done by placing a dore bar inside a plastic trash bag and allowing it to sit for 3-4 hours. Next, use a mercury vapor analyzer to determine if any mercury has off gassed from the dore bar which can be done by inserting a probe through the bag and obtaining a reading with the mercury vapor analyzer. If mercury is present, the bars can be wrapped in plastic to reduce the amount of mercury entering the vault. In addition, the vault should be well ventilated to limit the accumulation of mercury vapor within this location.

VIII. Refinery Housekeeping Practices

Cleanliness in the refinery cannot be over-emphasized. The following practices will assist in

keeping minimum background levels of mercury vapor in the refinery.

- C The refinery should be cleaned on a daily basis. A clean-up protocol is located in Appendix “B”.
- C Beads of metallic mercury or accumulations of mercury contaminated debris should not be washed into the sump. They should be removed using only a mercury vacuum cleaner. A standard shop vacuum should not be used for this purpose.
- C The refinery should not be used as a miscellaneous storage area. Only tools and equipment necessary to operate the refinery should be kept at this location.
- C Tools and equipment that have become contaminated with mercury should be cleaned with a mercury complexing agent prior to storage. The waste material from the cleaning process should be placed in a mercury retort to remove the mercury. As always, rubber gloves should be worn when handling mercury-contaminated materials. Hand tools used to perform maintenance activities in the refinery should be dedicated to this work area, which will minimize the chances of spreading mercury to other work areas of the cyanidation plant. Employees’ personal tools should not be allowed in the refinery.
- C Employees should change work coveralls at least twice each work shift. Employees who work directly with the concentrate or on mercury contaminated equipment should change their coveralls immediately after completing the work assignment.
- C Personal protective equipment should be stored in a clean area that is away from sources of contaminants. The equipment should be cleaned on a regular basis.

REFINERY CHECKLIST

I. Location and Interior Layout

YES NO

- | | | |
|---|---|--|
| “ | “ | Is the refinery separated from the carbon adsorption and reactivation circuits? |
| “ | “ | Is the layout of the refinery process such that it will simplify the installation of local exhaust ventilation systems? |
| “ | “ | Is the mercury retort and related equipment isolated from the rest of the refinery? |
| “ | “ | Is the refinery equipped with a sump to permit wash down of this location? |
| “ | “ | Is the sump equipped with a mercury trap or mercury filtration device to minimize the accumulation of mercury in the sump? Is the sump being cleaned on a scheduled basis with a mercury complexing agent? |
| “ | “ | Has the potential for a steam explosion been considered when using water to clean the refinery? |

II. Heating, Ventilation and Air Conditioning System

YES NO

- | | | |
|---|---|--|
| “ | “ | Is the refinery ventilation system providing 10 percent more make up air to the interior of the building than is being exhausted by local exhaust ventilation systems used for contaminant control? |
| “ | “ | Are the supply air diffusers located near the ceiling and along the wall opposite to where the process equipment is located causing the air to sweep across the refinery toward the process equipment? |
| “ | “ | Are the intake air vents located in a mercury vapor-free zone? |
| “ | “ | Has a maintenance program been developed for the ventilation systems? |
| “ | “ | Is the temperature within the refinery being regulated to keep the air temperature as low as practical? |

III. Electrowinning

YES NO

- “ “ Are the electrowinning tanks equipped with local exhaust ventilation?
- “ “ Are the cathodes being cooled prior to stripping them?
- “ “ Does the design of the wash tank for stainless steel cathodes minimize the handling of the cathodes?
- “ “ Are carbon steel cathodes being used? If so, is the cathode stripping table sealed with an epoxy paint and provided with local exhaust ventilation?
- “ “ Is the electrowon sponge being placed immediately into the retort after stripping it from the cathodes?

IV. Zinc Precipitation

YES NO

- “ “ Are the filter presses being cooled prior to scraping the precipitate into the retort pans?
- “ “ Is the precipitate being placed into the retort immediately after stripping the presses?
- “ “ Has the filter press blow-down procedure been checked to determine the amount of mercury vapor emitted during this process? If mercury vapor is present, is the air being scrubbed prior to being introduced into the atmosphere?
- “ “ Is the air from the filter press blow-down procedure being discharged to the outside of the refinery building?

V. Mercury Retort

YES NO

- “ “ Is the retort room maintained under a negative static pressure with respect to the rest of the refinery?
- “ “ Are the wall fans or the exhaust ventilation duct located near the floor of the retort room?

YES NO

- “ “ Is the retort room being cleaned on a daily basis?
- “ “ Have test runs been conducted to determine the mercury retort optimum operating parameters?
- “ “ Is the mercury retort equipped with a mercury vapor removal system?
- “ “ Is the air that is being discharged from the retort vacuum pump being discharged to the outside of the refinery building?
- “ “ Is the charcoal scrubber system being monitored for saturation or break through?
- “ “ Are the doors to the retort being left open when not in use?
- “ “ Is the condensed liquid mercury being transferred directly to a mercury flask from the retort condensation pot?
- “ “ Is the retort equipment being cleaned prior to storage?

VI. Smelting

YES NO

- “ “ Is the introduction of the fluxes and the concentrate into the furnace being done using a vacuum system?
- “ “ If mixing of the fluxes with the concentrate is being done by hand, is this process being done under the influence of local exhaust ventilation?
- “ “ Is the furnace equipped with an exhaust ventilation hood?
- “ “ Has the fume capture effectiveness of the furnace exhaust hood been evaluated using chemical smoke tubes and an instantaneous mercury vapor analyzer?
- “ “ Has an exhaust hood been constructed to capture the metal fumes generated while pouring the dore bars?
- “ “ Are the dore bars being placed under an exhaust hood until cool?
- “ “ Are the dore bars allowed to cool below the melting point of silver prior to handling them?

YES NO

- | | | |
|---|---|---|
| “ | “ | Are the slag pots being cooled under an exhaust hood? |
| “ | “ | Have engineering controls and work practices been developed to limit refiners' exposures to silver dust when descaling the dore bars? |
| “ | “ | Have the dore bars been checked to determine if they are a source of mercury vapor? |
| “ | “ | Is the vault ventilated to prevent the accumulation of mercury vapor within this location? |

VII. Housekeeping

YES NO

- | | | |
|---|---|---|
| “ | “ | Is the refinery being cleaned on a daily basis? |
| “ | “ | Are mercury vapor monitors, both integrated and instantaneous types, being used to monitor the levels of mercury vapor in the refinery? Have action levels been established to initiate corrective action procedures? |
| “ | “ | Are employees' personal tools banned from the refinery? |
| “ | “ | Are you sure the refinery is not being used as a miscellaneous storage area for equipment that is not vital to the maintenance and operation of the refinery? |
| “ | “ | Are hand tools and equipment being cleaned prior to storage? |
| “ | “ | Is a mercury vacuum cleaner being used to remove droplets of metallic mercury and accumulations of mercury contaminated debris? |
| “ | “ | Are employees changing their work coveralls at least twice a shift? Are employees changing their coveralls immediately after handling the concentrate or working on mercury contaminated equipment? |

GENERAL ENGINEERING CONTROLS

The primary engineering controls that can be used to limit mercury vapor within the carbon adsorption and reactivation building and the refinery are:

- C Local Exhaust Ventilation
- C General Dilution Ventilation
- C Temperature Control
- C Water Filtration using Activated Carbon

The following is a brief discussion of each control measure. It should be noted that air monitoring should be performed to check the adequacy of control measures in limiting employees' exposures to mercury and other contaminants.

I. Local Exhaust Ventilation

Local exhaust ventilation systems are used to control contamination at the source. The following guidelines should be applied to the design of these systems.

- C The length of ductwork should be kept to a minimum. Ductwork should be smooth and slope downward to facilitate removal of condensed mercury that may collect inside. Condensed mercury should drain to a single collection trap. The same mercury removal techniques discussed in the section entitled "Retort" should be used to drain mercury from the trap. The pipe should be labeled as being contaminated with metallic mercury.
- C The ventilation system should not contain long runs of flexible ducting. This type of ducting has a higher static pressure loss per foot as compared with smooth ducting and is difficult to clean. Mercury is more apt to condense and become trapped in flexible ducting rather than standard, smooth duct work.
- C Vertical exhaust ducts inside the refinery or carbon handling building should be avoided. Mercury will condense inside these pipes and become a contaminated source in both liquid and vapor phases. If the use of vertical exhaust ducts cannot be avoided, they should be equipped with drains for mercury removal.
- C A common mercury removal system consists of a water scrubber and an open water tank used to collect condensed mercury. Water alone is not an effective barrier against mercury vapor. The water inside the tank should be kept cool to limit the emission of mercury vapor. In addition, this type of system is not as efficient when compared to other mercury removal systems.
- C A multiple mercury scrubbing system is recommended in lieu of a single venturi scrubbing unit to treat air being exhausted from various point sources within the carbon handling

areas and the refinery. These units usually consists of a water quench system, venturi scrubber, a demister, and an activated carbon adsorber system consisting of coconut-shell-based and chemically treated activated carbon.

- C Both temperature and humidity affect the adsorption capacity of activated carbon. The adsorption capacity of the carbon is reduced with increased temperature. High humidity (greater than 50 percent RH) affects sulfur impregnated carbon. The absorbed water will form a thin wall and will prevent the reaction between the sulfur and mercury. However, due to the higher solubility of I_3 or KI in water, the high humidity will not affect the adsorption capacity of iodine impregnated carbon, and in this case it will act as a medium for the reaction to occur between I_3 or KI and mercury.⁴⁵
- C The ventilation system exhaust stack should extend well above roof line to aid in the dispersion of contaminants bypassing the scrubber. This will also reduce the potential of those contaminants being entrained into fresh air intake vents.
- C An active make-up air system should be used to provide conditioned air to the interior of the building. Passive make-up air registers and louvers create additional static pressure losses that local exhaust ventilation systems must overcome in order to work at their designed air quantities. A negative pressure can develop inside the building and adversely affect the performance of exhaust ventilation systems.

II. General Dilution Ventilation

General dilution ventilation is used to dilute the contaminants of concern with uncontaminated air. Alone, it is not satisfactory because it does not control contaminants at the source of generation. Therefore, it should be used in conjunction with local exhaust ventilation systems to assist in control of exposures to toxic substances. Wall fans are commonly used to provide general ventilation inside the refinery. Wall fans are commonly used to provide general ventilation inside the above mentioned areas. The following parameters should be considered when using wall fans as an engineering control.

- C Wall fans should be located on the lower portion of the wall opposite to the fresh make-up air plenum for the building.
- C Mercury vapor captured by wall fans and exhausted directly to the outside of the building will contaminate the immediate area.
- C The location of the fans should not disrupt the contaminant capture efficiency of local exhaust ventilation hoods.
- C Use of ceiling fans is not recommended due to the density of mercury vapor.

III. Temperature Control

Temperature control within the refinery and the carbon handling building is an important factor in controlling exposures to mercury vapor. Evaporative coolers and air conditioning units can be used to provide make-up air to the above locations. Duct work should be double walled so that duct insulating material is not exposed to the intake air stream. These cooling devices must be properly maintained and the intake air monitored for the presence of mercury vapor. It is desirable to keep the above locations between 60°F and 65°F.

Cooling the cathodes with water prior to stripping them is an important control technique in limiting exposures to mercury vapor. If quench tanks are used to reduce the temperature of the cathodes, they should be cleaned regularly, which can be done by pumping the contents through a filter press. The filtered material can be retorted and smelted to recover the precious metals.

IV. Water Filtration with Activated Carbon

Sumps and drains are well documented sources of mercury exposures. These sources can be minimized by limiting the amount of liquid mercury and contaminated debris from entering sumps and drains. In addition, filters containing activated carbon can be used for removal of mercury from waste water. This technology can be used to treat effluent from the employee hygiene facility, refinery and carbon adsorption and reactivation building, which would reduce the amount of mercury being recycled back through the cyanidation process as well as limit the accumulation of mercury in the drains and sumps.

ENGINEERING CONTROLS CHECKLIST

I. Local Exhaust Ventilation

YES NO

- | | | |
|---|---|--|
| “ | “ | Have you avoided incorporating long runs of horizontal duct work in the design of the exhaust ventilation systems? |
| “ | “ | Are ducts sloped to allow for the removal of condensed mercury? |
| “ | “ | Have you ensured that extended vertical runs of duct work do not exist inside the refinery and carbon adsorption and reactivation buildings? |
| “ | “ | Have tests been done to determine the type of mercury collection system that will be required for local exhaust ventilation systems (a single water scrubber or a multiple mercury scrubbing system)? |
| “ | “ | Is the fan exhaust stack extended above the roof line? |
| “ | “ | Is 10 percent more fresh make-up air being introduced to the interior of the building to ensure that local exhaust ventilation systems function as designed? |
| “ | “ | Are fresh air vents located in a mercury vapor-free zone? |
| “ | “ | Has a maintenance program been developed for the exhaust ventilation systems which includes collecting of air pressure measurements to determine the performance of the systems? Static pressure taps can be used to facilitate the taking of the measurement. The desired static pressure can be written on the duct itself for immediate comparison with the measured value. |

II. General Dilution Ventilation

YES NO

- | | | |
|---|---|---|
| “ | “ | Are the wall fans located on the lower portion of the wall that is opposite of the building fresh make-up air plenum which will allow air to sweep across the interior of the building? |
| “ | “ | Are the fans positioned so that airflow will not disrupt the contaminant capture efficiency of local exhaust ventilation hoods? |

III. Temperature Control

YES NO

“ “ Are swamp coolers and air conditioning systems being used to regulate the air temperature inside the refinery and carbon adsorption and reactivation building (between 60°F and 65°F)?

IV. Water Treatment

YES NO

“ “ Is an activated carbon filtration system being used to limit the amount of mercury circulating through the cyanidation plant? This same system can also be used to prevent the accumulation of mercury in sumps and drains.

MAINTENANCE

Maintenance operations

Maintenance workers are especially at risk of exposure to mercury as well as other contaminants. Extra care should be taken to monitor their work activities to ensure that personal exposures to contaminants are below MSHA limits. Engineering controls must be used to reduce exposure, which often means reviewing the work prior to initiation, bringing in temporary controls, and cleaning equipment. Because of the unique physical configurations of many maintenance operations, special care must be given to ensure that the employees are wearing appropriate personal protective equipment.

