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INTRODUCTION TO OPERATOR AIR SAMPLING PROGRAMS

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BACKGROUND

Exposure to respirable silica-bearing dust (silica dust) can put miners at grave risk. Silicosis, a potentially fatal lung disease associated with overexposure to silica dust, is entirely preventable if mine operators and miners act in concert to prevent exposures to hazardous levels of silica dust. As part of the Mine Safety and Health Administration's (MSHA) national effort to eliminate silicosis in the mining industry, MSHA reminded operators of their obligation under 30 CFR 56.5002 and 57.5002 (exposure monitoring) to conduct sampling as frequently as necessary. This sampling is conducted to determine the adequacy of measures that have been implemented to control the levels of employee exposure to silica dust as well as other airborne contaminants.

Engineering controls are the most effective and reliable method for assuring that individuals are not exposed to unhealthful levels of silica dust. The only sure way to determine the effectiveness of these engineering controls is to conduct airborne contaminant sampling on a regular basis. To assist operators in determining the adequacy of their control measures and in planning for effective monitoring of their employees' exposure, MSHA is preparing general guidance materials. The following is the first in the series and is intended to provide an introduction to the subject of operator air sampling programs.

INTRODUCTION

The following information has been prepared as basic guidance material to assist mine operators in planning for effective monitoring of their employees' exposures to silica dust and other airborne contaminants, and in determining the various needs for and adequacy of control measures required by 30 CFR 56/57.5002. This information may also assist affected miners and their representatives in understanding or otherwise questioning various monitoring and control measures taken in regard to hazardous airborne contaminants.

The ultimate goal of mine operator sampling activities is the prevention of occupational disease. Occupational disease may be prevented by limiting miner exposure to physical and chemical hazards. A successful program involves the recognition, evaluation and control of health hazards in the work environment. This can be done by:

- evaluating the work environment by examining work operations and processes, determining the presence of hazards, and measuring the extent of exposures;
- interpreting environmental sampling results and determining the nature of workplace health hazards;
- implementing adequate and appropriate hazard control measures, and;
- seeking appropriate assistance in the recognition and control of health hazards in the work environment.

The following gives an overview of the basic elements of a mine operator sampling program.

Determining Sampling Strategy

The collection of valid exposure measurements is necessary for measuring occupational health hazards and determining the need for environmental controls. There is not one best sampling strategy or plan for all work and exposure situations, and the choice of a strategy should be based on site-specific conditions. The following basic considerations can be used to help develop a sampling strategy:

- type and nature of contaminants
- miner location, nature of work operations/exposure duration
- number of samples required to evaluate the exposure
- availability of sampling equipment
- availability of sample analytical facilities
- availability of personnel for surveillance

The objective of all sampling strategies is that the collected samples be representative of a miner's normal, typical work activity and exposure so that overexposures can be prevented. Conditions within the work environment on the day or week of sampling must be similar to those likely to be experienced by the miner when sampling is not being done. It may be necessary to observe the miner's activities during the work shift. Notes should be taken on the

miner's time spent in each work area, on the work routines, on the duration of work activities, and on the location and condition of engineering controls such as ventilation and baghouses. Converse with miners to obtain information about work that has not been observed and to determine whether their activities and exposures are representative of a "normal" work day or week.

A normal work day or week in some operations may include large variations in work activity as determined from observations and conversations. Indications of representative activity may include the number of:

- truckloads of material processed by a crusher operator
- holes or feet drilled by a driller
- trucks loaded by a shovel operator
- bags produced by a bagging machine operator
- pieces of equipment running during a production day

Samples are representative when collected on days which are within the range of these variations. However, it is important to remember that preventing overexposures is the objective.

Personal samples should not be collected when conditions of exposure are not representative of typical mining conditions. However, if miners are repeatedly exposed to situations, such as engineering control breakdowns or rainy days, those situations may be representative, and it would be proper to continue sampling even if such situations occurred during the sampling period. Re-sample miners as often as necessary in order to collect representative samples.

Whom to Sample

Preliminary walk-around observations and direct-read area sampling data can be used to select miners for personal monitoring. In an ideal situation, each potentially exposed miner would be individually sampled. It is not necessary, however, to sample all miners on a mine property in order to evaluate occupational exposures.

Maximum Risk Miner

Suspected and potential health hazards may be reasonably and adequately evaluated by sampling the "maximum risk miner" in a work area or area of well defined exposure sources. The maximum risk miner is the one expected to have the greatest exposure of all of the miners in the area. Other miners in the same work area or area of common exposure sources should experience lesser concentrations of occupational hazards than the maximum risk miner. A given work area may have more than one maximum risk miner when activities or operations are non-uniform or when multiple and varied exposure sources exist.

