A Practical Guide to an Occupational Health Program for Respirable Crystalline Silica

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Intent and Scope

This document provides guidance in the development and maintenance of an occupational health program for exposure to respirable crystalline silica. It has been prepared to assist work groups potentially exposed to respirable crystalline silica in work environments.

Information contained in this guide is intended for individuals with diverse education and experience in occupational health. An effort has been made to blend easy-to-follow guidance with more in-depth discussion for this reason. For additional information and assistance, reference sources appear throughout this document.

Dust control measures such as engineering, administrative and respiratory protection are reviewed but not addressed in detail. More detailed information is provided in regard to workplace dust monitoring and medical surveillance. Medical surveillance information in this guide should be shared with health care providers as appropriate.

Further, the workplace air monitoring and medical programs described in this guide must not be considered total programs. Other workplace stresses such as noise, heat, radiation, non-silica-bearing dusts and chemical exposures, although obvious elements of a total occupational health program, are beyond the intended coverage of this guide.

The guidance included in this document reflects the recommendations of health research organizations such as the American Thoracic Society (ATS) and the National Institute for Occupational Safety and Health (NIOSH). Best practices supported by regulatory agencies and professional occupational health organizations such as the American Industrial Hygiene Association (AIHA) is included as well. They are provided to assist companies in protecting workers against the harmful effects of exposure to respirable crystalline silica.

Disclaimer

This is a best practices' guide that is not intended to satisfy or substitute for the safety and health requirements of federal, state, or local regulatory agencies. Appropriate regulations and laws should be consulted and followed.

Each company is ultimately responsible for tailoring its program to meet its individual needs. Competent physicians, industrial hygienists, and other professionals should be consulted as needed for advice on implementing a program that meets these guidelines.

All information and recommendations contained within this document are for general informational purposes only. The contents of this guide are not intended to be all-encompassing, nor should they be relied upon to serve as site-specific industrial hygiene or health recommendations by the developers of this document. Given workplace variability, it is essential that a comprehensive workplace-specific evaluation be performed on-site by a qualified industrial hygienist.

Workers reading this guide are directed to their employers for specific training and information on all potential workplace hazards, including exposure to respirable crystalline silica. Your employer is required to comply with certain federal and state laws concerning hazards in the workplace. Your employer, working with health and safety professionals, can provide information to you about potential hazards in your workplace, what your employer is doing to protect you from those hazards, and what you can do to protect yourself from them.

The recognition, evaluation, and control of potential hazards in a workplace, including respirable crystalline silica hazards, is a complex task that requires site-specific information and analysis that may not be found in this manual.

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Revisions and expanded information contained in this guide were reviewed by additional outside advisors. Those advisors include: Robert Glenn, CIH – of Crowell & Moring LLP, and Brian Boehlecke, MD - Professor of Medicine (pulmonary) of the University of North Carolina, Chapel Hill.

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Introduction

Crystalline silica is necessary for the manufacture of a wide range of products. It is an indispensable ingredient in glass. It becomes walls and windows of buildings, mirrors, curtains, light bulbs, television tubes, eyeglasses and other optics, and even windows for spacecraft. It is an integral part of boat and automobile bodies, food and beverage containers, and laboratory and hospital equipment. As an ingredient in ceramic products, it becomes china and porcelain, cookware, household appliances, pottery, bathroom fixtures, and floor and wall coverings. Crystalline silica is also used extensively for water filtration.

The resistance of crystalline silica to heat makes it a necessity in ferrous and nonferrous foundries and to steel mills, which use it as a surface lining in the conveying, casting, and molding of molten metals. Ground silica is an ingredient in fiberglass and paints. Nearly all industries in our complex civilization use crystalline silica in some way. For many of these uses there are no known suitable substitutes for silica.

Crystalline silica is also one of the most abundant minerals found in the earth's crust. As such, it is commonly encountered in the mining, processing and use of many minerals. It is a common component in many aggregate and building materials for this reason. A background level of respirable crystalline silica dust exists in ambient air. The term "respirable" typically refers to particulates 10 micrometers or less in diameter.

There are three forms of crystalline silica – quartz, cristobalite, and tridymite. Quartz is by far the most common form of crystalline silica and one of the most significant occupational health hazards encountered in the minerals industry. The primary health risk is from the inhalation of respirable silica dust, which may result in silicosis and other occupational lung diseases. In more recent years inhalation of respirable crystalline silica has been identified as a risk factor in the development of lung cancer.

The anticipation, recognition, evaluation, and control of exposures to respirable silica have long been a concern to the occupational health profession, the minerals industry and the regulatory community. The primary purpose of this guide is to help individual companies in properly and systematically monitoring the workplace environment and the respiratory health status of employees for the purpose of adequately protecting the workforce from the effects of overexposure to respirable crystalline silica.

Section 1 – Respiratory Health Effects of Exposure to Respirable Crystalline Silica

The Human Respiratory System

Airborne dusts may enter the body by inhalation, but depending upon the particle size only some of the inhaled particles are deposited in the respiratory system. The remainder is expelled or swallowed. Some particles are removed from these deposition sites by clearance mechanisms, while those that remain behind may react within the lung to produce local injury. Soluble particles enter the bloodstream and may be carried to a remote susceptible organ. Particle size and other physico-chemical characteristics (e.g., density) largely determine where, and what fraction of particles is deposited. Understanding the process by which inhaled particles are deposited in the lung requires knowledge of the structure of the human respiratory system. The following provides introductory material on this subject.