Equipment that has come in contact with mercury can absorb it into the material pores and cracks as well as have surface contamination. Heating, cutting and welding on this equipment will volatilize the mercury causing high airborne concentrations of this contaminant. In addition, maintenance workers may be exposed to other types of contaminants such as cyanide and welding fumes. Equipment maintenance procedures should be developed for working on mercury contaminated equipment. Each protocol should focus on identifying the hazards associated with a particular job and the means of controlling all potential routes of employees' exposures to the contaminants.

MAINTENANCE CHECKLIST

YES NO

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|---|---|--|
| “ | “ | Has a general maintenance program been developed to establish set procedures to use while working on mercury contaminated equipment? |
| “ | “ | Have all the hazards connected with specific maintenance tasks been identified and the means to control employees' exposures to them been developed? |
| “ | “ | Has the type of personal protective equipment required for each maintenance task been determined? |
| “ | “ | Have employees been trained in the maintenance protocols they will perform as well and in the use of their personal protective equipment? |
| “ | “ | Is air monitoring being conducted to ensure that employees are not being overexposed to mercury and other contaminants? |

PERSONAL PROTECTIVE EQUIPMENT

Mercury vapor is odorless and cannot be seen or tasted. Its presence can only be determined through the use of mercury vapor analyzers and spot test kits. The major route of exposure is through inhalation. Secondary routes of mercury exposure are through skin absorption and ingestion. The following is a discussion of the types of personal protective equipment that should be worn by employees who work around elemental mercury.

I. Respiratory Protection

As a minimum, a respiratory protection program consistent with the American National Standards Institute (ANSI) Z88.2-1969, "Practices for Respiratory Protection" should be implemented. The ANSI standard was updated in 1992. NIOSH, in its Guide to Industrial Respiratory Protection document and ANSI, standard Z88.6-1984, ". . . Respiratory Protection - Respirator Use - Physical Qualifications for Personnel" provides information on medical evaluations governing respirator use. The guidelines outlined in these documents should be implemented in conjunction with ANSI standard Z88.2-1969. The purpose of this information is to provide guidance and information for examining physicians to assist them in determining the suitability of personnel for respirator use.

Only NIOSH certified respirators approved for metallic mercury vapor should be used. Since mercury vapor cannot be detected by the respirator wearer, approved mercury vapor cartridges will have end-of-service indicators that change color to indicate saturation. When the indicator changes color, the cartridges must be replaced. The end-of-service indicator should be checked throughout the entire shift. NIOSH provides the following guidelines for respirator selection given various concentrations of metallic mercury vapor. Respirator users should remember that a particular metallic mercury vapor cartridge will have specific limitations on its use. These limitations take precedence over the table found below when selecting a particular type of respirator. For example, a full-facepiece PAPR that utilizes a mercury vapor cartridge that limits its use to a concentration of 0.500 mg/m³ of mercury vapor would only provide a protection factor of ten in lieu of fifty. The manufacturer should be consulted on the limitations of their mercury vapor cartridges prior to their use. It is important to ensure that employees are cleaning and checking their respirators on a daily basis to ensure that they will function as designed and that are free of contamination. A mercury vapor analyzer can be used to scan the respirators for the presence of mercury.

Because mercury has no warning properties, it is essential that the respirator fit be maintained at all times. Employees must be trained to check the fit, and should be fit tested at least annually.

NIOSH Respirator Selection Guide for Chemical Cartridge Respirators

Type of Respirator	Protection Factor	Maximum Allowable Limit (mg/m ³)
Any chemical cartridge respirator & noncontinuous supplied air respirator	10	$10 \times 0.050 = 0.500$
Supplied air, continuous flow mode & any canister PAPR	25	$25 \times 0.050 = 1.25$
Full Facepiece chemical cartridge respirator, any supplied-air respirator, continuous flow mode with tight fitting facepiece, any PAPR with a tight-fitting facepiece, SCBA & any supplied-air respirator with a full facepiece	50	$50 \times 0.050 = 2.5$

II. Skin Protection

Employees should be provided with and required to use coveralls, rubber or neoprene gloves and rubber boots to prevent repeated or prolonged skin contact with metallic mercury. These items should be of such material and construction as to minimize the possibility of the clothing acting as a secondary source of mercury vapor.

Coveralls

It is recommended that outer coveralls without pockets, belts or cuffs be worn to minimize trapping of mercury that can be a continuing source of mercury vapor in the microenvironment surrounding a person. There is some evidence that it may be more difficult to wash mercury out of dyed fabrics than out of white fabrics.⁴⁶ Coveralls should be changed at least twice a shift. In addition, the coveralls should be changed immediately after an individual has worked with the concentrate or on mercury contaminated equipment.

Footwear & Gloves

Porous leather boots or gloves should not be worn in areas potentially exposed or contaminated with mercury. Rubber or neoprene boots or gloves need to be cleaned and monitored to ensure that they are free of mercury contamination.

III. Personal Hygiene

Employees who work around mercury should wash their hands thoroughly with Hgx soap and water before eating, smoking or using the toilet facilities. In addition, eating or smoking should not be permitted in areas where mercury is present. The use of good personal hygiene practices should be reinforced through the use of educational posters and periodic training.

PERSONAL PROTECTIVE EQUIPMENT CHECKLIST

I. General Guidelines

YES NO

- “ “ Has a training program been developed that will inform employees on the use, care and limitations of their personal protective equipment and the consequences if it is not worn properly?
- “ “ Do employees understand the health hazards connected with elemental mercury and how they can protect themselves from being overexposed to mercury?
- “ “ Have provisions been made to provide personal protective equipment to visitors?

II. Respiratory Protection

YES NO

- “ “ Has a respiratory protection program been developed that meets the minimal requirements outlined in the American National Standards Institute guideline Z88.2-1969- “Practices for Respiratory Protection”?
- “ “ Is ANSI standard Z88.6-1984, “For the Respiratory Protection - Respirator Use - Physical Qualifications for Personnel” being used to assist physicians in determining whether an employee can wear a respirator?
- “ “ Are respirators approved by NIOSH?
- “ “ Has a training program been developed that will inform employees on the use, care and limitations of their respirators and the consequences if the respirator is not worn properly?

III. Skin Protection

YES NO

- “ “ Are only rubber or neoprene boots and gloves being worn in areas potentially exposed to or contaminated with mercury?
- “ “ Are coveralls being provided to employees who work in mercury contaminated areas? Are they being changed at least twice a shift and more often as dictated by the type of work assignment?

YES NO

“ “ Have arrangements been made to wash reusable coveralls, either in-house or by an outside contractor?

IV. Personal Hygiene

YES NO

“ “ Have employees been informed of the importance of good hygiene habits?

“ “ Are educational posters predominately displayed to reinforce the benefits of good hygiene habits?

WORKPLACE MONITORING for ELEMENTAL MERCURY

There are several methods that can be used to determine and quantify the presence of elemental mercury both liquid and vapor within the workplace. The type of sampling method selected depends on the objectives of the survey. The following methods will be discussed:

- C Personal Airborne Exposure Sampling.
- C Area Airborne Sampling.
- C Surface Sampling.
- C Environmental Screening Samples.

Results of the sampling should be shared with all employees.

I. Personal Air Monitoring

The purpose of personal air monitoring is to determine an individual's exposure to airborne metallic mercury vapor. A sampling device is placed on the employee within his/her breathing zone, which usually involves clipping the monitor to the shirt collar. The sampling time is dependent on the objectives of the survey. The sampling results are compared to either predetermined values established by the company or to regulatory standards to ascertain whether corrective action is needed to ensure the health of the employee. MSHA's full-shift exposure limit is 0.050 mg/m^3 and its fifteen minute excursion limit is 0.150 mg/m^3 . Exceeding either of these limits requires corrective action on the part of the mine operator.

There are two sampling methods that can be used to obtain an individual's exposure to airborne mercury vapor. Passive diffusion monitors can be used to collect full-shift samples. The primary benefit of using this sampling protocol is the ease of use. The other method is active-integrated sampling, which entails using a calibrated sampling pump and a sorbent tube. The pump draws air, at a predetermined flow rate, through a sorbent tube where the contaminant is captured. The sorbent tube is sent to a laboratory to determine the amount of the contaminant collected on the sampling media. The results for both air monitoring methods are presented in either $\mu\text{g/m}^3$ or mg/m^3 of mercury. A gold coil mercury dosimeter is also available for personal sampling. This is an active sampling device that uses a low flow pump to draw air past a gold coil. The mercury contained in the airstream is adsorbed onto the gold film. The sample results are obtained by burning the mercury off the gold coil using the Jerome, model 431-x mercury vapor analyzer. The advantage of this method is that the sample results can be determined on-site.

II. Area Airborne Monitoring

The purpose of obtaining area airborne samples is to determine specific sources of mercury vapor within the plant and to ascertain the effectiveness of clean-up and equipment decontamination procedures. Area samples should not be used as a substitute for personal exposure sampling. This type of monitoring should be used only to approximate employees' personal exposures to

mercury vapor or to determine contamination of an area or objects.

Area airborne monitoring can be done using the same sampling techniques described above for personal exposure monitoring. In addition, there are two types of hand-held instruments that can be used to obtain instantaneous airborne concentrations of metallic mercury vapor. Bacharach Instrument Company* makes a mercury vapor analyzer that is based on ultra-violet (UV) absorption principle. It has a sensitivity of 0.01 mg/m³ and is accurate within +/- 5 percent. Since the mercury vapor detector depends on the absorption of UV radiation by the sample, it will be affected to some extent by any substances that have a greater absorption of UV light than does normal air. Commonly encountered substances are vapors of various hydrocarbons, water vapor, sulfur compounds, and particulate, such as smoke. The advantage of the UV instrument is that it can be used continuously in relatively high concentrations of mercury vapor (less than 1.0 mg/m³) whereas the gold film instrument requires periodic regeneration of the gold film. The disadvantages of the UV instrument are that the instrument must be zeroed between samples and its sensitivity. Arizona Instruments Inc.* makes a gold film mercury vapor monitor that is based on mercury's ability to alter the resistance of a gold film. The instrument's sensitivity is 0.003 mg/m³ and the accuracy is +/- 5 percent at 0.100 mg/m³. Ammonia and acid gases are the principle chemicals that interfere with the operation of the instrument. The instrument is also temperature sensitive. The advantage of the gold film instrument is its sensitivity and its ability to automatically zero itself between each sample.

III. Surface Sampling

Wipe samples are used to determine the effectiveness of equipment decontamination procedures and clean-up protocols used for the hygiene facility and lunch room. This type of sampling involves swiping a 100cm² area with moist filter paper. The wipe sample is placed in a vial and submitted to a laboratory for analysis. The results are presented in either micrograms or milligrams of mercury. These results should be used only to determine the presence or absence of mercury. Also, there are commercially available surface test kits for evaluating surface contamination. They can be used as indicators of the presence or absence of mercury on various surfaces. Scrape samples can be used to determine the presence of mercury on equipment and other surfaces, such as concrete and paint. These samples can be analyzed in-house using the following procedure:

- C Place approximately three grams of sample inside a funnel flask,
- C Seal the flask and connect it to a mercury vapor analyzer,
- C Heat the flask to approximately 140°F, and
- C Determine the presence or absence of mercury vapor by sampling with the mercury vapor analyzer.

**** No specific brand-name product is required to be used under Mine Safety and Health Administration (MSHA) regulations. MSHA provides product information solely as a service to the general public. Reference to any specific product by trade name, trademark, manufacturer, or otherwise in this report does not constitute or imply its endorsement, recommendation, or favoring by MSHA.***

Although not quantitative, this procedure will provide the necessary information to determine if the materials contain mercury. If desired, samples may be sent to a laboratory for quantitative analysis.

IV. Environmental Screening Samples

The purpose of this type of sampling is to determine the presence of mercury in soil. The sampling and analysis can be performed on-site by using the following approach:

- C Invert a plastic cup over the soil and seal the edges with dirt,
- C Allow the cup to sit for approximately five hours, and
- C Measure the mercury vapor by inserting a probe that is attached to a mercury vapor analyzer and activating the instrument.⁴⁷

This method identifies only the presence and relative amounts of mercury out-gassing from the soil surface. It should not be used to determine actual concentrations of mercury in the soil. Figure 13 illustrates this sampling procedure.

MERCURY MONITORING CHECKLIST

I. General Considerations

YES NO

- | | | |
|---|---|--|
| “ | “ | Has an airborne mercury monitoring program been developed and implemented to determine employees' personal exposures to mercury vapor? |
| “ | “ | Has an area mercury monitoring program been developed and implemented to determine the principle sources of mercury? |
| “ | “ | Has a clean-up protocol been developed to remediate areas that are contaminated with mercury? |
| “ | “ | Are the mercury vapor analyzers being calibrated on a regular basis? |
| “ | “ | Have action limits been established to determine when corrective action is required to ensure the health of the employees? |
| “ | “ | Are sampling results being logged and submitted to management for review? |
| “ | “ | Are sampling results being shared with all employees? |

BIOLOGICAL MONITORING⁴⁸

I. Biological Monitoring

Biological monitoring assesses the internal exposure of an individual.⁴⁹ That is, it measures the amount of an agent actually absorbed into the body. For elemental mercury, the assessment is made by measuring the amount of this constituent in the blood or urine. Measurement of mercury in urine is the recommended biological monitor for workers exposed to metallic mercury in lieu of mercury in blood. The reason is that the latter reflects exposure to organic mercury as well as metallic and inorganic mercury. Thus, blood tests can be influenced by the consumption of fish containing methyl mercury. This is not the case for urine tests. Persons without occupational or unusual environmental exposure to mercury rarely excrete more than 5µg/g creatinine in their urine.⁵⁰

There are a number of variables that must be considered in the collection and interpretation of the sampling results. For example, excretion of mercury from the body fluctuates considerably, independent of exposure; therefore, individual findings cannot be used to determine the intensity of exposure or the presence or absence of mercury toxicity. The program should be under the direct supervision of a medical doctor who is familiar with the toxicity of elemental mercury. Together, the company and physician should establish criteria on which corrective action will be taken based on an individual's biological monitoring history.

The ACGIH recommends that the level of mercury in the urine not exceed 35µg adjusted for creatinine.⁵¹ Accordingly, any employee who was found to have exceeded this level (35 µg hg/Cr) should be removed from the source of mercury contamination until levels return below that level. The purpose of the biological monitoring program should be explained to all the affected employees. The employees should receive their monitoring results as soon as practical. The results should be explained to them so the employees have a complete understanding of what they mean as it relates to their health and well-being.