There is no single method for selecting the maximum risk miner in all mining operations and processes. A miner experiences high risk because of his or her work area (location) or work procedures (tasks). The following considerations may be used to help identify a maximum risk miner:

- *Proximity of Contaminant Source:* Observe the operation and select the miner or miners who are closest to the source of the hazardous material being generated. This guideline is applicable particularly when the exposed miner is stationary while performing work assignments. As the miner's distance from a contaminant source increases, the ambient air dilutes the contaminant. Examples of miners who generally work close to a contamination source are material baggers, crusher operators, welders, and vehicle operators.
- *Frequency of Proximity to Contaminant Source:* When miners are mobile in their various work tasks, observe the operation and select the miner or miners who spend the most time near the generation source of a hazardous material. Careful observation is required to determine the sources of a miner's exposure within the work environment.
- *Miner Complaints and Illness:* Miners who have complained about unhealthful working conditions and miners who have become ill on the job are candidates for personal sampling. Complaints and illnesses can involve miners who experience significantly greater exposures to contaminants than their co-workers.

The mine operator may find it useful in determining sampling priority to compare the inherent toxicity of the contaminant to the possibility or likelihood of exposure. The prioritization process then becomes:

TOXICITY How dangerous is the substance?	RISK OF EXPOSURE how often, how long	SAMPLING PRIORITY
Low	Low	Low
Low	High	Medium
High	Low	Medium
High	High	High

Table 1. Prioritization of Sampling

Where to Sample

The identification of a high risk area may be more straightforward than the selection of a maximum risk miner. The following considerations should help determine sampling areas:

- *Measurement:* Direct-read instruments, such as detector tubes and methanometers, may be used to measure the immediate concentration of contaminant in a given area. Due to the normal variability and fluctuations within the mining environment, the results of an instantaneous sample may not be representative of conditions throughout the normal work day. Further evaluation should be made when a direct-read instrument indicates a potentially elevated contaminant concentration.

- *Experience:* Mining processes and operations using known toxic reagents or generating recognized toxic by-products should be considered for sampling. Hazardous contaminants are known to be generated during mining operations which involve grinding, crushing, welding, cutting, combustion, spraying, and metal melting.

A change, in an operation, production process, or control measure, may lead to increased release of contaminants to the work area air. When such changes have been made, sampling in order to re-evaluate occupational exposures is prudent.

- *Observation:* Hazardous conditions may exist when area observation reveals the following: visible clouds of dust or fume (although the absence of visible dust does not necessarily indicate the absence of a problem); the detection of strong odors or eye and skin irritation; poor housekeeping; and chemical containers without lids or covers.

Observation of air movement patterns within a work area is helpful in determining potential miner exposure and risk. Natural or mechanical ventilation may transport contaminants a considerable distance away from the point of generation. Consider the location of intake and exhaust air fans, and open doors and windows, which could affect air flow patterns. The result may be higher contaminant concentrations farther away from the source. For example, a miner downstream but further away from a welding operation could receive a higher exposure to welding fumes than a miner who is closer but upstream of the welding operation.

How to Sample

Contaminant-specific sampling procedures may be obtained from the sources referenced in the appendix. Health specialists and industrial hygienists in your local Metal and Nonmetal Mine Safety and Health (MNMSH) District office are also available to assist you.

Personal Exposure vs. Area Samples

Most allowable exposure levels require the measurement of hazardous substance concentrations in the miner's breathing zone (a two-foot diameter sphere surrounding the miner's head). Breathing zone samples are personal exposure samples and are collected by either holding the sample collection device in the miner's breathing zone or attaching the sampling device directly to the miner. Breathing zone concentrations cannot be determined by area sampling.

Area samples are collected to determine concentrations of standard mine gases, to screen qualitatively for the presence of other potential contaminants, and to determine the effectiveness of controls.

Area samples may also be used to identify potentially hazardous areas so that more detailed observations and personal sampling can be performed in accordance with the hazard level that was detected.

Number and Duration of Samples

Allowable exposure levels are established in terms of time-weighted average exposures, short-term exposures, and ceiling values. The duration of sample collection should be sufficient to compare a miner's exposure to the appropriate allowable exposure level.

Full-shift sampling minimizes errors associated with fluctuations in airborne contaminant concentrations during the work shift, and avoids speculation about exposures during unsampled periods of the work shift. Full-period, single-sample measurements (one full-shift sample), or full-period, consecutive-sample measurements (several samples collected back-to-back through out the shift) are, therefore, preferred for time-weighted average exposures. Random or representative partial-period sampling is acceptable for certain contaminant types.

What to Sample For and Why

The following sections describe the most common types of contaminants sampled, the usual sources of these contaminants, some of the health effects encountered with each, and give suggestions for evaluating the hazard and designing a sampling strategy.

MINERAL DUSTS

Mineral dusts are created by the breaking, crushing, grinding, drilling, or general abrasive handling of a solid mineral. For sampling purposes, mineral dusts may be collected as either *respirable* or *total dust*.