Description of the Respiratory Tract

The purpose of the lungs is to supply oxygen needed by the body's cells and to remove carbon dioxide, a waste product produced as cells use oxygen. This process is referred to as *gas exchange.* As shown in Figure 1-1, air entering through the nose or mouth passes immediately into the pharynx and then into the larynx, or voice box. From this point, the air enters the trachea, or windpipe, the beginning anatomical structure of the lung, which eventually divides into the right and left bronchi. The bronchi divide into successively smaller branches called bronchioles, whose total cross-sectional area increases with progression down the respiratory tract. The trachea, bronchi, and larger bronchioles are lined with a mucous membrane whose outermost cells are covered with cilia. The cilia, minute hair-like structures, constantly lash back and forth in the mucus, which moistens the airway walls. This process is called *mucociliary action.* This action physically carries deposited debris out of these lung areas (see "Fate of Deposited Dust" below).

Beyond the terminal bronchioles are alveolar structures whose walls contain indentations, alveoli, 150-400 micrometers in diameter (the width of a typical human hair is 100 micrometers). The walls of the alveoli contain pulmonary capillaries within which the oxygen and carbon dioxide exchanges occur.

In a healthy adult there are approximately 300 million alveoli in the respiratory system, along with 14 million alveolar ducts. The total alveolar surface varies between 30 and 80 square meters, depending on individual factors such as age, sex, body structure, and state of health.

Because of the delicacy and complicated structure of the thin walls that separate the alveolar air spaces from the bloodstream, the lungs are extremely vulnerable to airborne

substances. The majority of the coarser airborne particles may be deposited in the winding passages through which the air must pass and may be removed by ciliary clearance action along these airways. However, these defenses may be compromised for a variety of reasons, including particle overload. As particles accumulate in the respiratory tract, inflammation and other adverse responses may occur, potentially progressing to disease.

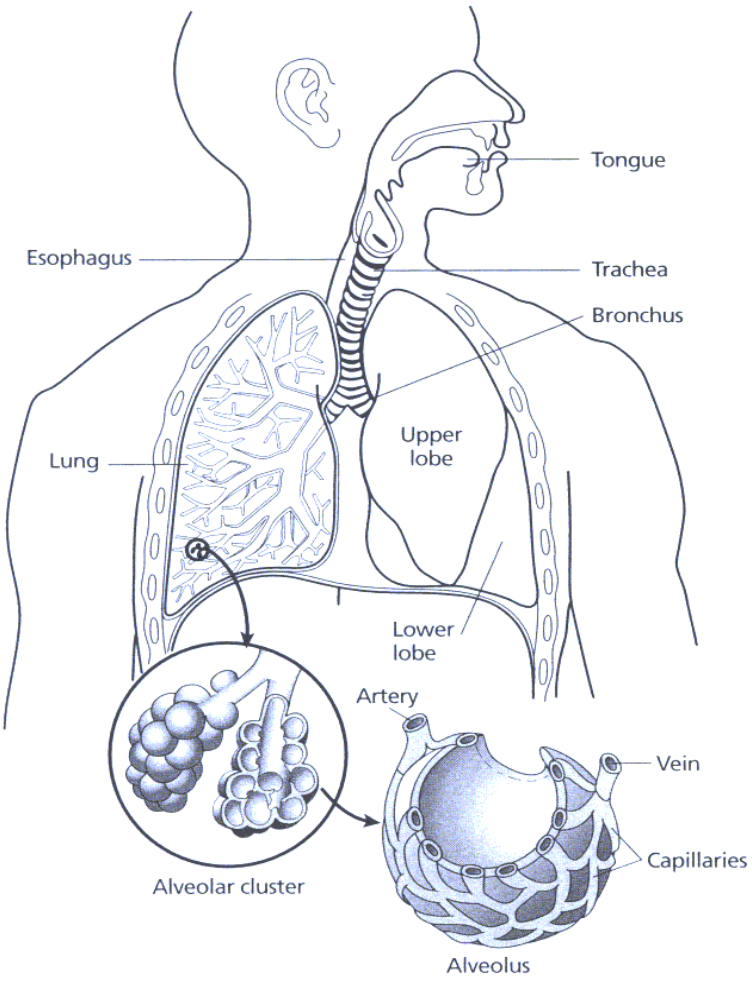


Figure 1-1 Human Respiratory System

Source: *Occupational Health Program for Exposure to Crystalline Silica.* First edition, March 1997. National Industrial Sand Association (NISA).

The Influence of Particle Size on Deposition

Particles entering the respiratory tract may be deposited or they may simply be exhaled. If deposition occurs, then retention or clearance is possible (as described in the next section). Three mechanisms are of importance in particulate deposition:

1. Inertial impaction.
2. Gravitational settling (sedimentation).
3. Diffusion (Brownian motion).

Inertial impaction occurs when an inhaled particle being carried along in an air stream is unable to follow changes in direction produced by the branching of the airways. The momentum of the particle carries it forward on its initial path so that it impacts the airway wall. With gravitational settling, particles inhaled into the lung are under the influence of gravity, and each falls at a constant speed. The speed at which a particle falls is known as the terminal settling velocity. The terminal settling velocity depends on the particle density and the square of its diameter.