II. Medical Surveillance

Medical Surveillance measures the end health effect of an exposure to a toxic substance and offers early detection of a problem. Employees who will be working with mercury should be given an initial medical examination that can be used as a baseline for future health evaluations. The examination should consist of a complete medical history and symptom questionnaire, with emphasis on:

- C The nervous system.
- C The kidneys.
- C The oral cavity.
- C The lungs.
- C The eyes.
- C The skin.

Signs of early mercury intoxication should be elicited and a baseline handwriting sample collected from the employee.⁵² The examinations should be repeated on an annual basis. The results of the examinations should be explained to the employees and remain confidential between them and their physician.

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BIOLOGICAL MONITORING & MEDICAL SURVEILLANCE CHECKLIST

YES NO

- | | | |
|---|---|--|
| “ | “ | Are employees who will be working with mercury given an initial medical examination that can be used as a baseline for future health evaluations? Are the examinations repeated on a yearly basis? |
| “ | “ | Are employees offered urine mercury tests? |
| “ | “ | Is the program under the direction of a physician who is familiar with elemental mercury toxicity and the interpretation of biological sample results? |
| “ | “ | Have criteria been established on which corrective action will be taken based on an individual's biological monitoring history? |
| “ | “ | Have employees been informed of the purpose of the biological monitoring program? |
| “ | “ | Are employees receiving their biological monitoring results in a timely fashion? |
| “ | “ | Do employees understand how to interpret their biological sampling results and how these results relate to their well-being? |

CONCLUSION

Mercury continues to represent a serious health risk to miners, which requires constant vigilance to control. As discussed in this “Best Practices” toolbox there are ways to control the hazards. MSHA is sharing this information with miners, mine operators and health and safety professionals to educate and inform the mining community about the protections that are available to guard against the hazard of exposure to mercury. MSHA encourages comments on this “Best Practices” toolbox.

Additional Reading Materials

Agency for Toxic Substance and Disease Registry Toxicological Profile for Mercury. ATSDR (1989). For a copy of this document phone (703) 487-4660.

Amendola, A., A and D.R. Telesca. National Institute for Occupational Safety and Health. A Survey of Health Hazard Control Systems for Mercury Use and Processing. Document Number 00134888. February, 1984.

American Conference of Governmental Industrial Hygienists. Documentation of Threshold Limit Value (TLV's) and Biological Exposure Indices. Cincinnati, Ohio. 1996.

Chamberlain, P. G. and M.G. Pojar. Gold and Silver Leaching Practices in the United States. U.S. Bureau of Mines, Information Circular 8969. 1984.

Guidelines for the Safe Clean-up of Mercury Spilled in the Home. Division of Epidemiology, Environmental and Occupational Health Services, New Jersey Department of Health. January, 1996. For a copy of this document phone (609) 984-1863.

Harvey, B. and G. Crockford eds. Handbook of Occupational Hygiene. Vol 2. Kluwer Publishing: Brentford, Middlesex, Great Britain. 1980.

Heinen, H. J., D.G. Peterson, and R.E. Lindstrom. Processing Gold Ores Using Heap Leach-Carbon Adsorption Methods. U.S. Bureau of Mines, Information Circular 8770. 1978.

Hudson, P.J. Elemental Mercury Exposure Among Children of Thermometer Plant Workers. Pediatrics. Vol. 79, June (1987), pp. 935-938.

Kudryk, V., D.A. Corrigan and W.W. Liang, eds. Precious Metals: Mining, Extraction, and Processing. New York: AIME, 1984.

Lynham, M. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Field Report Number D7999-T579. August, 1993.

Marsden, J, and I. House. The Chemistry of Gold Extraction. Ellis Horwood Limited: Chichester, West Sussex, England. 1992.

Mullen, J., C. Project Manager - Dappolonia. "Clean-up of Mercury Contaminated Equipment & Work Area". Project Number RM82-1488. June 1982.

National Institute for Occupational Safety and Health (1973). A recommended standard for

occupational exposure to inorganic mercury. DHEW (NIOSH). Publication No. HSM 73-11024.

Patty's Industrial Hygiene and Toxicology. 4th Edition. Mercury, pp. 2124. John Wiley & Sons. 1993.

Report to Congress on the Worker s' Home Contamination Study Conducted by the National Institute for Occupational Safety and Health. NIOSH Publication No. 95-123, September 1995. Cincinnati, Ohio.

Senn E. P. Controlling Metallic Mercury Exposure in the Workplace, A Guide for Employers. New Jersey Department of Health Occupational Health Service. Feb. 1996. For a copy of this document phone (609) 984-1863.

Trabant, G. and M. Lynham. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Field Report Number D8163-T606. October, 1994.

Trabant, G. and S. Kneipple. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Field Report Number D8248-T612. May, 1995.

Trabant, G. and M. Lynham. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Field Report Number D8266-T617. May, 1995.

Your Mercury Exposure - Important Information for People Exposed to Mercury at Work, at Home, and in the Community Environment. Division of Environmental and Occupational Health Services, New Jersey Department of Health. February, 1997. For a copy of this document phone (609) 984-1863.

Zirschky J. and Witherell, L. Cleanup of Mercury Contamination of Thermometer Workers' Homes. AIHA Journal. 48 (I):81-84.

APPENDIX A:
REPORTS ON MERCURY VAPOR CONTROL COMPLETED BY
MSHA'S DENVER SAFETY AND HEALTH TECHNOLOGY CENTER,
1992-1996

Weems, G. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Newmont Gold Company, Mine ID Number: 26-00500, Carlin, NV. Field Report Number D7562-T524. February, 1992.

Weems, G. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. American Barrick Company, Mine ID Number: 26-01089, Elko, NV. Field Report Number D7858-T548. August, 1993.

Lynham, M. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Amax Gold Company, Mine ID Number: 26-01932, Winnemucca, NV. Field Report Number D7999-T579. August, 1993.

Trabant, G. and M. Lynham. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Pegasus Gold Corporation, Mine ID Number: 10-01839, Burley, ID. Field Report Number D8163-T606. October, 1994.

Trabant, G. and S. Kneipple. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Newmont Gold Company, Mine ID Number: 26-00500, Carlin, NV. Field Report Number D8248-T612. May, 1995.

Trabant, G. and M. Lynham. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Castle Mountain Joint Venture, Mine ID Number: 04-04918, Searchlight, CA. Field Report Number D8266-T617. May, 1995.

Lynham, M. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Santa Fe Pacific Gold Corporation, Mine ID Number: 26-01942, Golconda, NV. Field Report Number D8342-T626. June, 1996.

Lynham, M. and T. Lloyd. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Getchell Gold Corporation, Mine ID Number: 26-01801, Golconda, NV. Field Report Number D8359-T631. August, 1996.

Lynham, M. and T. Lloyd. Mine Safety and Health Administration, Denver Safety and Health Technology Center, Toxic Materials Division. Mercury Vapor Control Evaluation. Echo Bay Minerals Company, Mine ID Number: 26-02051, Battle Mountain, NV. Field Report Number D8366-T633. August, 1996.

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APPENDIX B: PROCEDURES TO CLEAN-UP MERCURY CONTAMINATED EQUIPMENT AND WORK AREAS

I. Introduction

This section addresses the actions necessary to remove mercury contamination from equipment and work areas at gold processing facilities. General clean-up procedures are followed by step-by-step procedures suggested for effective remediation. The recommended clean-up procedures consist of the following five steps:

- C Vacuuming all surfaces using a mercury vacuum.
- C Scrubbing with a mercury sponge.
- C Washing surfaces with sodium thiosulfate solution and water.
- C Applying mercury complexing agent vapor absorbent.
- C Re-vacuuming.

These steps are most applicable to sealed, painted and metal surfaces in the refining and retort rooms. A list of materials and equipment necessary for clean-up of mercury contamination is contained in Appendix "C". The following is a discussion of each of step.

II. Clean-Up Procedures

Protective Clothing

During clean-up operations, personnel must wear protective gloves, rubber boots, coveralls and respirators. Cartridge type respirators should be worn to limit mercury vapor exposures. Proper training in respirator inspection and use is necessary to assure that the units function properly. After each day, disposable clothing is to be sealed in plastic bags and placed in the disposal drum(s) provided.

Personal Hygiene

At the end of each day, all persons involved in clean-up operations should shower and scrub thoroughly with soap. Any contaminated clothing or rubber boots to be reused should be vacuumed, decontaminated with a mercury complexing agent and placed in lockers used only for work clothes (street clothing should not be placed in the same locker).

During actual clean-up operations, the following procedures and precautions should also be used:

- C All jewelry should be removed prior to cleanup (particularly watches, rings, and necklaces).
- C Faces should be clean shaven to provide a proper seal with the respirators.

- C Smoking, drinking, and eating should not be allowed in potentially contaminated areas.
- C Coveralls should be removed before entering the lunch/shower (clean room) facilities. Preferably, the coveralls should be removed when exiting the contaminated area.
- C Hands should be thoroughly washed with soap prior to eating or drinking.
- C Levels of mercury (in milligrams of mercury per cubic meter of air) should be determined from the dosimeters and recorded in a permanent file.
- C A hand-held mercury vapor analyzer should be used to obtain instantaneous readings to ensure mercury vapor concentration levels do not exceed the limits of the respirator's protection factor.

III. Step-By-Step Procedure

As previously stated, the clean-up is designed to eliminate or reduce mercury contamination. In some cases where porous materials are present, complete decontamination is impossible; therefore, items such as rugs and wood surfaces should be removed and disposed of in accordance with State and Federal environmental regulations. Porous concrete and cinder blocks also cannot be completely decontaminated and should be sealed with an epoxy paint to facilitate cleaning. On most metal and painted surfaces, the clean-up activities described below will eliminate or reduce the mercury levels significantly. All materials should be checked for the presence of mercury after clean-up. If mercury still exists, remedial actions (such as application of a sealant) are recommended. In other areas (e.g., where insulation has been exposed to mercury vapor), replacement or covering with a smooth, nonporous surface may be necessary.

Vacuum

The mercury vacuum cleaner is designed specifically to clean-up mercury and mercury contaminated materials. The vacuum is usually made up of the following components:

- C Centrifugal droplet collector.
- C Dust collector (with disposable bags).
- C Iodine activated carbon air filter.
- C Microfilter (99.5% efficient at 2 microns).
- C HEPA filter (99.97% efficient at 0.3 microns).

The vacuum is designed to collect liquid mercury, contain particulate materials and adsorb mercury vapors. The vacuum cleaner must be used to clean all exposed surfaces. Extension tubes can be used to reach all beams and lights from ladders or scaffolding. When appropriate, the crevice or other attachments are used for cracks, corners, and other hard to get places. The manufacturer's instructions should be carefully read and followed. The extension tubes should be washed (with a mercury complexing agent) after use and stored with the vacuum in an exhausted closet. If mercury remains on aluminum extension tubes it will amalgamate (combine) with the aluminum and become a potential source of mercury vapor. Typically, the carbon filter on the vacuum has a capacity for up to two years of use. However, to avoid a potential problem and to

maximize this equipment's effectiveness, the exhaust from the vacuum should periodically be monitored using a mercury vapor analyzer. The centrifugal droplet collection device should be checked periodically during clean-up and its contents sealed in a plastic bag and placed in the disposal drum. The disposable dust collector bag should be periodically checked and when full should also be sealed in a plastic bag and placed in the disposal drum. All items placed in the drums should be recorded on the disposal form. After use, the vacuum should be disassembled, the bag replaced and the filters cleaned.

Mercury Sponge (optional)

After vacuum clean-up of all surfaces, difficult to clean locations where mercury may collect such as cracks may be scrubbed with mercury sponges. The sponge is a zinc scrubbing pad which is activated with sulfamic acid and a wetting agent. Any free mercury present will amalgamate with the zinc. After use, the sponge should be sealed in a plastic bag and placed in the designated disposal drum. Experience has shown that the sponge does not effectively adsorb mercury that has already amalgamated with other metals, therefore, the use of the sponge is probably best reserved for use with free mercury.

Washing Surfaces

All nonporous surfaces (metal, sealed or painted surface) should be washed and scrubbed with fresh water to remove the dirt. The surface should then be scrubbed with a sodium thiosulfate solution (3% by weight in water). The thiosulfate will complex with and remove the mercury. Finally, the surfaces should be rinsed with fresh water to remove the thiosulfate solution.

Absorptive Material

A carbon that has been activated with iodine can be used to absorb material. At the end of the previous steps, the material should be spread on cracks and put in hard to reach places. The material will adsorb any mercury present as vapor or finely divided micro-droplets. When applied, the material should be left overnight.

Re-vacuuming

After a sufficient period (about 12 hours), the mercury complexing agent should be vacuumed using the mercury vacuum cleaner. All waste material collected should be sealed in a plastic bag and placed in the disposal drum.

IV. Evaluation of Decontamination Effectiveness

An important part of the clean-up program is determining the level at which clean-up was effective. An evaluation should be performed using the following techniques:

- C Chemical indicators should be used to detect mercury vapors.
- C Scrape samples of paints, concrete, metal and tool surfaces should be analyzed for mercury.
- C The ambient air concentrations of mercury should also be evaluated.

Chemical Indicator (Optional)

A chemical mercury indicator may be applied to selected surfaces during clean-up operations (preferably at the same time that the mercury complexing agent is applied). The indicator will turn pink or black (depending on the mercury concentrations) if mercury vapors are being evolved from the surfaces. Experience has shown that only large concentrations of mercury can be detected using the indicator.

Scrape Samples

Scrape samples of paints, concrete and metal should be obtained from various locations in the work areas and placed individually in a funnel flask. If possible, a minimum of two to three gram samples should be used. The flask should then be sealed, connected to the mercury vapor analyzer and heated to approximately 135 degrees Fahrenheit (57 degrees Celsius). If mercury vapor is evolved from the material, its presence will be detected by this procedure. Although not quantitative, this procedure will provide the necessary information to determine if the material still contains mercury. If desired, samples may be sent to a laboratory for quantitative analysis.

Air Monitoring

After clean-up, the mercury concentration in the ambient air should be monitored. The values obtained should be compared to dosimeter measurements before, during and after clean-up and ambient air levels before and during clean-up. This comparison is extremely important because selected surfaces or materials may still contain some mercury that contaminates small areas while the overall air concentration has been reduced to an acceptable level. As part of this procedure, a comparison should be made of the values obtained prior to and after clean-up from scrape samples and ambient air. Depending upon the values obtained, the following future actions may be required:

- C No future action is necessary as the ambient air concentration is well below recommended levels.
- C Certain equipment cannot be decontaminated, therefore, it must be removed from the work environment.
- C Certain porous or fibrous surfaces cannot be decontaminated, therefore, these surfaces should be either covered with a smooth nonporous material, sealed with epoxy paint, or removed and replaced.