Respirable dust is a term which describes the aerodynamic diameter of dust particles which can penetrate deeply into the respiratory system, beyond the bronchioles to the alveoli. Particles which penetrate this deeply into the respiratory system are generally beyond the body's natural clearance mechanisms of cilia and mucous and are more likely to be retained and be harmful.

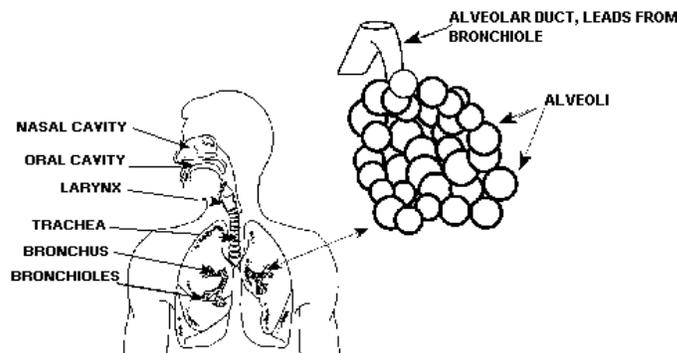


Figure 1. Human Respiratory System

Respirable dust is also defined as the fraction of the dust which passes a size selector (e.g., cyclone). MSHA's Metal and Nonmetal division defines respirable dust as having the following characteristics:

Aerodynamic Diameter (μm) (Unit density sphere)	% Passing Selector
≥ 2.0	90
2.5	75
3.5	50
5.0	25
10.0	0

It is important to remember that, at less than $10 \mu\text{m}$ in diameter, respirable particles are too small to be seen with the naked eye. For comparison, a human hair is about $50 \mu\text{m}$ in diameter. Visible dust may indicate the presence of respirable dust, but a lack of visible dust does not mean that respirable dust is not present.

Total dust is a term which refers to airborne particles that are not selectively collected with regard to their size. Large particles that make up the total dust cloud may overcome the body's natural clearance mechanisms simply by overwhelming those defenses. The smaller particles can be drawn deeply into the respiratory system and retained.

The fraction of the total dust which is respirable varies widely depending upon the nature of the operation and the composition of the ore. In turn, the concentration of any specific contaminant also may vary in the different size fractions. Respirable-size dust particles do not readily settle out of the air, and can remain suspended for long periods of time. Once settled, however, accumulations can be re-suspended by vehicles, by persons walking through the accumulations, or by the wind, and continue to present an inhalation hazard.

Health Effects:

Pneumoconiosis is a disease caused by the accumulation of mineral or metallic particles in the lungs and the tissue reaction to their presence. Pneumoconiosis is the common name for a number of dust-related lung diseases. Five factors which contribute to the development of pneumoconiosis are:

- composition of the dust
- concentration of the dust
- size of the particles
- duration of exposure
- individual susceptibility

Silicosis, a form of pneumoconiosis, is a condition of the lungs caused by the inhalation of silica dust and marked by nodular fibrosis (scarring of the lung tissue) resulting in shortness of breath. **Silicosis, in its advanced stages, is progressive even if the individual is removed from exposure. Silicosis is an irreversible disease.** As the disease progresses, the body's ability to fight infections may decrease and susceptibility to diseases such as tuberculosis and pneumonia may increase.

Chronic silicosis is the most common form of the disease. It is caused by long-term exposure to crystalline silica at relatively low levels and may not show up for 10 years or more. *Accelerated silicosis* results from exposure to high concentrations of crystalline silica and develops five to 10 years after the initial exposure. *Acute silicosis* can occur in miners exposed to very high dust levels. Unlike chronic silicosis, acute silicosis develops rapidly, usually after months, not years, of exposure.

Cigarette smoking increases the incidence of respiratory cancers and other diseases caused by the inhalation of toxic substances, such as silica dust. In addition, other contaminants in the workplace may have synergistic effects with the mineral dust, that is, the combined effect is greater than separate exposures to each of the individual contaminants.

Evaluating the Hazard:

Quartz, *crystalite*, and *tridymite* are three forms of crystalline (free) silica; quartz, however, is the most common. *Cristobalite* and *tridymite* have a different crystalline structure than quartz and are generally considered to be more harmful biologically.

Cristobalite and *tridymite* are thermally altered forms of quartz. They may be present in areas where substances containing quartz are heated, such as in refractories, sintering, calcining, or heat expansion. Because these two substances are not detected in routine quartz analysis, mine operators should request a special analysis for *cristobalite* or *tridymite* if either of these silica materials are suspected to

be present in the dust.