The third mechanism promoting deposition in the lungs is diffusion, or Brownian motion. All airborne particles move randomly as a result of their constant bombardment by gas molecules in the air. Particles less than 0.5 micrometer in diameter, and especially those less than 0.1 micrometer in diameter, have such a small volume and mass that these particles have significant Brownian motion. Their movement is completely random, and if a particle is in close proximity to the alveolar wall, it is likely to be deposited in this fashion. The three mechanisms and examples of how the branching of airways influences deposition are shown in Figure 1-2.

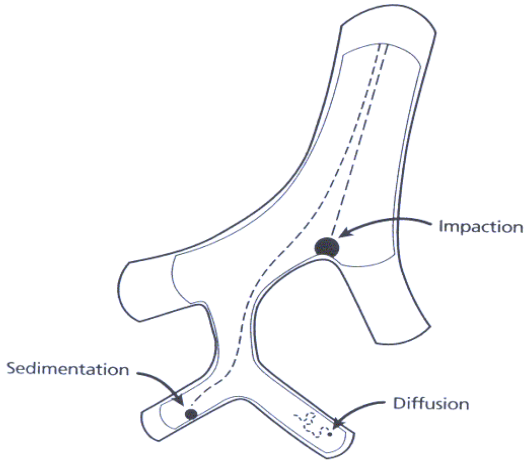


Figure 1-2 Principal Mechanisms of
Aerosol Deposition in the Lung

Source: *Occupational Health Program for Exposure to Crystalline Silica.* First edition, March 1997. National Industrial Sand Association (NISA).

The first two deposition mechanisms decrease in effectiveness as particle size decreases, and it is only the smallest particles that are deposited by the diffusion process. Inertial impaction increases with air velocity; in contrast, both gravitational settling and diffusion are favored by minimal air movement. From these competing physical laws and knowledge of airflow patterns during the respiratory cycle, one can make the following predictions:

The coarsest particles commonly found in industrial dust exposures (10 micrometers and larger in diameter) will be deposited largely by impaction in the nasal chamber, and will rarely reach lower levels owing to relatively high air velocities in this entrance structure (see Figure 1-3 Dust Deposition in man). To a lesser extent (and with decreasing effect), inertial deposition will also take place at points of branching as the dust-laden air descends through the passageways of the upper respiratory tract. Although the rate of gravitational settling is greatest for the coarsest particles, the probability of removal by this mechanism increases with depth of penetration into the respiratory structure owing to two facts - the decreasing distance of fall to the fixed surface of the increasingly smaller airways, and the longer time available for settlement as the air velocity decreases markedly with penetration. The alveolar spaces provide ideal settling chambers because of their minute size and the nearly still air conditions that prevail. Removal by diffusion is significant only for submicron-sized particles and is especially favored in the minute alveoli.

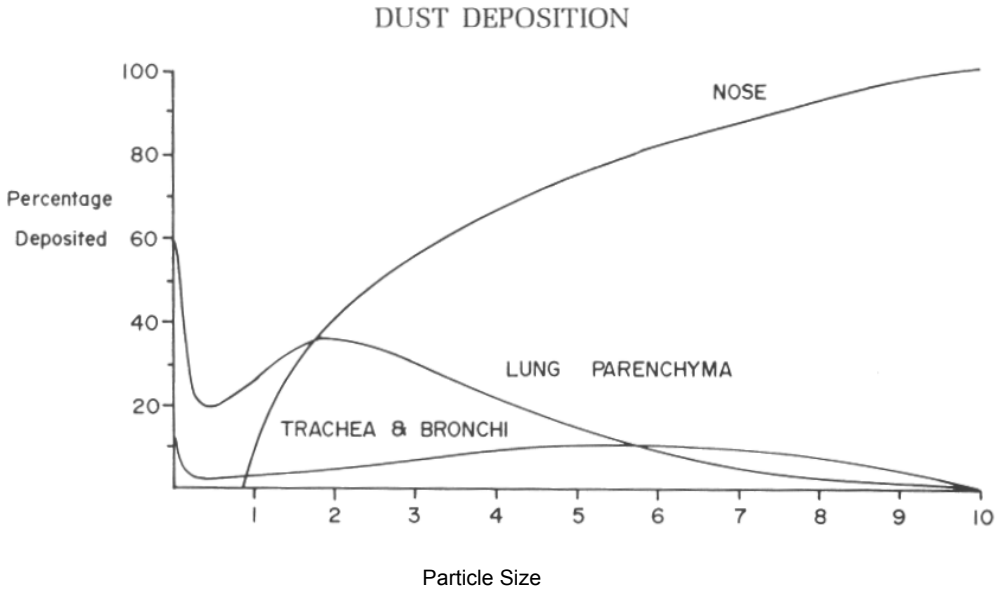


Figure 1-3 Regional deposition of particles as a fraction of their size in microns. This assumes a respiratory rate of 15 per minute and a tidal volume of 700 to 750 ml.

Source: Morgan, W.K.C., and Seaton, A., *Occupational Lung Diseases* (3rd ed.). Philadelphia: W.B. Saunders, 1995.

The importance of the deposition mechanisms in the production of silicosis and other pneumoconioses is the fact that the dust of direct interest penetrates to and is retained in the alveoli (air exchange region of the lung) for long periods of time. Generally speaking, respirable dust that reaches this region will have a diameter of less than 10 micrometers (with most particles falling below 4 or 5 micrometers) (**1-1**). Not all the dust that penetrates to the alveolar region is retained. Some of the dust is exhaled without deposition, and some that does deposit in the alveoli is quickly cleared from the lung by the protective mechanisms discussed below.