The actions required will depend upon site-specific information and input from on-site personnel.

Any proposed requirements may consist of a combination of all three actions listed above or may be combined with personal hygiene and monitoring programs such as limiting exposure time in the room or changing operational procedures. Records of sampling results and pertinent sampling information should be maintained.

V. Disposal

Waste items will require secured disposal:

- C Clothing (disposable).
- C Mercury complexing agent.
- C Dust.
- C Vacuum cleaner filters.
- C Other contaminated materials.

When the use of the equipment or clothing is completed or when it has become contaminated, it should be placed in plastic bags and sealed, then placed in disposal drums. The drum should be lined with teflon and labeled "MERCURY CONTAMINATED WASTE". The drum should be clamped shut so that it is sealed when not in use. After a drum is full, it should be handled and disposed of according to Federal and State requirements.

CLEAN-UP PROTOCOL CHECKLIST

I. Equipment

YES NO

- | | | |
|---|---|--|
| G | G | Do you have all of the following equipment to use for effective clean-up of mercury contaminated equipment and work areas? |
| | | ! Mercury vacuum cleaner. |
| | | ! Sodium thiosulfate. |
| | | ! Granular carbon impregnated with iodine. |
| | | ! Mercury vapor analyzer. |
| | | ! Mercury sponge. |
| | | ! Personal mercury exposure monitors. |
| | | ! Disposal Drums. |
| G | G | Have employees been provided with all of the following personal protective equipment? |
| | | ! Respirators. |
| | | ! Rubber gloves. |
| | | ! Rubber boots. |
| | | ! Coveralls. |
| G | G | Have mercury-contaminated materials been properly disposed of in accordance with federal and state requirements? |

II. Clean-up Procedures

1. Vacuum all surfaces to remove droplets of elemental mercury and mercury contaminated debris.
2. Remove porous materials that cannot be completely cleaned or sealed with an epoxy paint and dispose of the debris properly.
3. Seal porous materials, such as cinder block or concrete with an epoxy paint.
4. Clean cracks and crevices that contain elemental mercury with a zinc scrubbing pad.
5. Wash all nonporous surfaces with fresh water to remove dirt, wash with a sodium thiosulfate solution, and rinse with fresh water to remove the thiosulfate.
6. Spread mercury complexing agent or similar material on cracks and hard-to-reach places to adsorb micro-droplets of mercury and leave overnight; then remove the material using a mercury vacuum cleaner.
7. Seal all waste material in a plastic bag and place the bag in disposal a drum.
8. Use chemical indicators, scrape samples, and air monitoring to evaluate decontamination effectiveness.
9. Re-clean areas that are still sources of mercury vapor, as indicated by the above step.

APPENDIX C: SOURCES OF EQUIPMENT AND SUPPLIES

The use of a specific brand of product is not required by MSHA regulations or under MSHA policy. While an effort has been made to make the list complete, the list may not be definitive of what is available in sampling devices, protective equipment, or control technology for mercury. Inclusion in this list does not imply MSHA approval or endorsement, and MSHA does not endorse one manufacturer over another. MSHA will be happy to add the names of other manufacturers of such equipment and control technology.

EQUIPMENT	SUPPLIER	PHONE NUMBER
MERCURY VACUUM SYSTEMS	Nilfisk of America, Inc. 300 Technology Dr. Malvern, PA 19355	(610) 647-6420 (800) 645-3475
	Hako Minuteman Through Lab Safety Supply	(800) 356-0783
MERCURY VAPOR ANALYZERS	Arizona Instruments 4114 East Wood St. Phoenix, AZ 85040	(602) 470-1414 (800) 235-3360
	Bacharach Instrument Company 625 Alpha Drive Pittsburgh, PA 15238	(412) 963-2000
MERCURY VAPOR PASSIVE MONITORS	3M Company 3M Occupational H&E Safety Div. 3M Center, Bldg. 76-01-01 St. Paul, MN 55107	(800) 243-4630
	SKC Inc. 334 Valley View Rd. RR1 P.O. Box 334 Eighty Four, PA 15330	(412) 941-9701 (800) 243-4360
	Advanced Chemical Sensors Company 3201 North Dixie Highway Boca Raton, FL 33431	(561) 338-3116

The use of a specific brand of product is not required by MSHA regulations or under MSHA policy. While an effort has been made to make the list complete, the list may not be definitive of what is available in sampling devices, protective equipment, or control technology for mercury. Inclusion in this list does not imply MSHA approval or endorsement, and MSHA does not endorse one manufacturer over another. MSHA will be happy to add the names of other manufacturers of such equipment and control technology.

EQUIPMENT	SUPPLIER	PHONE NUMBER
MERCURY RETORTS	Denver Minerals Engineers, Inc 10001 S. Highway 121, RR1 Littleton, CO	(303) 932-6280
	Custom Equipment Corporation P.O. Box 747 350 W. 300 South Salt Lake City, UT 84110	(801) 533-8557
MERCURY SCRUBBER SYSTEMS	Barneby & Sutcliffe Corporation P.O. Box 2526 Columbus, OH 42316	(614) 258-9501
	Cameron-Yakima, Inc. 1414 S. First St. P.O. Box 1554 Yakima, WA 98907	(509) 452-6605
PERSONAL PROTECTIVE EQUIPMENT	Mine Safety Appliance P.O. Box 426 Pittsburgh, PA 15230	(800) 672-2222
C Coveralls		
C Gloves		
C Faceshields	Lab Safety Supply P.O. Box 1368 Janesville, WI 53547	(800) 356-0783 Tech Support Line (800) 356-2501
C Goggles	VWR Scientific P.O. Box 66929 Chicago, IL 60666	(708) 879-0600 (800) 932-5000

The use of a specific brand of product is not required by MSHA regulations or under MSHA policy. While an effort has been made to make the list complete, the list may not be definitive of what is available in sampling devices, protective equipment, or control technology for mercury. Inclusion in this list does not imply MSHA approval or endorsement, and MSHA does not endorse one manufacturer over another. MSHA will be happy to add the names of other manufacturers of such equipment and control technology.

EQUIPMENT	SUPPLIER	PHONE NUMBER
PERSONAL PROTECTIVE EQUIPMENT		
C Respirators	Mine Safety Appliance P.O. Box 426 Pittsburgh, PA 15230	(800) 672-2222
	Glendale Protective Technologies 130 Crossways Park Dr. Woodbury, NY 11797	(516) 921-5800 (800) 645-7530
	Lab Safety Supply P.O. Box 1368 Janesville, WI 53547	(800) 356-0783 Tech Support Line (800) 356-2501
CLEAN-UP MATERIALS		
C RESISORB or silmilar material	Lab Safety Supply P.O. Box 1368 Janesville, WI 53547	(800) 356-0783 Tech Support Line (800) 356-2501
C Mercury Sponge		
C Mercury Indicators	VWR Scientific	(708) 879-0600
C Sodium Thiosulfate	P.O. Box 66929	(800) 932-5000
C HGX	Chicago, IL 60666	
	Action Technologies, Inc. 100 Thompson St. Pittston, PA 18640	(717) 654-0612
	EPS Chemicals, Inc. Unit 8 7551 Vantage Way Delta, B.C., Canada V4G1C9	(604) 940-0975 (800) 663-8303
EPOXY COATINGS	Pacific Polymers, Inc. 12271 Monarch St. Garden Grove, CA 92671	(714) 898-0025 (800) 888-8340

APPENDIX D: SELECTED MSHA STANDARDS

56/57.5001 Exposure limits for airborne contaminants.

Except as permitted by §57.5005--

(a) Except as provided in paragraph (b), the exposure to airborne contaminants shall not exceed, on the basis of a time weighted average, the threshold limit values adopted by the American Conference of Governmental Industrial Hygienists, as set forth and explained in the 1973 edition of the Conference's publication, entitled "TLV's Threshold Limit Values for Chemical Substances in Workroom Air Adopted by ACGIH for 1973," pages 1 through 54, which are hereby incorporated by reference and made a part hereof. This publication may be obtained from the American Conference of Governmental Industrial Hygienists by writing the Secretary-Treasurer, P.O. Box 1937, Cincinnati, Ohio 45210, or may be examined in any Metal and Nonmetal Safety and Health District Office of the Mine Safety and Health Administration. Excursions above the listed thresholds shall not be of a greater magnitude than is characterized as permissible by the Conference.

The TLV for Mercury (all forms except alkyl) - $0.05\text{mg}/\text{m}^3$
and its excursion limit is - $0.015\text{mg}/\text{m}^3$

56/57.5002 Exposure monitoring.

Dust, gas, mist, and fume surveys shall be conducted as frequently as necessary to determine the adequacy of control measures.

56/57.5005 Control of exposure to airborne contaminants.

Control of employee exposure to harmful airborne contaminants shall be, insofar as feasible, by prevention of contamination, removal by exhaust ventilation, or by dilution with uncontaminated air. However, where accepted engineering control measures have not been developed or when necessary by the nature or work involved (for example, while establishing controls of occasional entry into hazardous atmospheres to perform maintenance or investigation), employees may work for reasonable periods of time in concentrations of airborne contaminants exceeding permissible levels if they are protected by appropriate respiratory protective equipment. Whenever respiratory protective equipment is used a program for selection, maintenance, training, fitting, supervision, cleaning, and use shall meet the following minimum requirements:

- (a) Respirators approved by NIOSH under 42 CFR part 84 which are applicable and suitable for the purpose intended shall be furnished and miners shall use the protective equipment in accordance with training and instruction.

(b) A respirator program consistent with the requirements of ANSI Z88.2-1969, published by the American National Standards Institute and entitled “American National Standards Practices for Respiratory Protection ANSI Z88.2-1969,” approved August 11, 1969, which is hereby incorporated by reference and made a part hereof. This publication may be obtained from the American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018, or may be examined in any Metal and Nonmetal Health District Office of the Mine Safety and Health Administration.

(c) When respiratory protection is used in atmosphere immediately harmful to life, the presence of at least one other person with backup equipment and rescue capability shall be required in the event of failure of the respiratory equipment.

56/57.15001 First aid materials

Adequate first-aid materials, including stretchers and blankets shall be provided at places convenient to all working areas. Water or neutralizing agents shall be available where corrosive chemicals or other harmful substances are stored, handled, or used.

56/57.15006 Protective equipment and clothing for hazards and irritants.

Special protective equipment and special protective clothing shall be provided, maintained in a sanitary and reliable condition and used whenever hazards or process or environment, chemical hazards, radiological hazards, or mechanical irritants are encountered in a manner capable of causing injury or impairment.

56/57.16003 Storage of hazardous materials.

Materials that can create hazards if accidentally liberated from their containers shall be stored in a manner that minimizes the dangers.

56/57.16004 Containers for hazardous materials.

Hazardous materials shall be stored in containers of a type approved for such use by recognized agencies; such containers shall be labeled appropriately.

56/57.16012 Storage of incompatible substances.

Chemical substances, including concentrated acids and alkalies shall be stored to prevent inadvertent contact with each other or with other substances, where such contact could cause a violent reaction of the liberation of harmful fumes or gases.

56/57.18002 Examination of working places.

(a) A competent person designated by the operator shall examine each working place at least once each shift for conditions which may adversely affect safety and health. The operator shall promptly initiate appropriate action to correct such conditions.

(b) A record that such examinations were conducted shall be kept by the operator for a period of one year, and shall be made available for review by the Secretary or his authorized representative.

(c) In addition, conditions that may present an imminent danger which are noted by the person conducting the examination shall be brought to the immediate attention of the operator who shall withdraw all persons from the area affected (except persons referred to in Section 104 (c) of the Federal Mine Safety and Health Act of 1977) until the danger is abated.

56/57.20011 Barricades and warning signs.

Areas where health or safety hazards exist that are not immediately obvious to employees shall be barricaded, or warning signs shall be posted at all approaches. Warning signs shall be readily visible, legible, and display the nature of the hazard and any protective action required.

56/57.20012 Labeling of toxic materials.

Toxic materials used in conjunction with or discarded from mining or milling of a product shall be plainly marked or labeled so as to positively identify the nature of the hazard and the protective action required.

56/57.20014 Prohibited areas for food and beverages.

No persons shall be allowed to consume or store food or beverages in a toilet room or in any area exposed to a toxic material.

ENDNOTES

1. Hamilton, A. Industrial Poisons of the United States. The Macmillan Company, New York, 1925.
2. American Conference of Governmental Industrial Hygienists (ACGIH). Documentation of Threshold Limit Values. Cincinnati, Ohio. 1996.
3. National Institute for Occupational Safety and Health. A Recommended Standard for Occupational Exposure to Mercury. DHEW (NIOSH). Publication No. 73-11024. 1973.
4. National Institute for Occupational Safety and Health. Report to Congress on Workers' Home Contamination Study Conducted Under the National Institute for Occupational Safety and Health. (NIOSH). Publication No. 95-123. September, 1995.
5. Ibid.
6. 30 CFR §§ 56/57.5001.
7. See Appendix A for a list of Technical Support Reports.
8. The Gold Institute. World Gold Mine Production 1995-1999. Washington, DC. August, 1996.
9. U.S. Geological Survey. Mineral Commodity Surveys 1997. Gold. February 1997, Reston, VA.
10. The Gold Institute, op. cit.
11. U.S. Geological Survey, op. cit.
12. U.S. Geological Survey. Mineral Industry Surveys. Annual Review (Gold) 1995. February 1997, Reston, VA.
13. Throughout this document, the term "gold mines" is meant to include silver mines which also produce gold.
14. U.S. Geological Survey. Annual Review (Gold). op. cit.
15. U.S. Geological Survey. Mineral Industry Surveys. Precious Metals in April 1997. June 2, 1997, Reston, VA.
16. U.S. Geological Survey. Annual Review (Gold). op.cit.
17. U.S. Geological Survey. Precious Metals in April 1997. op. cit.