The *Threshold Limit Value*[®] (TLV[®]) for silica-bearing dust is dependent upon the amount (percentage) of free silica present in the dust. The TLV[®] for silica-bearing dust decreases as the percentage of free silica increases. Whenever the dust composition includes two or more hazardous substances which affect the same organ or body system, the combined effect (additive) must be given primary consideration. If the dust composition includes two or more hazardous substances that do not have the same biological effect, the TLV[®] for that dust will be the most restrictive TLV[®] of the constituents.

MISTS AND ELEMENTAL DUSTS

A *mist* is a finely divided airborne liquid created by condensation from the gaseous state or by breaking up a liquid into a dispersed state, such as by spraying or splashing.

Dust is a term used to describe airborne solid particles, ranging in size from 0.1 to 25 micrometers, created by the crushing, grinding, breaking, drilling, or the general abrasive handling of a solid material.

Elemental is the term used when sampling for, or requesting an analysis for, any of the substances in the "Periodic Table of Elements" without consideration of the compounds or mixtures in which the substance may be present.

Sources of Mists and Elemental Dusts:

There are two common types of mists encountered in the mining industry: oil mists and liquid reagent mists. Oil mists are produced during such operations as equipment maintenance or cutting and grinding. Liquid reagent mists may be formed during such operations as mixing, spraying and pouring. Cyanide heap leaching, for example, requires spraying the liquid cyanide solution over the ore, and solvent degreasing may involve scrubbing a part with the liquid degreaser.

The sources of elemental dust in the mining industry are the same as those for mineral dusts in general. Certain elemental dusts, however, are associated with specific ores. Vanadium and uranium, for example, are elements commonly found in uranium mine dust; arsenic may be encountered in salt mine dust; antimony is found associated with lead and arsenic, as well as copper and silver.

Health Effects:

The pneumoconiosis caused by the inhalation of metal particles can range from simple dust accumulation, for example, iron and titanium, to nodular or interstitial fibrosis (lung scarring), such as may be caused by beryllium.

Systemic reactions are caused by the absorption of a toxic agent into the body. The reactions may occur in other parts of the body in addition to the original site of absorption. Inhalation is the most common route of entry. However, systemic poisons may also be ingested or absorbed through the skin. The effects of acute inhalation poisoning may appear quickly because of the rapidity with which the toxic agent can be absorbed in the lungs and pass into the bloodstream. Acute symptoms of systemic poisoning such as blurred vision, headache, nausea, fatigue, weakness, dizziness, delirium, breathing difficulties, and diarrhea, may be non-specific as to cause. Some chronic symptoms, such as a blue line appearing in the gingival tissue at the margin of a tooth (lead), or a green tongue (vanadium), are known to be caused by a specific contaminant.

Sensitization is considered to be a systemic allergic-like reaction because absorption of a small amount of the contaminant at one point can cause a reaction in all areas of the body. A sensitization reaction is the abnormal response of an individual to a contaminant due to previous exposure. A sensitization reaction may be triggered by increasingly lower concentrations of the sensitizing contaminant.

Dermatitis is a condition of the skin caused by chemical reactions, physical irritation, or systemic poisoning.

Evaluating the Hazard:

As with mineral dusts, the TLV[®] for exposure of the miner to mists and elemental dusts may be a single TLV[®] for a single element or a TLV[®] representing additive or non-additive multiple exposures.

Sampling Strategy:

In addition to samples for exposure to silica, samples of mist and/or elemental dust should be taken to determine exposures to other particulate contaminants found in mining. For example, the mine operator should sample for lead in lead mines, uranium and vanadium in uranium mines, cyanides at operations which use cyanides, sulfuric acid mist at operations where it may be produced, oil mists at operations where it is visible, and arsenic in salt mines.

Personal exposure sampling for mists requires a series of partial-shift consecutive samples or random short-term samples. Personal exposure sampling for elemental dusts requires full-shift sampling.

FUMES

A *fume* is an airborne particle formed in close proximity to a molten metal by vaporization of the metal, oxidation of the vapor, and condensation of the oxide. Fume particles usually assume rounded or smooth, irregular shapes and are generally one micron (µm) or smaller in size. Fumes may also agglomerate to form larger particles.

Health Effects:

Metal fume fever is an illness caused by a brief, high exposure to generated fumes of metals such as zinc and magnesium. Symptoms appear from 4 to 12 hours after exposure and consist of fever and shaking chills. Although complete recovery usually occurs within one day, an attack may recur with resumption of exposure after a period of no contact with the fume.

Pneumoconiosis caused by the inhalation of metal fumes can range from simple dust accumulation to nodular or interstitial fibrosis (lung scarring).

Sources of Fumes:

The two most frequently encountered sources of fumes will be welding operations and furnaces which produce molten materials during or as a result of the process. Other fume sources, such as the small furnaces in assay labs, may also be encountered. The welding rod, the

material being welded, the coating material on the surface to be welded, and the welding flux will all contribute to the amount and composition of the welding fume and gases generated. Although sampling techniques will be similar in both cases, specific variations may occur in the placement of cassettes and the need for short-term samples in addition to full-shift measurements.