Fate of Deposited Dust

Within the alveoli are cells called *macrophages* (i.e., scavenger cells*)* that are released by the stimulus of foreign bodies, such as dust. The macrophages engulf the dust particles deposited in the lung. Some of the dust-laden macrophages, which have the ability to move freely within the air spaces of the lung and alveoli, are removed from the lung by two different pathways.

1. *Mucociliary escalator*: The dust-laden macrophages move to the finer bronchioles, from which further clearance takes place by mucociliary action, as described above. Eventually these cells, along with the coarser particles initially deposited within the upper respiratory tract, reach the mouth and are swallowed or expectorated. Most of the dust deposited in the alveolar spaces is removed in this manner.

2. *Lymphatic system:* Dust-laden macrophage cells may pass through the alveolar walls of the lungs into the lymphatic system, which starts as a mesh of fine vessels and drains the tissue spaces. These vessels come together to form larger and larger vessels that eventually discharge the lymph into the bloodstream (see Figure 1-4). At the various branching points (bifurcations) of the trachea and the bronchi, the lymph passes through glands termed lymph nodes, one of whose functions is the filtration of foreign bodies. Hence, a great deal of particulate matter is deposited by the macrophages at the lymph nodes, and it is here that fibrosis of healthy tissue often starts. Other dust-laden cells may be deposited and remain on the alveolar walls where, again, fibrosis can be initiated.

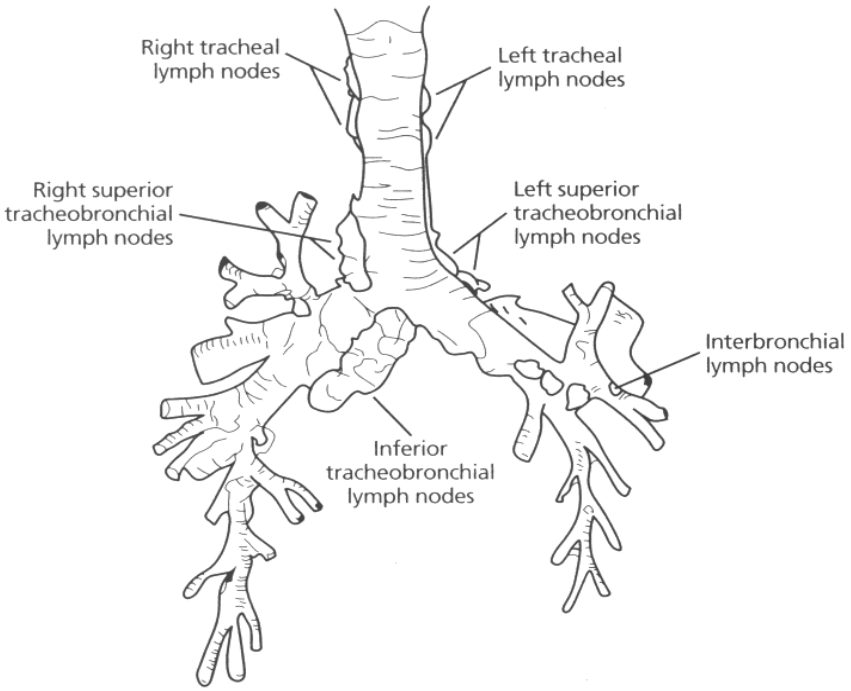


Figure 1-4 Position of Lymph Nodes in the Respiratory System

Source: *Occupational Health Program for Exposure to Crystalline Silica.* First edition, March 1997. National Industrial Sand Association (NISA).

Pneumoconiosis

In general, the human respiratory system's physiological reaction to any inhaled particulate depends on many factors including size, form, durability, solubility, concentration, and chemical composition. A wide variety of reactions is possible including irritation of the upper respiratory tract (nose and throat), mid (bronchi), and lower (alveoli) respiratory tract, allergic reaction, metal fume fever, pneumoconiosis, systemic reaction, radioactive damage, and lung cancer **(1-3)**. Of these, pneumoconiosis is the primary concern with silica-containing dusts. The issue of silica and lung cancer is discussed later in this section.

The term *pneumoconiosis* literally means dust in the lungs and is defined by the International Labor Organization (ILO) as the accumulation of dust in the lungs and the tissue's reaction to its presence (**1-2**). The inhalation of many types of dust, over a long period and at sufficient concentrations, can result in the formation of scar tissue and loss of elasticity, referred to as *fibrosis.* In general, a reaction of this type to a dust is termed pneumoconiosis, and depending on the specific dust, the condition is termed *silicosis* when associated with silica exposure, *asbestosis* when associated with asbestos exposure, *coal workers' pneumoconiosis* linked to coal dust exposure, *talcosis* associated with talc exposure and so forth.