18. The Gold Institute, op. cit.
19. Mine Safety and Health Administration, Office of Injury and Employment Information. MSHA-IRC: CM665MSX, Cycle 96-115, "Summary employment and injury information by commodity and subunit (excluding contractors) 01/96 thru 12/96, metal/nonmetal" (computer printout), process date 3/3/97, Denver, CO.
20. U.S. Geological Survey. Annual Review (Gold) 1995. op. cit.
21. Christensen, Jon. Gold Diggers of 1996; Nevada Mining Shifts Underground to Get the Deep Ore. New York Times, Nov. 16, 1996; Timmons, Tony, Underground--The next frontier for Nevada miners. Business Dateline, Las Vegas Business Press. March 10, 1997.
22. Staker, W. L., W. W. Simpson and R. G. Sandberg. Mercury Removal From Gold Cyanide Leach Solutions. Minerals and Metallurgical Processing. May 1984: pp. 56-61.
23. Ibid.
24. Marsden, J, and I. House. The Chemistry of Gold Extraction. Ellis Horwood Limited, Chichester, West Sussex, England, 1992: p.45.
25. "Hydro" refers to the processes that are used to recover the precious metals from the pregnant solution. The term "Pyro" refers to the smelting of the concentrate in a furnace to produce dore bars.
26. National Institute for Occupational Safety and Health. Report to Congress on Workers' Home Contamination Study Conducted by the National Institute for Occupational Safety and Health (NIOSH). op. cit.
27. Centers for Disease Control: Acute and Chronic Poisoning from Residential Exposures to Elemental Mercury. Michigan, 1989-1990. Morbidity and Mortality Weekly Report 40(23):393-395 (June 14, 1991).
28. McFarland, R.B.; Reigel, H.: Chronic Mercury Poisoning from a Single Brief Exposure. J. Occup. Med. Med. 20:532-534 (1978).
29. American Conference of Governmental Industrial Hygienists, op. cit.
30. Ibid.
31. Clayton, George & Florence Clayton, eds. Patty's Industrial Hygiene and Toxicology. 4th ed. Vol. 2. Part A. John Wiley & Sons, New York: 1994. p. 2128.
32. American Conference of Governmental Industrial Hygienists, op. cit.

33. Hursch, J.B., Clarkson TW., Goldsmith L.A. Percutaneous Absorption of Mercury by Man. Arch. Environmental Health. March/ April 1989. Vol.44 (No.2), pp. 120-127.
34. Friberg, L.; Vostal, J.: Mercury in the Environment- A Toxicological and Epidemiological Appraisal. CRC Press, Cleveland, OH (1972).
35. ACGIH CD-ROM, TLVs and other Occupational Exposure Values- 1996, Mercury, all forms except alkyl.
36. ACGIH, 1996 TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices, Cincinnati, Ohio, p. 26.
37. NIOSH, A recommended standard for occupational exposure to unorganic mercury. DHEW (NIOSH). Publication No. 73-11024. 1973.
38. Occupational Safety and Health Administration 29 CFR § 1910.1000 Air Contaminants.
39. Clayton, and Clayton, op. cit. p. 2142.
40. The term “dirty” room refers to an area that is solely used to store and wash employees’ work clothes. This location has the potential to be contaminated with metallic mercury. This area must be kept clean to reduce employees’ exposures to mercury.
41. Marsden and House. op. cit. p. 326.
42. American Conference of Governmental Industrial Hygienists, Inc. Industrial Ventilation, A Manual of Recommended Practices. 20th ed. ACGIH 1988, pp. 10-53.
43. Beckett, R. and Sanders, M.L. Industrial Hygienists-Puget Sound Navy Yard. Corrections submitted to NIOSH pertaining to the NIOSH criteria for recommended standard...Occupational Exposure to Inorganic Mercury. (Date unknown.)
44. Marsden and House. op. cit. p. 463.
45. Barnebey & Sutcliffe Corp. “Removal of HG Using Impregnated Activated Carbon in Air and Water Treatment.” December 12, 1991. This document can be obtained from the above company by calling the following phone number: (614) 258-9501.
46. Harvey, B., G. Crockford & Silk. Eds. Handbook of Occupational Hygiene. Kluwer Publishing. Middlesex, Great Britain. 1988. pp. 8.13-18.
47. This method was developed by Stephen M. Kneipple and Michael L. Lynham, industrial hygienists formerly with MSHA’s Denver Safety and Health Technology Center.
48. Much of this section was adapted, with permission, from McDiarmid, Melissa, A. and Edward A. Emmett. Biologic Monitoring and Medical Surveillance of Workers Exposed to

Antineoplastic Agents. American Journal of Hospital Pharmacy. Vol. 47 May, 1990.

49. McDiarmid, Melissa, A. and Edward A. Emmett. Biologic Monitoring and Medical Surveillance of Workers Exposed to Antineoplastic Agents. American Journal of Hospital Pharmacy. Vol. 47 May, 1990.

50. Senn, Eileen P. Controlling Metallic Mercury Exposure in the Workplace, A Guide for Employers. New Jersey Department of Health, Occupational Health Service. February, 1996. p. B-4.

51. ACGIH, 1996 TLVs and BEIs, op. cit.

52. Senn, E., op. cit.

Graphic Image Number 1:

General Cyanidation Process Flow Sheet

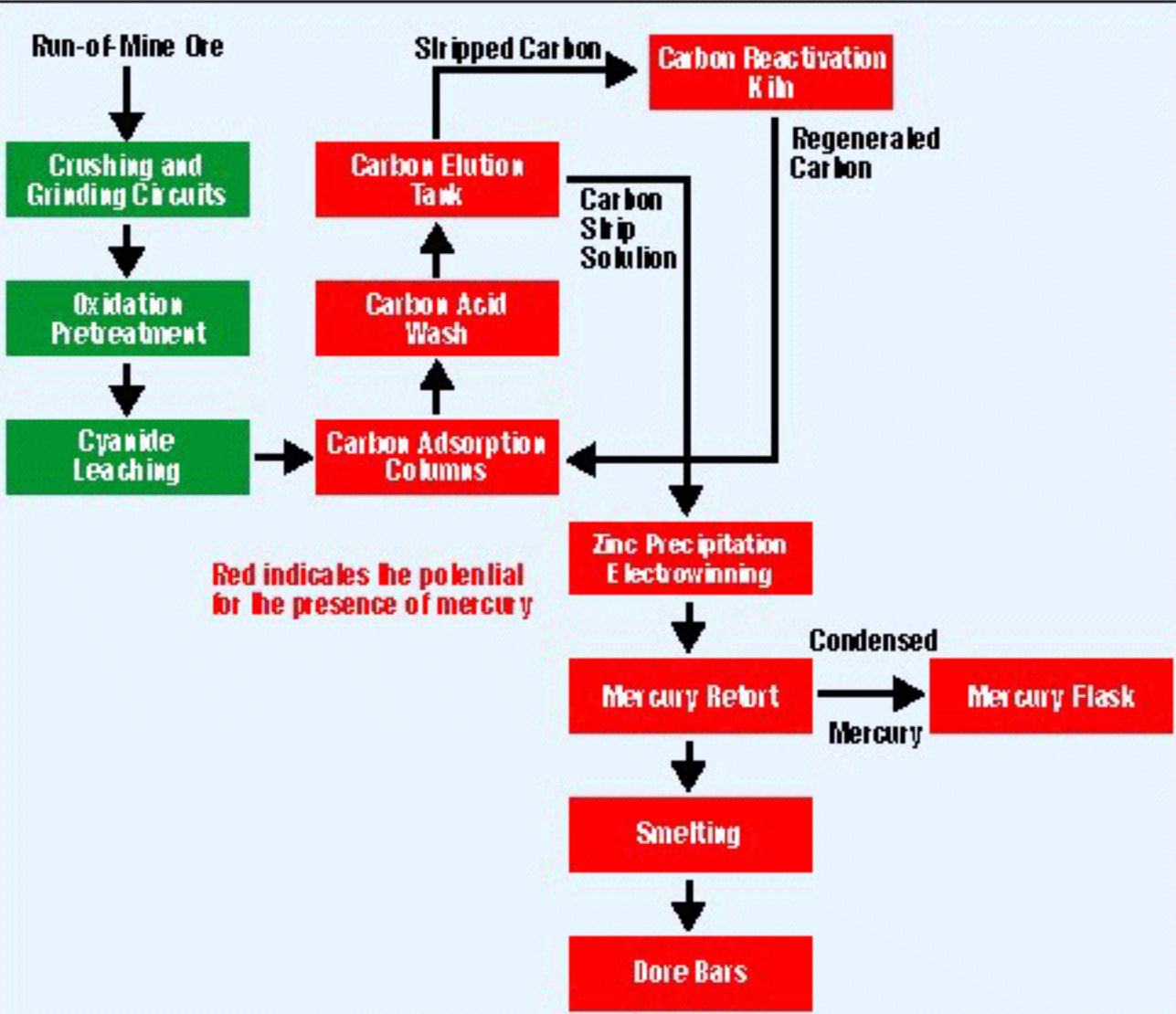
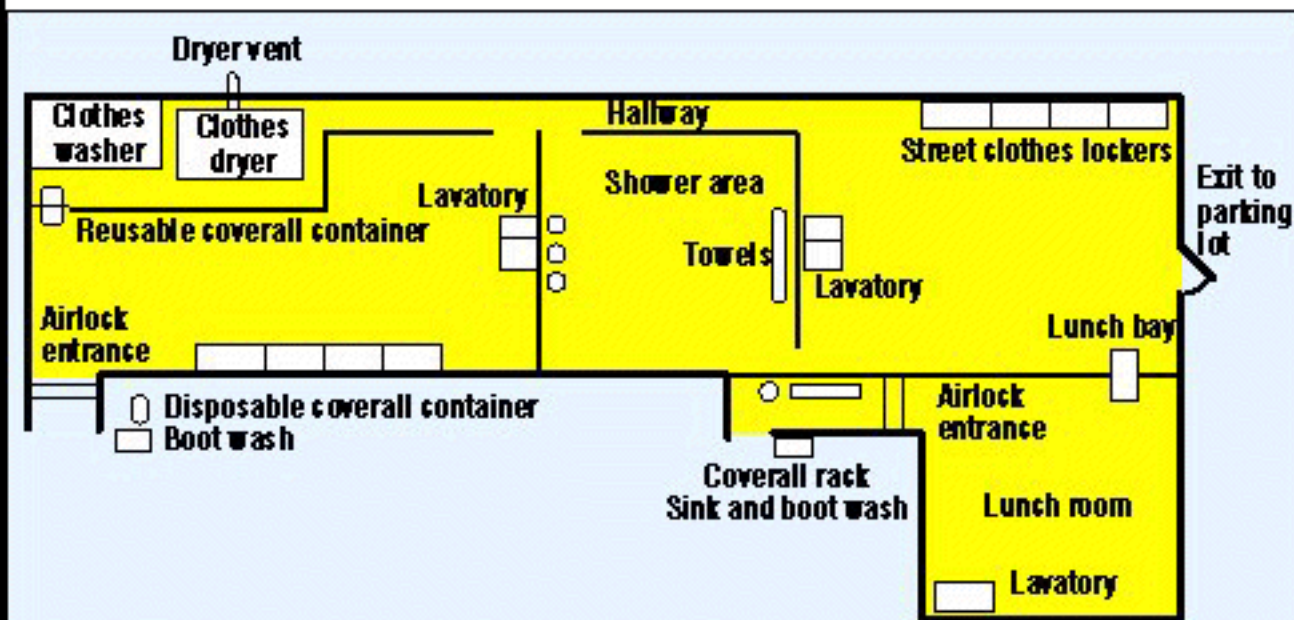


Figure 1.—General cyanidation process flow sheet

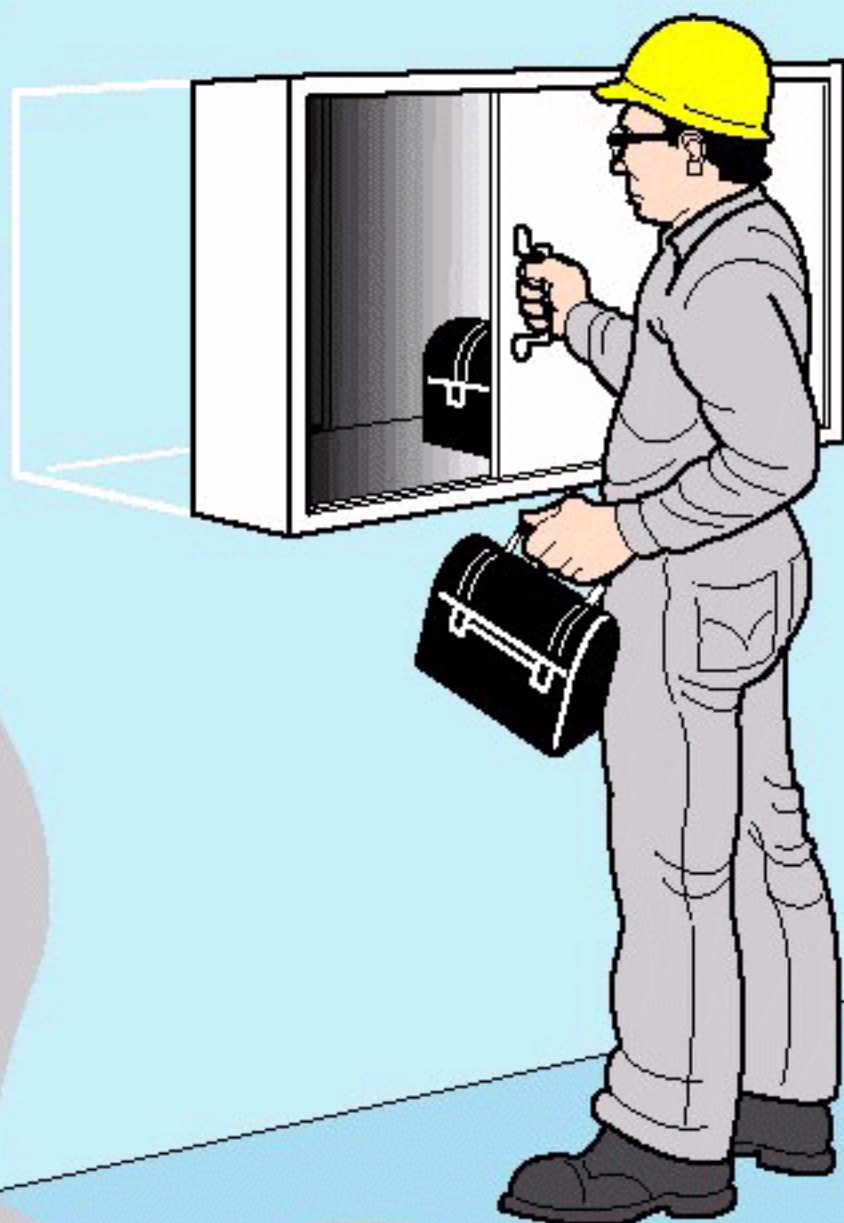
Graphic Image Number 2: Employee Hygiene Facility and Lunch Room