Any welding operation should be checked for hazardous concentrations of contaminants. The base material in most cases will be iron or steel, resulting in airborne concentrations of iron oxide (Fe_2O_3), nickel compounds (Ni), and chromic oxide (Cr_2O_3). Hard facing on stainless steel can result in hazardous concentrations of manganese (Mn) and other highly toxic compounds. Welding of nonferrous metals, such as brass and copper alloys, may produce copper oxide fume (CuO), zinc oxide fume (ZnO), lead fume (Pb), or tin oxide fume (SnO_2). Aluminum welding can produce an aluminum oxide fume (Al_2O_3).

Coatings on base metals will be vaporized. Galvanized metal, when welded, will release cadmium fume (Cd) or zinc oxide fume (ZnO). Metals with lead based paint will release lead fume (Pb) when welded. Some latex paints contain mercury that will be vaporized when heated. It is also possible that the base metal being welded has surface deposits of the ore being mined or milled or has residue of cleaning solvents or other chemicals that could become a toxic air contaminant. This would be true, for example, if the ore contains lead, arsenic, beryllium, barium, cadmium, mercury, platinum, selenium, or other metal compounds.

During arc-welding, part of the welding rod will be vaporized and will release metal fumes into the atmosphere. Fluorides will be produced in gaseous or particulate forms from welding rods containing fluorides. The filler material on most welding rod coatings is a silica or calcium compound, and, therefore, silicon dioxide (SiO_2) or calcium oxide (CaO) can also be expected as air contaminants. These contaminants should be counted as part of the total dust concentration.

Consult the welding rod manufacturer's literature or a local supplier to determine the major components of the rods in use at the site to be sampled. Any of the components could be released by vaporization and many could become a health hazard.

Gases Associated with Fume Generation:

The generation of metal fume particles commonly occurs in conjunction with the generation of gases such as carbon monoxide, carbon dioxide, ozone, oxides of nitrogen, phosgene, and phosphine. Arc or gas welding and cutting in the presence of chlorinated hydrocarbons in or near the weld or cut will produce hazardous concentrations of phosgene gas (COCl_2) and hydrogen chloride (HCl). Chlorinated hydrocarbons are present in solvents, such as chloroform, trichloroethylene, perchloroethylene, and methyl chloroform. The phosgene and hydrogen chloride are generated by the thermal decomposition of the solvents. Metals should not be degreased with chlorinated solvents.

Evaluating the Hazard:

Mine operators should be able to recognize fume generation activities at the mining property, select ventilation measures suitable for fume control, determine the type of personal protection most effective for the contaminant involved, recognize symptoms of fume overexposure, and sample for exposures to fumes. Special attention should be given to areas where ceilings are low, the welder works in cramped conditions, or ventilation is poor.

All personal samples should be taken in the miner's breathing zone. The breathing zone of a welder wearing a welding hood is considered to be under the hood. The cassette must be placed under the hood whenever possible.

Full-shift sampling should be done when miners will be welding or exposed to other fume sources for all or most of their work shift. Short-term samples should be taken along with any full-shift samples to determine if short-term or ceiling limits for any contaminants are exceeded. If full-shift sampling is interrupted to take short-term samples, the contaminant amounts determined by analysis of the full-shift sample and each short-term sample must be added to determine the full-shift exposure for each contaminant.

Additional short-term samples should be taken when the welding rod, material being welded, or welding flux is varied during the shift. The welding samples will, therefore, have to be monitored closely. Short-term samples should cover at least the maximum time period allowed by the short-term exposure limit that has been set for the specific contaminant(s) sampled.

Sampling performed in areas where molten metals may be generated by a furnace will have to address the known or suspected elements present. These operations are usually performed at a permanent site and on a more regular basis than welding.

Sampling Strategy:

Personal exposure sampling for fumes requires both full-shift and short-term sampling. If full-shift sampling is interrupted by the short-term sampling, the contaminant amounts determined by analysis of the full-shift sample and each short-term sample must be added to obtain the full-shift exposure for each contaminant.

In all cases, whether or not short-term sampling interrupts the full-shift sampling, each short-term sample should be analyzed and evaluated to determine if exposure exceeds a ceiling limit or short-term limit for specific contaminants.

The interrupted and simultaneous sampling strategies for collecting full-shift and short-term samples are illustrated below.

Interrupted:

Full-shift sample S_1 <-----> <-----> <----->
 Short-term samples S_2 <--> S_3 <-->
 Full-shift exposure = $S_1 + S_2 + S_3$

Simultaneous:

Full-shift sample S_1 <----->
 Short-term samples S_2 <--> S_3 <-->
 Full-shift exposure = S_1

Controlling the Hazard:

Good ventilation and reduced exposure time are two methods used to reduce health hazards from metal fumes. Small, confined, unventilated conditions will produce the worst health hazards. Although outdoor operations will seldom produce overexposures to miners, only sampling can verify this assumption.