Silicosis

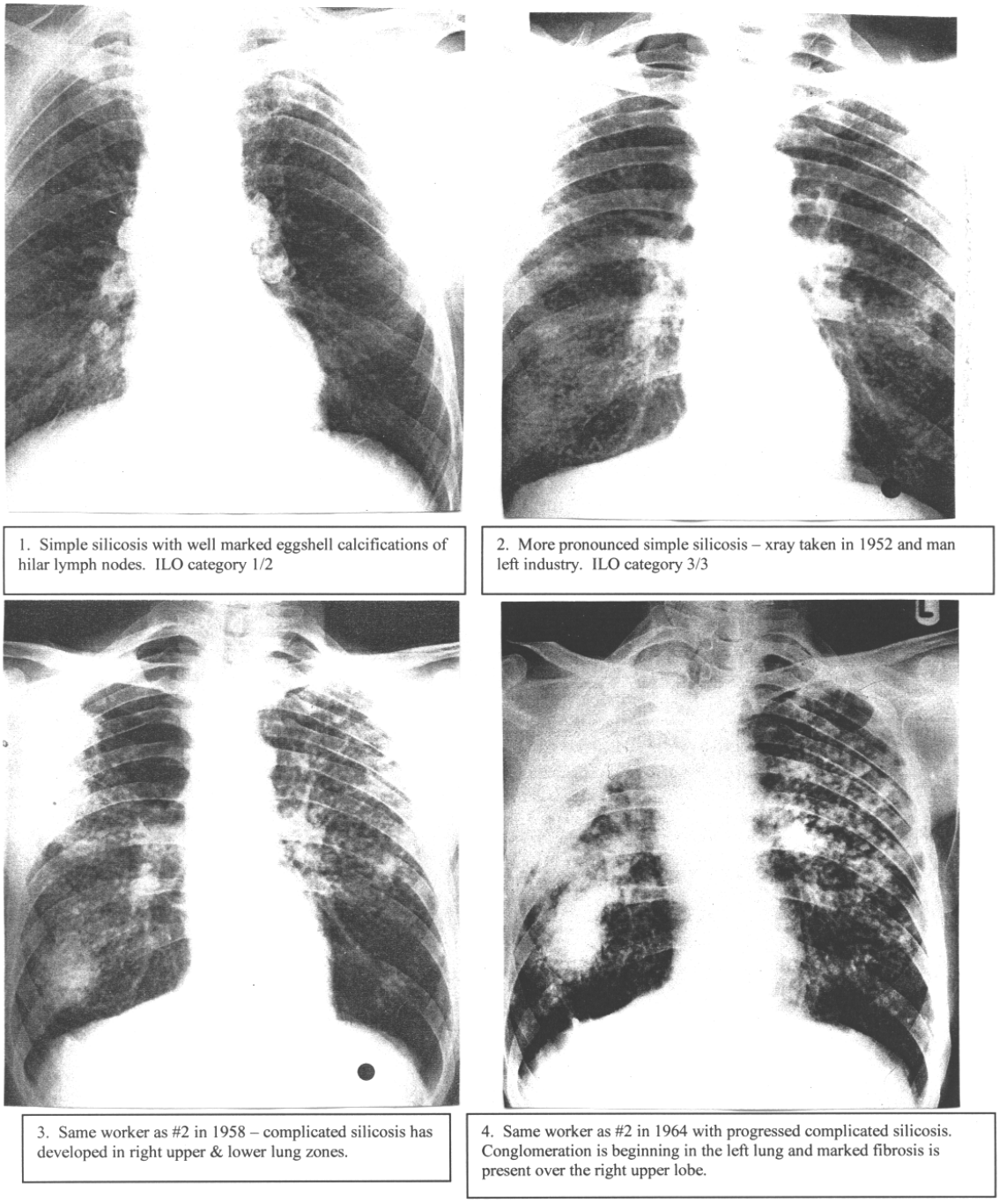
There are three clinical types or presentations of silicosis that can be produced from the inhalation and deposition of dusts containing respirable crystalline silica – classic silicosis (sometimes referred to as chronic silicosis), accelerated silicosis, and acute silicosis. Once each of these conditions develops, there is no known cure, no reversal of the condition, and, in some cases, the pulmonary effects worsen even after there is no further exposure (**1-3, 1-4, 1-5**). There has been recent interest in identifying biomarkers of silica exposure to indicate its uptake and presence in the body, and biomarkers of effect to indicate processes that may precede or predict the development of silicosis (**1-6**). Although the number of work-related deaths in the United States attributed to silicosis as an underlying or contributing cause decreased from 1970 to 2002 (**1-7**)**,** the prevention of silicosis remains a high occupational health priority. The elimination of silicosis in the workplace is the ultimate goal.

Classic (Chronic) Silicosis

Classic silicosis is the most common clinical presentation of the disease and results in fibrotic changes in the air exchange region of the lung that may occur after many years, usually 10 to 30, of inhalation of respirable crystalline silica. The fibrotic changes (like scars) increasingly affect the ability of the lung to exchange gases. Those changes in turn place extra stress on the cardiovascular system and reduce the body's ability to combat respiratory infections. There is an increased incidence of tuberculosis associated with silicosis. Classic (or chronic) silicosis is further subdivided into simple silicosis and complicated silicosis based on the appearance of the chest radiograph (x-ray classifications).

Assigning an exact exposure limit or "dose" at which workers are at risk of classic silicosis is an extremely difficult task for a variety of reasons (e.g., lack of reliable past dust exposure information, insufficient medical surveillance information, individual susceptibility, the role of other exposures such as smoking, etc.). It is generally believed, however, that daily workplace exposures that exceed established exposure standards or "limits" (see section on Exposure Limits in Section 2) can result in classic (chronic) silicosis.

Simple silicosis is the x-ray term used to describe the mildest and earliest form of chronic silicosis. Workers with simple silicosis are usually without any symptoms. If symptoms occur, they are typically limited to a chronic cough with phlegm (mucus) production. The fibrosis in simple silicosis occurs predominantly in the upper lung zones and appears on the chest x-ray as small discrete nodules (lesions) arranged in a birdshot pattern. Eggshell calcification of the bronchopulmonary (hilar) lymph nodes is often referenced. See example in Figure 1-5.