Designed by: M. Lynham
MSHA, Denver Safety & Health Technology Center, Toxic Materials Division

Figure 2.—Employee hygiene facility and lunch room

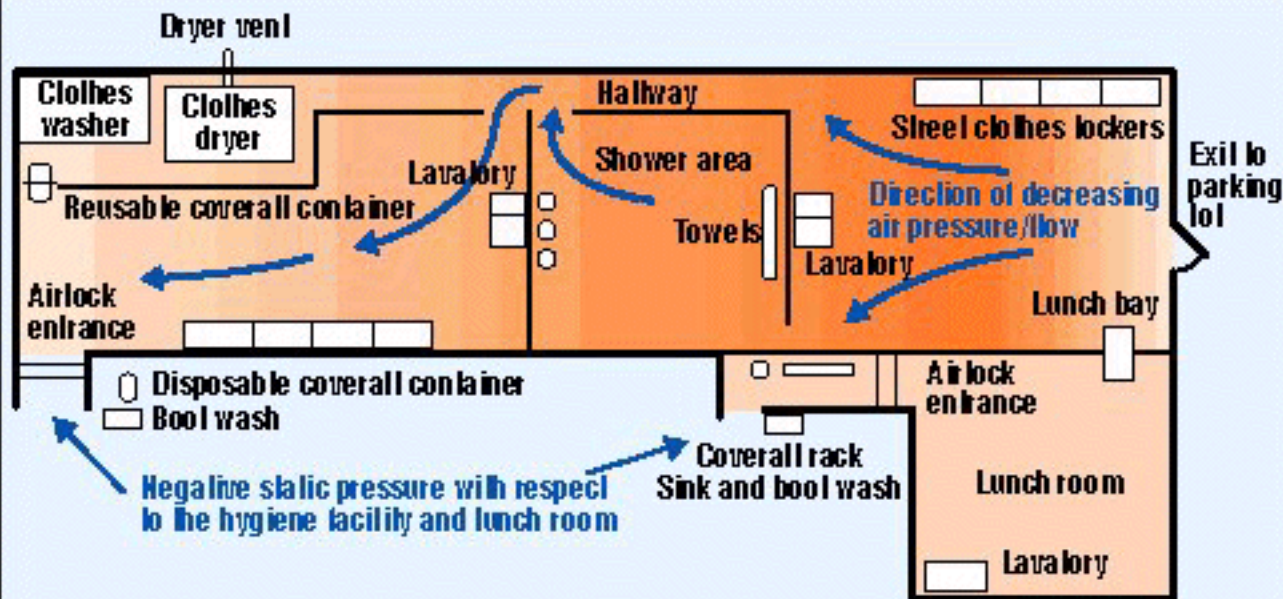
Graphic Image Number 3: Lunch Bay



Designed by: M. Lynham
MSHA, Denver Safety & Health Technology Center, Toxic Materials Division
Illustration by R. Duran and F. Bigio

Figure 3.—Lunch bay

Graphic Image Number 4: Static Pressure Gradient for the Hygiene Facility and Lunch Room

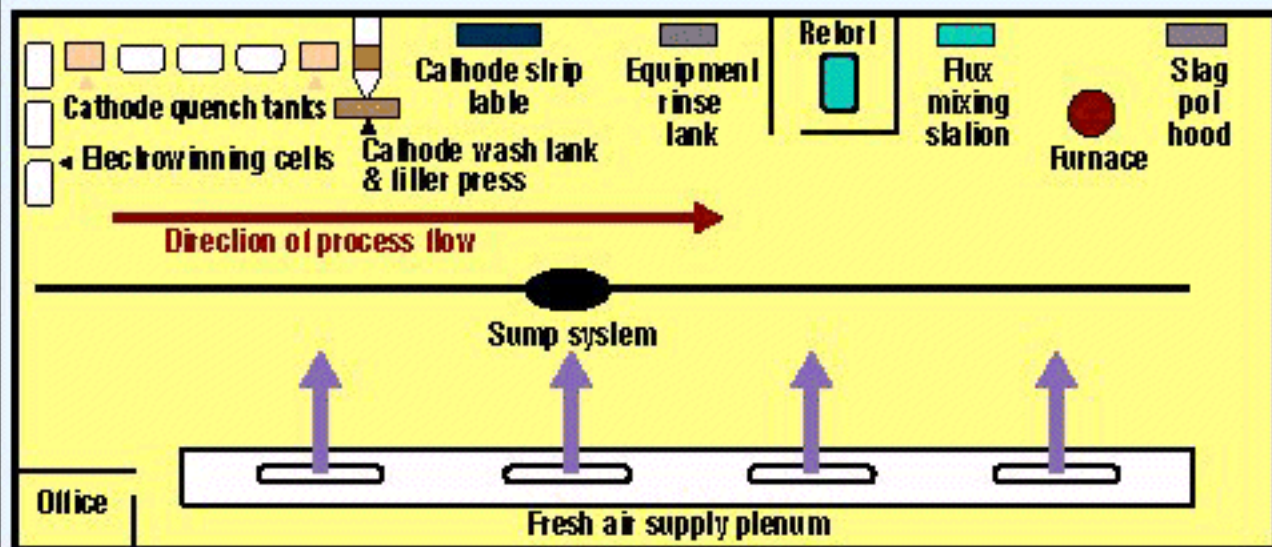


Designed by: M. Lynham

MSHA, Denver Safety & Health Technology Center, Toxic Materials Division

Figure 4.—Static pressure gradient for the hygiene facility and lunch room

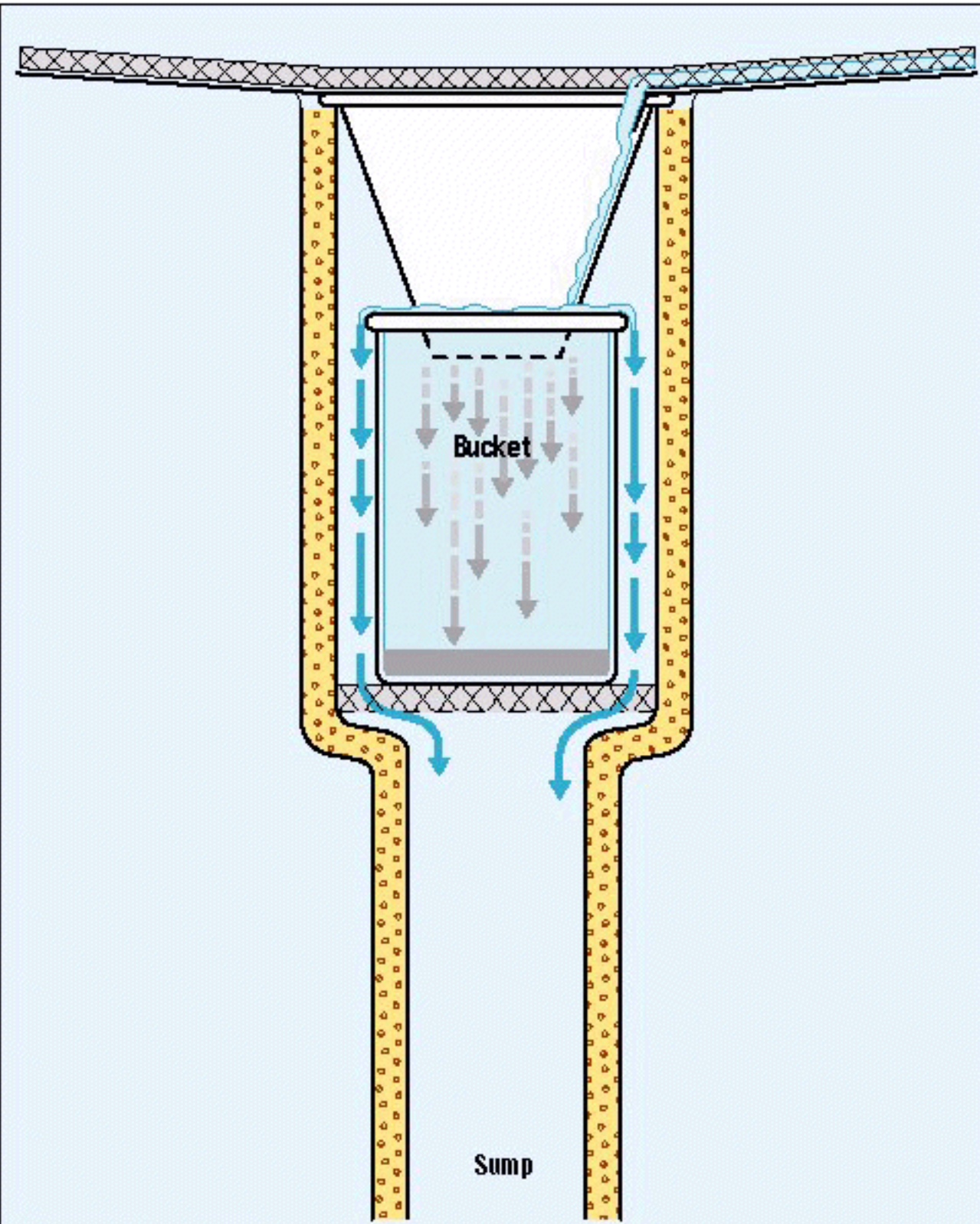
Graphic Image Number 5: Refinery Building



Designed by: M. Lynham
MSHA, Denver Safety & Health Technology Center, Toxic Materials Division

Figure 5.—Refinery building

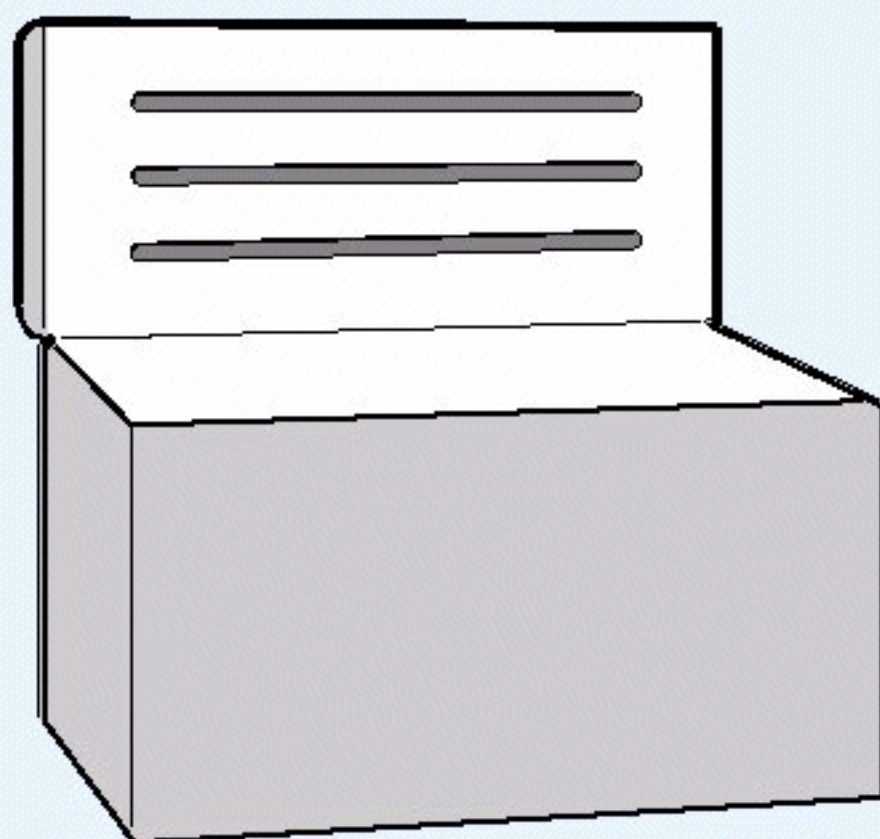
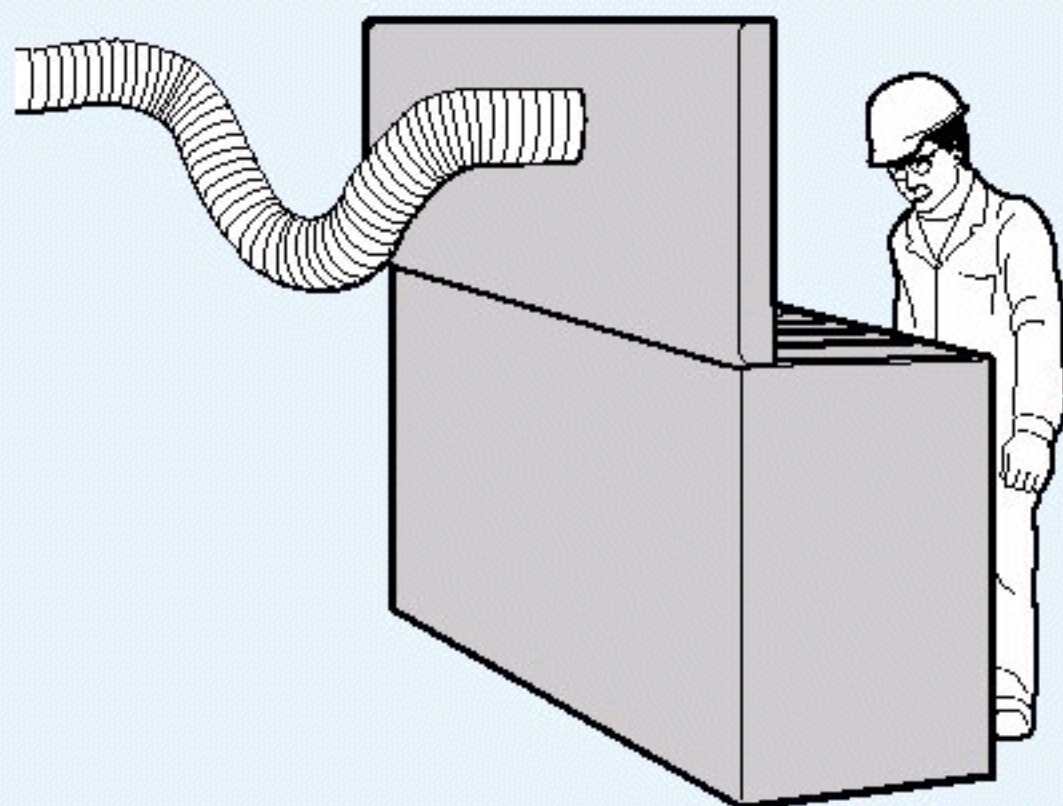
**Graphic Image Number 6:
Gravity Mercury Trap**