Permanent indoor facilities can be equipped with local exhaust ventilation to minimize the exposures. In general, the capture hood should

be placed no further from the source of the contaminant than a distance equal to the size of the capture hood opening. Care must be taken to place the capture hood where it will not draw the fumes across the miner's breathing zone en route to the exhaust duct. A hood placed above the miner's head, for example, may have ample capture velocity to remove the contaminant, but may do so by drawing the fumes across the miner's face. The hood should be located behind the fume generation source so that it will remove the contaminant without exposing the miner.

Simple smoke tube checks may help determine the adequacy of the capture hood and the air currents in the miner's breathing zone. Inoperable fans, open doors or windows, holes in duct work or hoods, faulty bag houses, and improperly adjusted blast gates may defeat the ventilation system. The effectiveness of well-designed systems is sometimes negated at a later date by the addition of collection points along a circuit.

ASBESTOS AND MINERAL FIBERS

Asbestos is a generic term for a number of hydrated silicates that, when crushed or processed, separate into flexible fibers made up of fibrils. The term *asbestos*, as used in 30 CFR 56/57.5001(b) refers to the following mineral fibers: chrysotile, amosite, crocidolite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos.

The term *mineral fiber* refers to particles greater than five μm in length which have a length at least three times greater than its width.

Fibrous talc is a magnesium silicate ($\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$) which is greater than five μm in length with a length three times greater than its width. Fibrous talc has the same fiber limit as asbestos. This is due to the similarity of the reaction in the lungs produced by fibrous talc and asbestos fibers.

Sources of Asbestos and Mineral Fibers:

In addition to asbestos mines, asbestos is found as a contaminant mineral in the host rock in non-asbestos mining operations. Asbestos or fibrous dust is created and released into the ambient air by the breaking, crushing, grinding, drilling, or general abrasive handling of a solid material having fibrous components. Chrysotile is the type of asbestos most commonly found in commercial products. Amosite and crocidolite are generally considered to be the most toxic.

Fibrous dust particles do not readily settle out of the air, but can remain suspended for long periods of time. As a result, accumulations of fibrous dust can continue to present an inhalation hazard when they are stirred up by vehicular traffic, by persons walking through them, or by the wind.

Asbestos exposure most often occurs from products brought on to the mine property, such as brake linings, asbestos welding blankets, and pipe insulation, or products that are used in building construction, such as transit panels. Replacement of these items with asbestos-free materials is encouraged, but should be done only by miners trained in asbestos removal and abatement methods.

Health Effects:

Asbestosis is a type of pneumoconiosis which results from the inhalation of asbestos fibers, and is also referred to as interstitial fibrosis. Fibers lodge in the lungs, causing a scar that may continue to grow even though there may be no further exposure to asbestos. *Lung cancer* is a simple term for carcinoma of the bronchus. Lung cancer is associated with all types of asbestos and is related to the degree of asbestosis present in the lungs and also to cigarette smoking, which greatly enhances the cancer-causing properties of asbestos. High rates of lung cancer have been observed in miners exposed directly and indirectly to asbestos dust.

Mesothelioma, another cancer associated with asbestos exposure, is a tumor made up of cells from the pleura (chest lining) or peritoneum (abdominal lining). Cancer of the gastrointestinal tract and of the larynx have also been associated with exposure to asbestos fibers.

Full-shift Limit: No miner shall be exposed to an 8-hour, time-weighted average airborne concentration of asbestos dust which exceeds 2 fibers, greater than 5 μm in length, per milliliter of air, as determined by the membrane filter method at 400-450 magnification, 4 millimeter objective, phase contrast illumination.

Short-term Limit: No miner shall be exposed at any time to airborne concentrations of asbestos fibers in excess of 10 fibers, longer than 5 μm , per milliliter of air, as determined by the membrane filter method over a minimum sampling time of 15 minutes.

MISCELLANEOUS GASES AND VAPORS

The hazards associated with certain mine gases are some of the most documented health and safety hazards in the mining industry. The purpose of the measurement and control of these contaminants is to prevent the occurrence of mine fires, unplanned explosions, and both acute and chronic occupational illnesses or injuries. Another purpose is to provide miners with environmental conditions that will not cause or contribute to an accident.

The gas sampling methods used for personal exposure or area monitoring are quite diverse. Mine operators may already be familiar with the vacuum bottles, Bistables, detector tubes, charcoal tubes, and direct-read instruments. However, certain gaseous contaminants may require the use of other less familiar sampling methods, such as gas bubblers with various collection fluids, adsorbent tubes other than charcoal, or the great variety of passive dosimeters on the market.