1. Simple silicosis with well marked eggshell calcifications of hilar lymph nodes. ILO category 1/2

2. More pronounced simple silicosis – xray taken in 1952 and man left industry. ILO category 3/3

3. Same worker as #2 in 1958 – complicated silicosis has developed in right upper & lower lung zones.

4. Same worker as #2 in 1964 with progressed complicated silicosis. Conglomeration is beginning in the left lung and marked fibrosis is present over the right upper lobe.

Figure 1-5 Chest Radiographs: Progression of Silicosis (Ref. 1-2)

Note*: See Section 4 Respiratory Medical Surveillance for Silicosis for discussion of the International Labor Organization (ILO) classification system and further discussion on chest radiographs.*

Complicated silicosis results when these small lesions increase in size and coalesce into larger lesions greater than 1 centimeter. Symptoms of a worker with complicated silicosis range from minimal complaints, which might include a chronic cough with phlegm production, to severe shortness of breath and rapidly occurring respiratory failure. The breathlessness is related to a loss in lung volume and can be progressive, ultimately disabling, and sometimes fatal.

Accelerated Silicosis

Accelerated silicosis results from the inhalation of very high concentrations (thought to be many times greater than established safe exposure limits) of respirable crystalline silica over a relatively short period, on the order of 5 to 10 years, whereas chronic silicosis may take 10 to 30 years to develop (**1-4, 1-8**).

Although accelerated silicosis develops in a pattern similar to that of chronic silicosis, with rounded nodular lesions in the upper lung zones, the time from initial exposure to the onset of disease and the progression to complicated disease are much faster. This form of the disease is life-threatening, and death may occur as a result of insufficient levels of oxygen in the blood in as little as 10 years and is more likely to be complicated by mycobacterial disease (e.g., tuberculosis) than chronic silicosis.

Acute Silicosis

Acute silicosis (silicoproteinosis) is the most aggressive of the silicotic diseases and develops from the inhalation of exceptionally high concentrations of respirable crystalline silica over a period ranging from as little as a month to 4 or 5 years **(1-3, 1-9)**. Acute silicosis differs from the other two forms in that the characteristic nodular pattern is absent; the x-ray's appearance is instead similar to that of diffuse ground glass, resulting from a filling of the air spaces by thick proteinaceous material (fluids and cells). Symptoms of acute silicosis include cough, weight loss, and fatigue and may progress rapidly to respiratory failure over a period of several months. Death occurs after a few months from insufficient oxygenation of the blood. Acute silicosis has been reported among sandblasters and drillers and has historically been reported among ground silica workers. Reports of acute silicosis are rare in more recent years.

Silica and Lung Cancer

In October 1996, after reevaluating the scientific literature on respirable crystalline silica, the International Agency for Research on Cancer (IARC) classified respirable crystalline silica from occupational sources as a human lung carcinogen (group 1). This category is used only when IARC finds there is sufficient evidence of carcinogenicity in humans.

The human studies reviewed by the working group included workplace inhalation exposures. In making the overall evaluation, the IARC working group noted that carcinogenicity was not detected in all industrial circumstances studied and may depend on inherent characteristics of the crystalline silica or on external factors affecting its biological activity or distribution of its polymorphs (i.e., different physical forms of the same chemical structure). The reclassification became official when IARC published its

Monograph Volume 68, Silica, Silicates, Dusts and Organic Fibers, in 1997 (**1-10**). This monograph can be found at http://monographs.iarc.fr/ENG/Monographs/vol68/volume68.pdf

Following the IARC classification, the Department of Health and Human Services National Toxicology Program (NTP) published its Ninth Report on Carcinogens. That report also classified respirable crystalline silica as a known human carcinogen (**1-11**). This report can be found at http://ntp.niehs.nih.gov/

The Role of Smoking in Respirable Crystalline Silica Risk

The Surgeon General issued the first report on smoking and health in 1964 and concluded that cigarette smoke causes lung cancer, nonmalignant respiratory disease and cardiovascular disease. Today, smoking is reported to be the leading preventable cause of disease and death in the United States, causing approximately 438,000 deaths each year with increasing reports of damage to most organ systems according to 2006 Centers for Disease Control and Prevention reports. This information can be found at: http://www.cdc.gov/tobacco/data_statistics/Factsheets/adult_cig_smoking.htm

The combined or "synergistic" role of smoking and exposure to airborne dusts such as respirable crystalline silica is not fully understood and is somewhat controversial (**1-12**). However, it is generally believed that the effects of respirable crystalline silica are made worse in combination with smoking. There are epidemiologic studies that suggest that simultaneous exposure to tobacco smoke and crystalline silica increases the cancer risk (**1-13**).

It is known that cigarette smoke adversely impacts several of the dust respiratory defenses discussed earlier. Cilia motility is slowed (mucociliary escalator), more mucous production occurs, metaplastic changes in the tracheal-bronchial tree may occur and alveolar macrophage function may be affected (**1-14**). In an effective silicosis prevention program, it is prudent and highly recommended to implement a smoking cessation program.

Guidance in the development of a smoking cessation program can be found at http://www.cancer.gov/cancertopics/smoking (National Cancer Institute) and http://www.cdc.gov/tobacco/policy.htm (Centers for Disease Control).