Designed by: M. Lynham
MSHA, Denver Safety & Health Technology Center, Toxic Materials Division
Illustration by R. Duran and F. Bigio

Figure 6.—Gravity mercury trap

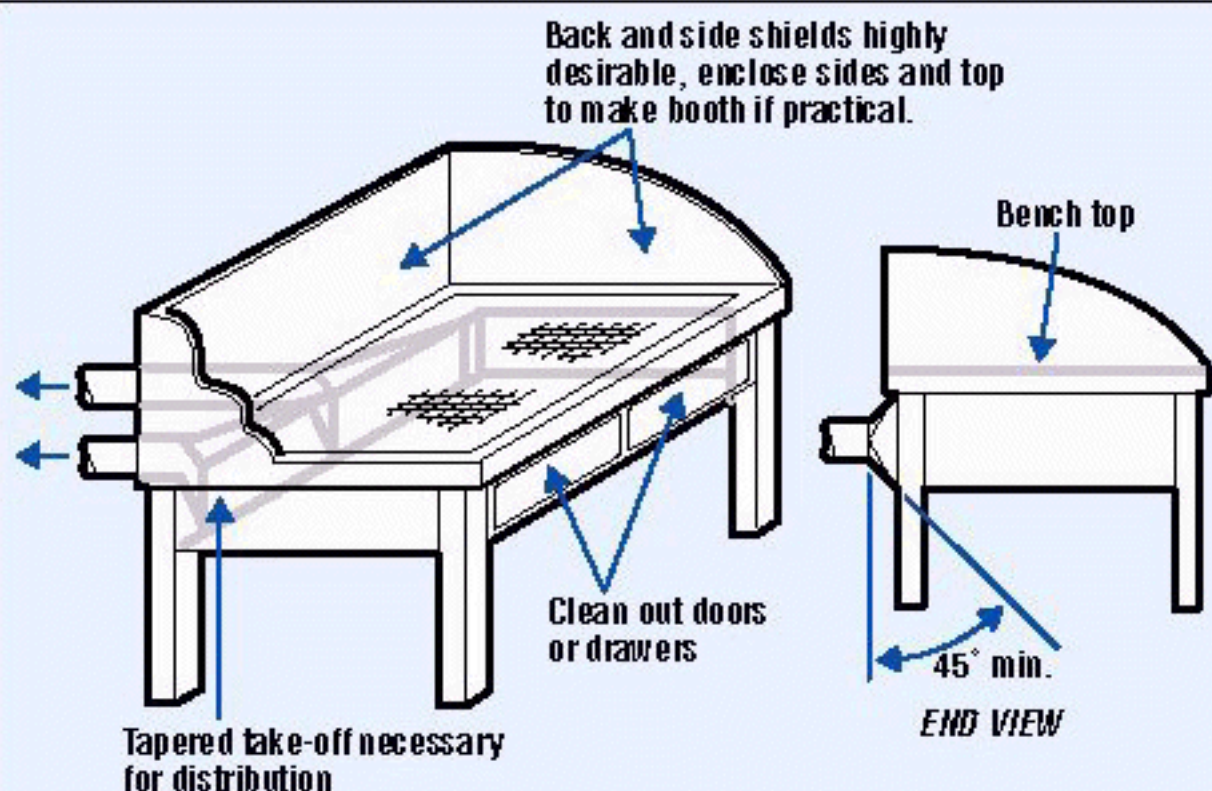
Graphic Image Number 7: Electrowinning Tank With Lid Plenum



Designed by: M. Lynham
MSHA, Denver Safety & Health Technology Center, Toxic Materials Division
Illustration by R. Duran and F. Bigio

Figure 7.—Electrowinning tank with lid plenum

Graphic Image Number 8: Down Draft Exhaust Hood



$Q = 150 - 250 \text{ cfm/sq. ft. of bench area.}$
 Minimum duct velocity = 3,500 fpm
 Entry loss = 0.25 VP for tapered take-off.

Grinding in booth, 100 fpm face velocity also suitable

For downdraft grilles in floor: $Q = 100 \text{ cfm/sq. ft. of working area}$

Provide equal distribution. Provide for cleanout.

ACGIH, Industrial Ventilation,
A Manual of Recommended Practice,
 22nd edition, 1995, p. 10-130.

American Conference of
 Governmental Industrial Hygienists

Portable Hand Grinding

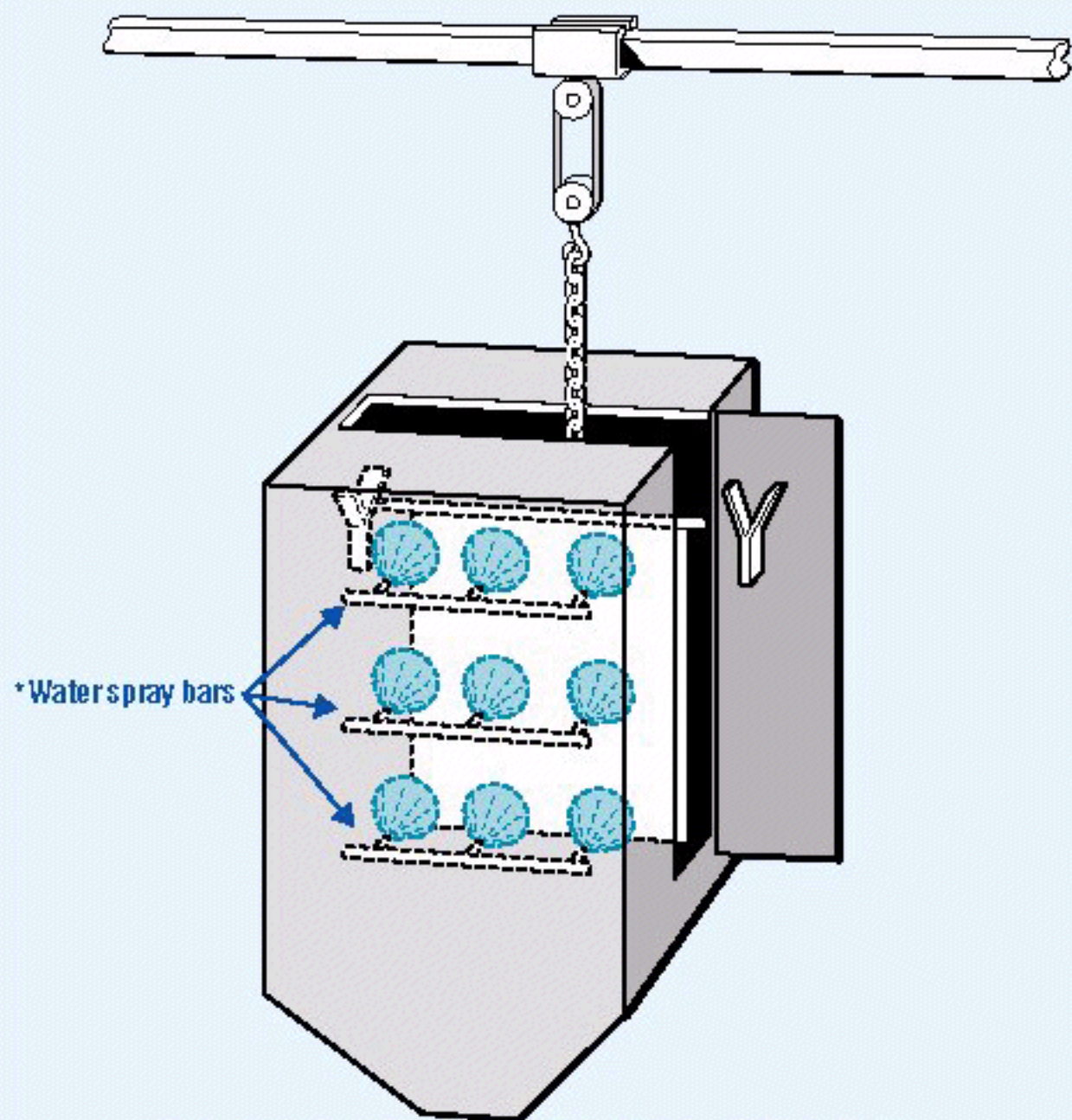
Date 1-64

VS-412

Figure 8.—Downdraft exhaust hood

"From American Conference of Governmental Industrial Hygienists (ACGIH):
Industrial Ventilation: A Manual of Recommended Practice, 20th Ed. 122nd. Ed.
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Graphic Image Number 9: Cathode Wash Tank

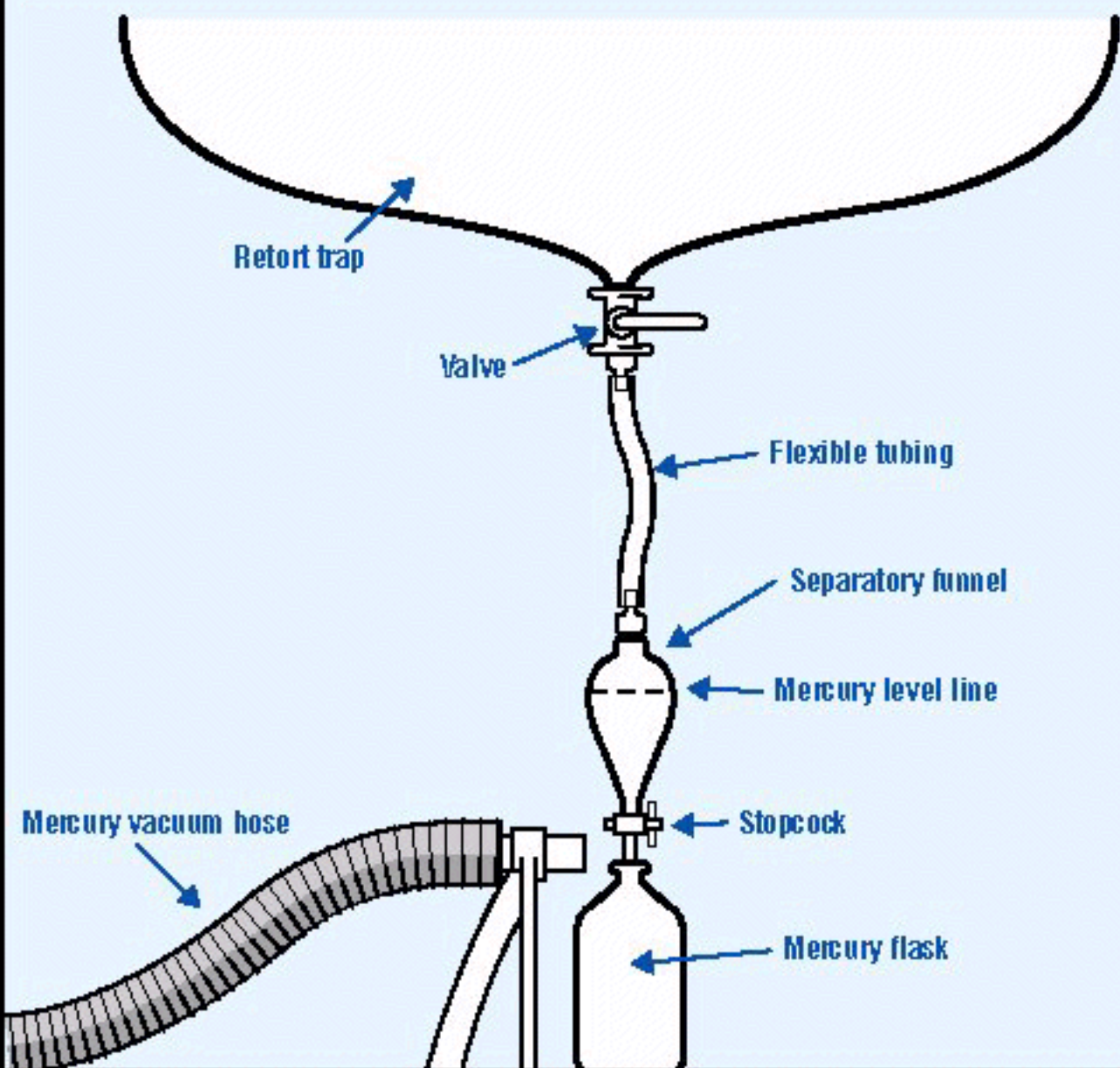


***The spray bars should be placed on both sides of the cathode**

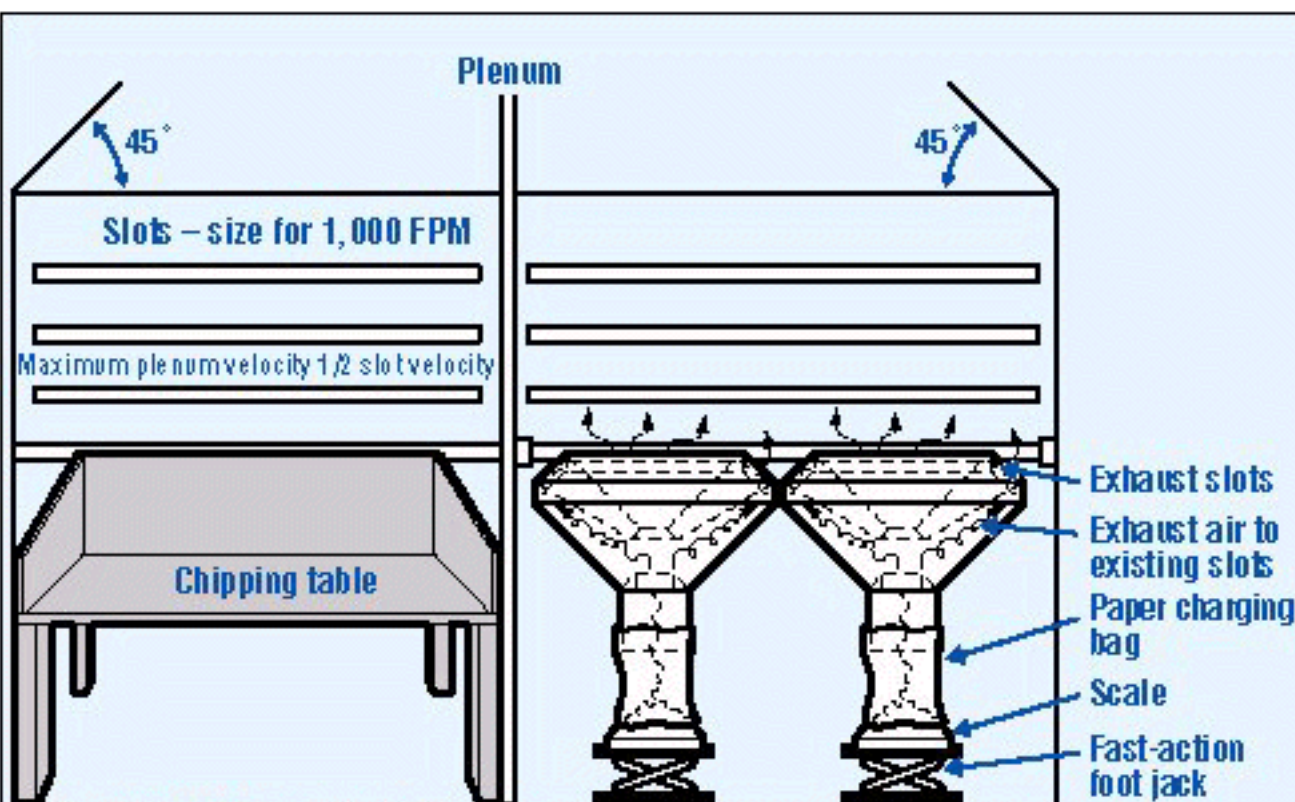
Designed by: Denver Mineral Engineers, Inc., Littleton, Colo., and
M. Lynham, MSHA, Denver Safety & Health Technology Center, Toxic Materials Division
Illustration by R. Duran and F. Bigio