Gases are formless fluids at room temperature and pressure, retaining no specific volume or shape. Gases diffuse, completely filling any space into which they are introduced. They can be expanded or compressed between wide limits.

A *vapor* is the gaseous form of a substance which is a liquid or solid at room temperature and pressure. Substances with a low boiling point will usually have a high vapor pressure at ambient temperatures.

Health Effects from Overexposure:

The body can absorb toxic gas or vapor directly into the bloodstream from the inhaled air. Inhalation is the major route of absorption for the majority of hazardous airborne contaminants. Other routes of absorption are through the skin, eyes, or mucous membranes. Gases and vapors are rarely absorbed through the gastrointestinal tract.

Asphyxiation is the result of a reduction of the oxygen and an increase of carbon dioxide in the body tissues and fluids, resulting in

suffocation. Simple asphyxiants, such as methane, hydrogen, and acetylene, act by replacing and lowering the percentage of oxygen in the inhaled air.

Other asphyxiants, called *chemical asphyxiants*, such as carbon monoxide and nitric oxide, act on the body tissues to alter their ability to pick up oxygen. Carbon monoxide, for example, binds the hemoglobin so that it cannot pick up oxygen.

The chemical action of certain gases or vapors causes inflammation at the area of their contact with or absorption by body tissue. Some results of this irritation may be eye burns, fluid in the lungs, hoarseness, holes in the tissue between the two nostrils, and various types of dermatitis.

Most irritant reactions are acute, that is, they are noticed almost immediately. However, there are some substances which cause a delayed reaction, working slowly to cause severe damage. The most notable example of this is NO₂, which causes a fluid build-up in the lungs which may not occur for several hours and which acts as a barrier, preventing inhaled oxygen from reaching the blood. Because the irritation is not felt immediately, the miner tends to remain for longer periods in hazardous concentrations.

Gases and vapors can cause the same *systemic reactions* as particulate contaminants. Gases and vapors are usually absorbed at a much faster rate than particles and, therefore, the symptoms are likely to appear faster. Almost all toxic gases and vapors cause one or more types of systemic reactions. Sensitization, which also may occur, is considered to be a systemic reaction because absorption of a small amount of the contaminant at one point can cause a reaction in all areas of the body. Systemic reactions may involve liver and kidney failure, central nervous system disorders, nausea, headache, or weakness.

Sources of Exposures:

Gases can be formed in pockets in the rock by natural processes and then seep out into the mine air through cracks in the rock. Under certain conditions, these gases may accumulate into hazardous concentrations in local areas. The most common naturally occurring contaminant gases encountered in mining are methane, hydrogen sulfide, and radon.

Toxic gases and vapors are routinely produced by many processes in the mining industry. Toxic and asphyxiant gases can be created by welding operations, combustion, and blasting. Exhausts from fuel-burning engines contain large amounts of toxic gases. Toxic vapors are usually found in the mineral process areas where liquid reagents are used. Vapors may be encountered around solvent cleaning operations, painting, fuel storage areas, maintenance shops, chemical storage areas, and certain reagent mixing areas.

The danger from toxic gases and vapors can be encountered anywhere that they can settle or collect. In addition, toxic gases can be formed accidentally when contaminants react with the ore, with moisture, or with each other. Often the accidental production of a toxic gas can be anticipated and precautions taken to minimize adverse effects.

Control of Gas and Vapor Exposures:

Ventilation is the major *engineering control* for toxic gases and vapors in mining. Ventilation methods include local exhaust, general mechanical, and natural draft. Natural draft ventilation alone is not considered a control method in closed or semi-closed areas such as shops or underground mines. Ventilation controls the contaminant concentration by either diluting it or by removing it from the workplace air.

Other methods of controlling miner exposure to a toxic gas are those which isolate the miner, such as in an environmentally controlled booth or cab, and those which prevent the contaminant from being released into the environment. These are also considered engineering controls. The latter method is preferred over ventilation controls. Some examples of controlling toxic gases or vapors prior to release into the environment are the catalytic converters on diesel equipment, the scrubbing systems on coal-fired furnaces, and activated charcoal filters for removing organic contaminants.

Administrative controls are those which involve changes in miner or production schedules or procedures to reduce miner exposure to a contaminant. Administrative controls may or may not change the contaminant level in the ambient environment. Some examples of administrative controls would be rotating miners so that each spends some time in the control booth and requiring that all blasting be done at the end of the workday.

Personal protective equipment (PPE), primarily respiratory protection, is appropriate while engineering controls are being installed, if the hazard can't be controlled any other way, or additional protection is required. Like administrative controls, PPE does not remove the hazard from the work area. Furthermore, respirators are often uncomfortable and may make it difficult for miners to breathe or communicate.