The Relationship Between Respiratory Medical Surveillance and Employee Protection

The respiratory medical surveillance program, discussed in detail in Section 4, should be structured to collect information for four primary purposes—baseline evaluations, respiratory health status evaluations, epidemiological studies, and as an indicator of the adequacy of past dust controls.

Baseline Evaluations

The baseline evaluation has many advantages, two of the more important being to assess whether the employee is physically capable of performing the essential job functions safely and to develop individual pulmonary status baseline information for use in assessing future pulmonary changes. The evaluation may also detect non-occupation-related chest conditions.

Respiratory Health Status Evaluations

Periodic evaluations should be made for early detection of occupational illness such as silicosis. In some instances, periodic health evaluations can aid in identifying jobs and operations that pose a hazard and require further control. When abnormalities are detected, whether or not they are occupationally-related, they must be disclosed to the employee with appropriate medical follow-up, as recommended by a physician.

Epidemiological Studies

It is important to collect medical data in a consistent and systematic manner that can be used to determine whether silicosis is occurring in exposed miners. These data can be analyzed to determine if the incidence is correlated with exposure to respirable crystalline silica.

Dust Controls

An observation of crystalline silica related occupational illness should prompt review of dust controls. Occupational dust disease noted today is closely associated with prior dust exposures, and, therefore, with the adequacy of prior dust controls. Commonly applied dust control technologies are discussed in Section 3 of this guide.

Extra-pulmonary Disease Effects

There are a number of papers in the medical literature which report an association between crystalline silica exposure (inhaled or ingested) and autoimmune disorders, such as scleroderma, a rare, progressive disease that leads to hardening and tightening of the skin and connective tissue. Some associations remain controversial such as reported links to rheumatoid arthritis, kidney disease and some connective tissue diseases. Such effects, however, are generally associated with elevated exposures to silica and workers diagnosed with silicosis. Guide users are encouraged to consult with a physician, preferably with occupational medicine expertise, familiar with crystalline silica health effects or refer to appropriate medical references for more detailed information in this area. A review of extra-pulmonary disease effects by the American Thoracic Society (ATS) (**1-15**) is recommended.

Section 2 – Workplace Dust Sampling Surveys

Purpose

The primary purpose of crystalline silica dust sampling is to identify exposed workers so that appropriate controls can be put in place and to prevent illness. Dust surveys are conducted as frequently as necessary to determine the adequacy, and monitor the continued effectiveness of control measures.

Worker exposure assessments are made by collecting and measuring respirable crystalline silica dust present in a worker's breathing zone during the work shift. This is known as *personal sampling.* A worker's breathing zone can be described as an imaginary sphere extending a few feet from the worker's head (see Figure 2-1).

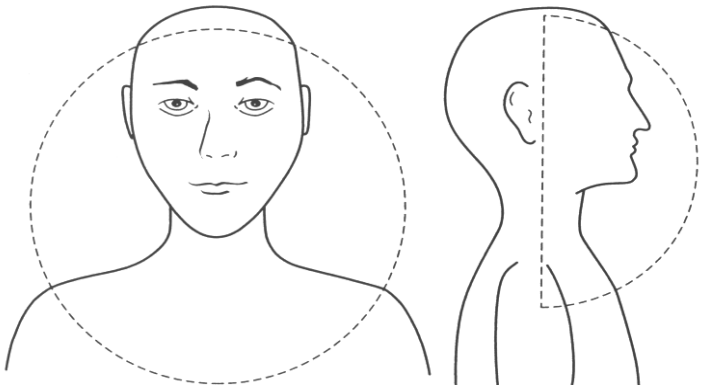


Figure 2-1 Personal Breathing Zone

Source: *Occupational Health Program for Exposure to Crystalline Silica.* First edition, March 1997. National Industrial Sand Association (NISA).

In contrast *Area sampling* is conducted by placing dust-sampling equipment in fixed locations. Area sampling will be addressed later in this section.

Workplace dust sampling can be broken down into the following basic steps:

- **Determine the need for initial sampling** (p. 16).
- **Determine what activity or area to sample** (p. 16).
- **Sample and record the process** (p. 18).
- **Engage a qualified laboratory for sample analysis** (p. 26).
- **Interpret standards and sample results** (p. 28).
- **Communicate sampling results to impacted parties** (p. 35).
- **Establish dust controls when sampling indicates the need** (p. 35).
- **Determine need, frequency and type of re-sampling** (p. 36).

Determine the Need to Sample

As earlier noted, crystalline silica is one of the most abundant minerals found in the earth's crust. It is commonly encountered in the mining, processing and use of many minerals and mineral containing products. If it is not known whether a crystalline silica exposure exists in the workplace, there are several steps that can be taken to determine its presence.

In mining operations, a review of available geological descriptions of the mining area and/or direct analysis of the ore mined for crystalline silica content is recommended. Analysis of waste or overburden materials for crystalline silica content should be done as well.

In industrial environments, a review of material safety data sheets (MSDSs) is recommended. Mining companies are required to prepare and distribute MSDSs for their mineral products. Products that contain more than 0.1% by weight of crystalline silica must reflect this content on the MSDS.

It is important to understand that a weight percent on an MSDS reflects the total crystalline silica content in bulk material – not just the respirable size fraction. While knowing the amount of crystalline silica in a mineral product aids in determining the need to sample, actual risk to a worker can only be determined by the amount of respirable crystalline silica in the air.

If an employer is unsure as to whether sampling for respirable crystalline silica is needed, assistance from an industrial hygienist should be sought (assistance sources are listed at the end of this section).