Figure 9.—Cathode wash tank

**Graphic Figure 10:
Mercury Trap Transfer Apparatus**



Graphic Image Number 11: Flux Mixing Table

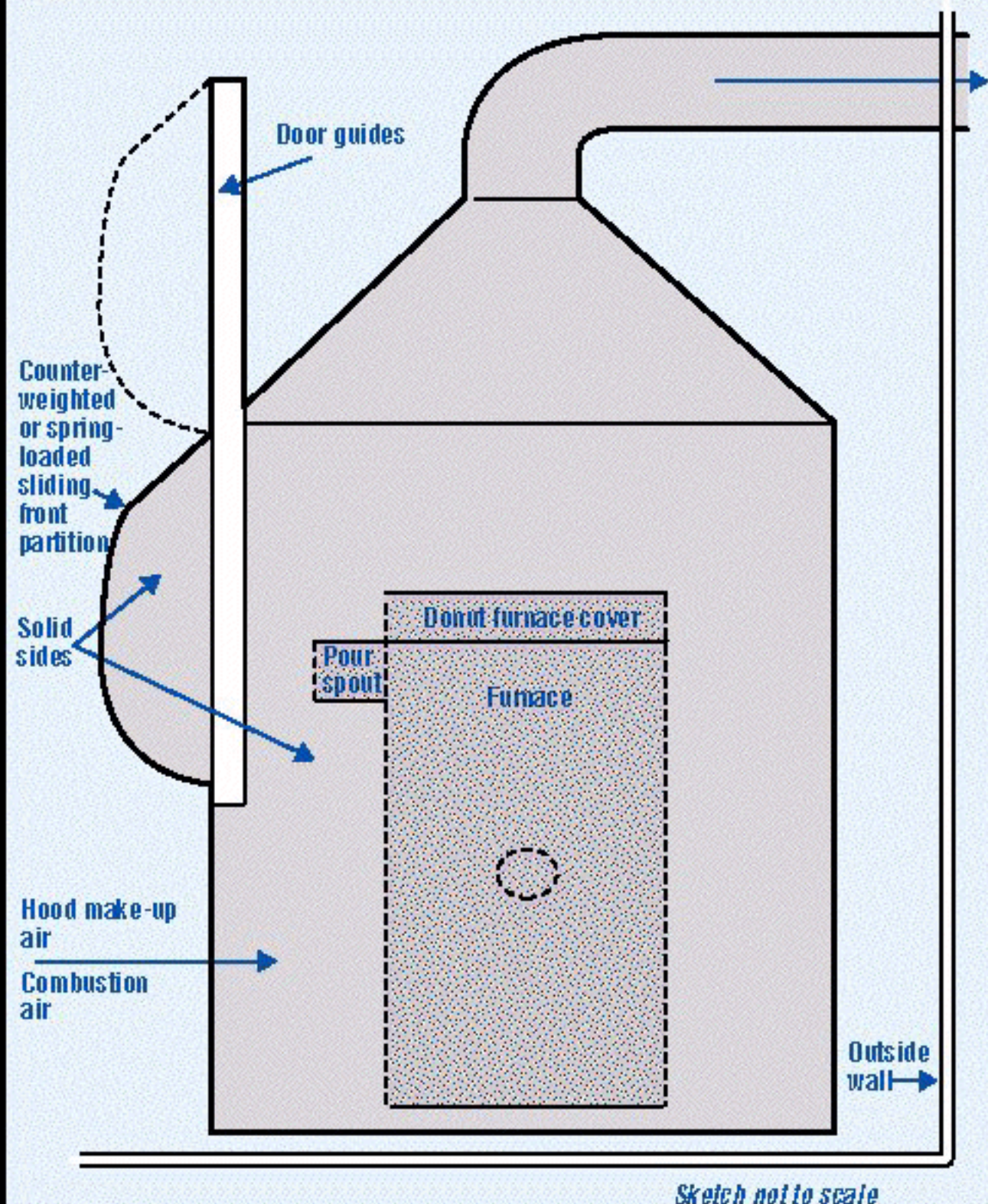


$Q = 350 \text{ CFM/Lineal foot of hood}$
Hood length = Required working space
Bench width = 24" maximum
Duct velocity = 1,000-3,000 FPM
Entry loss = 1.75 slot VP + 0.25 duct VP

Designed by: G. Trabant and M. Lynham
MSHA, Denver Safety & Health Technology Center, Toxic Materials Division
Illustration by R. Duran and F. Bigio

Figure 11.—Flux mixing table

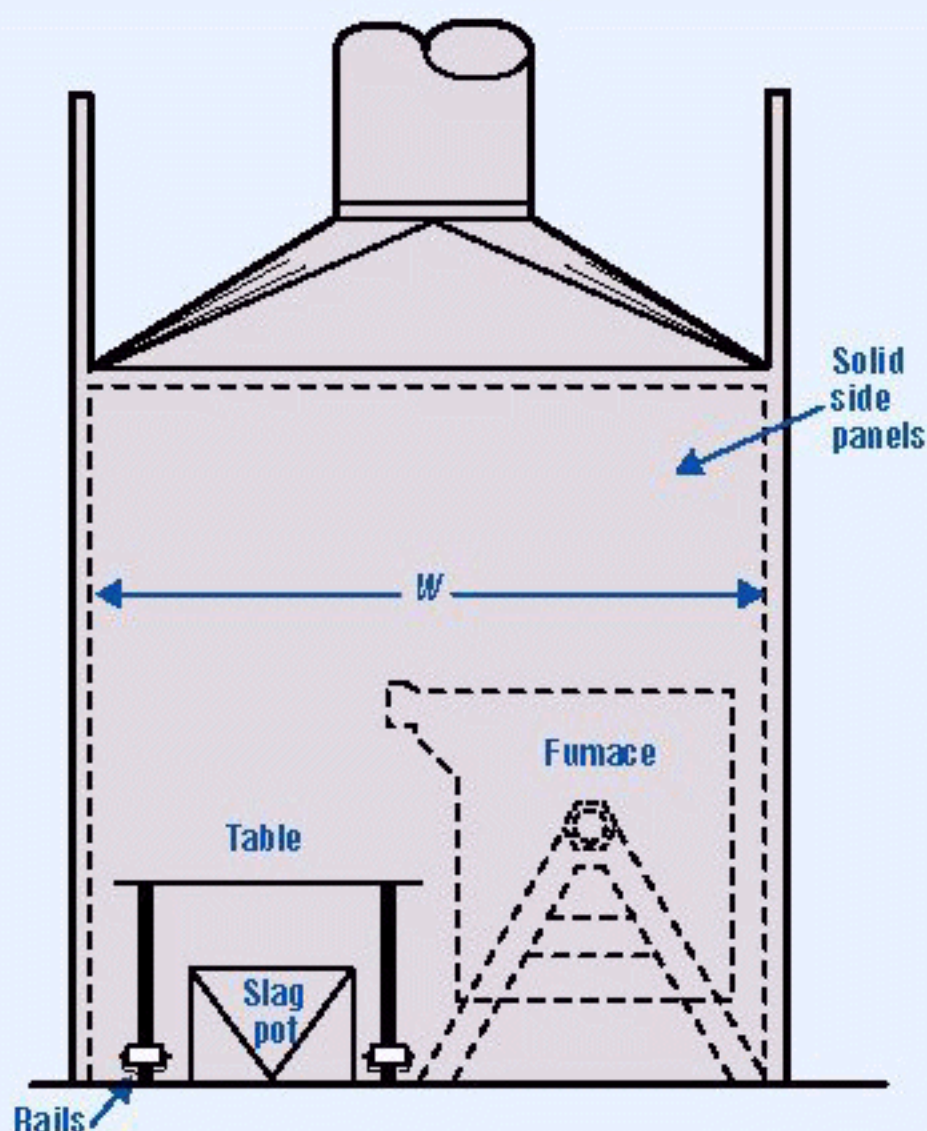
Graphic Image Number 12: Gas Furnace Exhaust Hood



Designed by G. Trabant and M. Lynham,
MSHA, Denver Safety & Health Technology Center, Toxic Materials Division

Figure 12.—Gas furnace exhaust hood

Graphic Image Number 12a: Electric Furnace Exhaust Hood



$Q = 200 LW$: but not less than
200 SCFM/Sq. ft. of all openings
with doors open*

Entry loss = 0.25 VP

Duct velocity = 1,000-3,500 FPM**

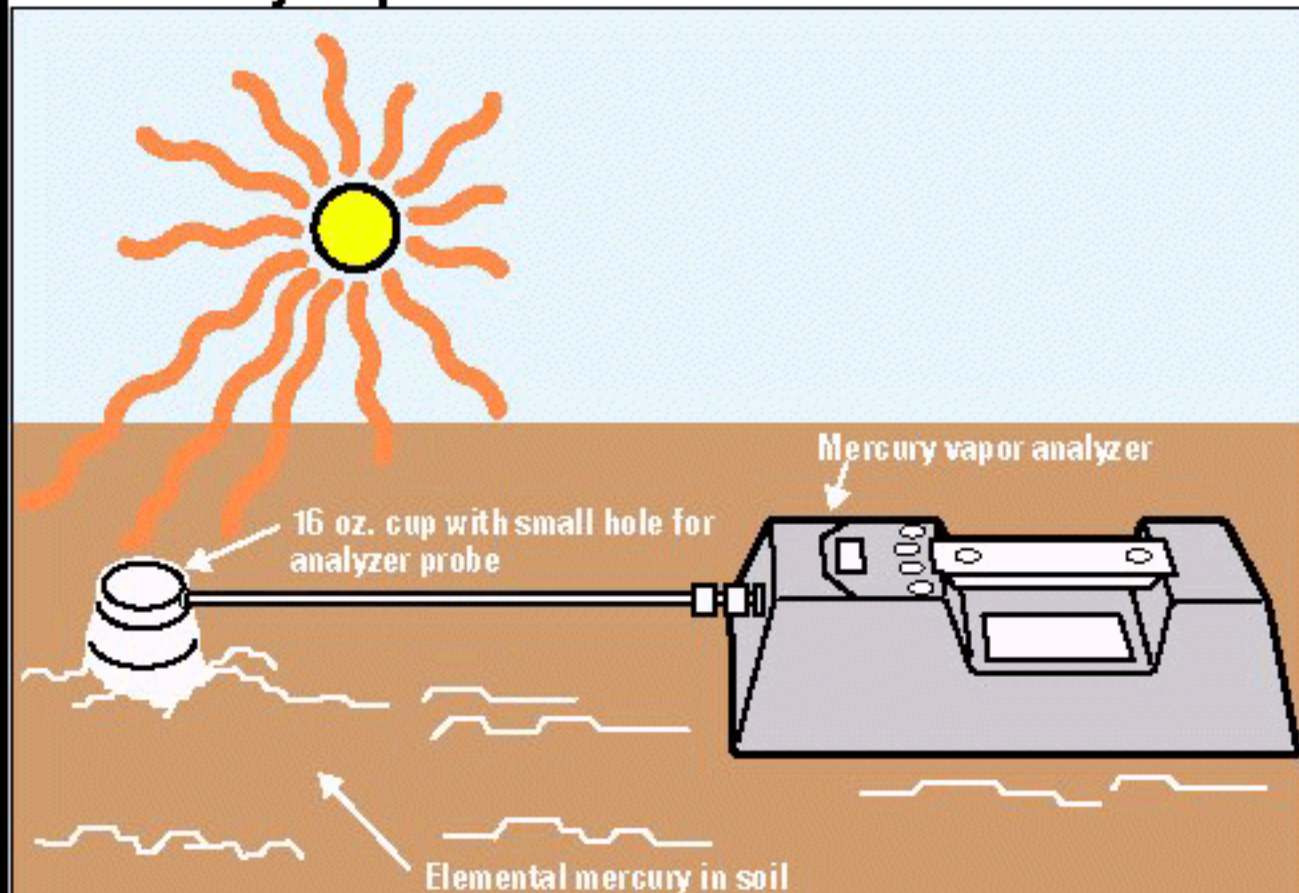
- * Correct for temperature and combustion products.
- ** For horizontal runs, transport velocity is necessary

ACGIH, Industrial Ventilation, A Manual of Recommended Practice, 20th edition, 1990

Figure 12A—Electric furnace exhaust hood

From American Conference of Governmental Industrial Hygienists (ACGIH):
Industrial Ventilation: A Manual of Recommended Practice, 20th Ed./22nd Ed.
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Graphic Image Number 13: Method For Detecting Low Levels Of Mercury Vapor In The Soil



Designed by: S. Kneipple and M. Lynham, MSHA, Denver Safety & Health Technology Center,
Toxic Materials Division
Illustration by R. Duran and F. Bigio

Figure 13.—Method for detecting low levels of mercury vapor in the soil