APPENDIX

General Sources of Publications

1. Mine Safety and Health Administration (MSHA)
US Department of Labor
4015 Wilson Blvd
Arlington, VA 22203
Phone: 703/235-8307
<http://www.MSHA.gov>
2. National Institute for Occupational Safety and Health (NIOSH)
4676 Columbia Parkway
Cincinnati, OH 45226
Phone: 800/35-NIOSH
<http://www.cdc.gov/niosh/homepage.html>
3. Occupational Safety and Health Administration (OSHA)
US Department of Labor

200 Constitution Ave
Washington D.C. 20210
Phone: 202/219-8151
<http://www.OSHA.gov>

8. American Industrial Hygiene Association (AIHA)
2700 Prosperity Ave., Suite 250
Fairfax, VA 22031
Phone: 703/849-8888
<http://www.AIHA.org>
9. American Conference of Governmental Industrial Hygienists (ACGIH)
1330 Kemper Meadow Dr., Suite 600
Cincinnati, OH 45240
Phone: 513/742-2020
<http://www.ACGIH.org>
10. American National Standards Institute, Inc. (ANSI)
1430 Broadway
New York, NY 10018
Phone: 212/642-4900
<http://www.ANSI.org>
11. US Department of Labor, MSHA
National Mine Health and Safety Academy
1301 Airport Road
Beaver, WV 25813-9591
Phone: 304/256-3267
<http://www.msha.gov>

General Reference Materials

1. Various NIOSH "Criteria Documents" for mining contaminants such as noise, crystalline silica, asbestos, etc.
2. NIOSH Manual of Analytical Methods, 4th edition, Peter M. Eller, editor. Pub. No. 94-113, 1994.
3. NIOSH Technical Guide to Industrial Respiratory Protection. N. J. Bollinger, R.H. Schutz. 1987 Phone: 800/35-NIOSH
4. Fundamentals of Industrial Hygiene, 4th edition. 1997. #15134-0000/W0000688. National Safety Council, 1121 Spring Lake Drive, Itasca, IL 60143-3201. Phone: 800/621-7619
5. TLVs[®] Threshold Limit Values for Chemical Substances in Workroom Air Adopted by ACGIH for 1973, 1973. American Conference of Governmental Industrial Hygienists.
6. Particle Size-Selective Sampling in the Workplace. 1985. Publication 0830. American Conference of Governmental Industrial Hygienists.
7. Methods of Air Sampling and Analysis, 3rd edition, James P. Lodge, Jr., editor, 1988. Publication 9066. ACGIH.
8. Industrial Ventilation: A Manual of Recommended Practice, 23rd Ed. 1998. Publication 2092. American Conference of Governmental Industrial Hygienists.
9. The Occupational Environment-its evaluation and control. 1997. Edited by S. R. DiNardi. # 252-BP-97. American Industrial Hygiene Association.
10. Air Sampling Instruments Handbook, 8th edition. 1995. Publication 0030. American Conference of Governmental Industrial Hygienists.
11. Basic Industrial Hygiene: A Training Manual, R.S. Brief. 1975. # 101-BP-75. AIHA
12. NIOSH Pocket Guide to Chemical Hazards, June 1997. Pub. No. 97-140, NIOSH.
13. ANSI Z88.2-1992, Title: Respiratory Protection. American National Standards Institute, Inc. New York, NY.
14. Industrial hygiene and noise training products from National Mine Health and Safety Academy. Phone: 304/256-3257. E-mail: Taylor.Sharon@dol.gov
15. Industrial Hygiene: Sampling for Silica and Noise, Metal and Nonmetal Specialized Training, Student Text Material, MSHA, 1999, Catalogue No: IG13a

16. Dust Control in Open Pit Mining. North Carolina Dept. of Labor, Mine and Quarry Division, 1983, Catalogue No: AV 3.
17. Industrial Hygiene for Healthier Miners. MSHA, 1987 Rev 1996, Catalogue No: SM 21
18. Industrial Hygiene for the Mining Industry. MSHA, 1986, Catalogue No: PI 12
19. Plain Talk About a Serious Problem-Silicosis. North Carolina Dept of Labor, Mine and Quarry Division, 1983, Catalogue No: VC 936.
20. Respiratory Protection Programs. MSHA, 1990, Catalogue No: VC 946.
21. Working Safely with Silica, A Guide to. DOL/NIOSH, 1998, Catalogue No: OT 33.
22. Patty's Industrial Hygiene and Toxicology, 4th edition, edited by George D. Clayton & Florence E. Clayton. 1991. Wiley-Interscience 605 Third Ave., New York, NY 10158-0012. Phone: 800/225-5945.
23. Sax's Dangerous Properties of Industrial Materials, 9th Edition. R.J. Lewis, Sr. 1996. #324-BP-98R.AIHA