Determine What Activity or Area to Sample

Once the need for air sampling is recognized, the next step is to determine where to sample and how many samples to take. One of the foremost references on this topic is NIOSH's *Occupational Exposure Sampling Strategy Manual* (**2-1**). This manual is available free of charge at the following website: http://www.cdc.gov/niosh/docs/77-173/. Additional detailed references are also available (**2-2, 2-3, 2-4**).

Workplace activities and areas that process the most crystalline silica-containing materials are intuitively prime candidates for sampling. However, particle size, material handling characteristics and existing dust controls also substantially influence dust exposure risk and must be considered as well.

Prior to sampling, industrial hygienists will often undertake a *walkthrough* of work areas to observe what actually happens as crystalline silica-containing material is processed. This is a *qualitative* step that helps identify activities and areas with possibly the highest dust exposures and thus most subject to sampling. Special attention is typically paid to the following:

- visible dust in the air
- dust settled around equipment, floors and other surfaces
- excessive dust on clothing
- process equipment emitting visible dust
- the nature of the process equipment (can it produce finer particles?)
- the number and proximity of workers to this equipment
- dust regeneration sources such as vibrating equipment, lift trucks and clean-up activities
- respiratory protection used
- similar jobs and dust exposures
- work patterns such as shift periods and worker rotations
- preliminary assessment of existing dust controls (see section 3)
- prior dust monitoring (if available) should be reviewed.

A reference that lists such considerations can be used to aid in the identification of sampling sites and priorities. **Appendix A** is an example of such an aid.

Employee participation and worker interviews are another element of the walkthrough evaluation. It is important to know how workers normally do their jobs and if the process varies at certain times during the workday, week, etc. If workers have complaints or concerns about working conditions or medical conditions that they feel may be work-related, this should be noted. Further, it is important to consider cleanup and maintenance personnel who move throughout the workplace. With care, fixed area dust sampling can also be used to identify the need and location of future worker sampling (see additional discussion on area sampling on page 25).

None of the signs and considerations mentioned above necessarily mean that there is an overexposure to respirable crystalline silica. They are clues, however, that a work area, job category or particular worker should be monitored and what the priority for this monitoring might be.

In choosing workers to be sampled, begin with those believed to have the highest dust exposures (understanding that workers with expected lower exposures may need to be sampled later). Enough workers with similarly high potential exposures should be sampled to gauge exposure variability within this group. Samples must be representative and cover routine daily dust exposure variations. The number of samples obtained is influenced by these considerations.

It is wise to check with the laboratory prior to sampling to determine if a bulk sample of the dust might be needed for use in conjunction with the analysis of the personal air filters. Such samples are typically obtained from building rafters or other undisturbed surfaces in the areas subject to air sampling, or from a high volume air sample intended to collect an elevated loading of total dust (all sizes) on a filter. Such samples are placed in clean bags or jars/vials, and labeled as “bulk” samples with the collection site described, dated, and provided to the laboratory separate from the personal air filters.

Sample and Record the Process

Once the need and location(s) for respirable crystalline silica sampling are determined, it is important that the sampling be conducted properly. Although respirable dust sampling is not complex and does not require extensive professional training, it does require focus, good record keeping and attention to detail. Failure in any aspect of sampling can result in wasted time and money because the exposure will not be properly measured. Dust sampling is the ***quantitative*** step in the dust survey.

Respirable Dust Sampling Equipment

For a respirable crystalline silica air sample, the following equipment is needed:

Particle size selective device*:* Respirable dust samples have been historically collected using a 10-millimeter nylon cyclone size-selective sampler (see Figure 2-2). Other acceptable size-selective samplers are commercially available and function similarly. For the purpose of this guide, the cyclone size selective sampler will be used as the example device.

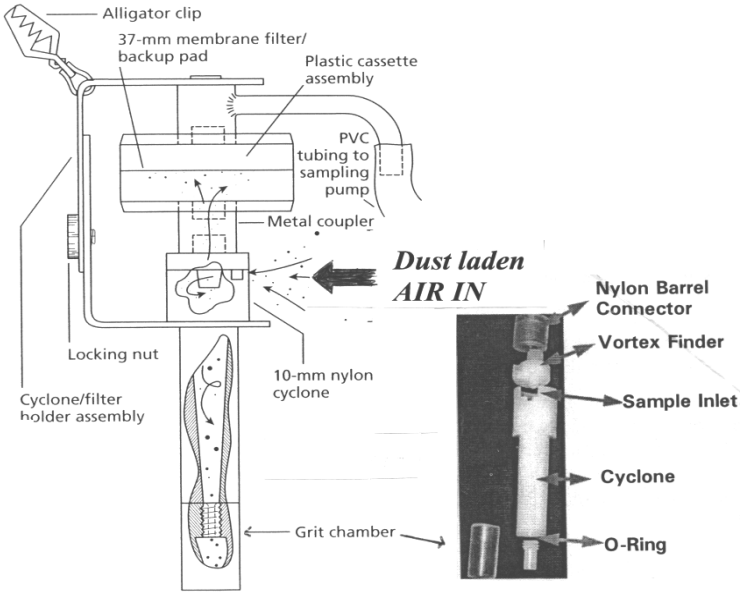


Figure 2-2 10 millimeter Cyclone with Filter

Source: *Occupational Health Program for Exposure to Crystalline Silica.* First edition, March 1997. National Industrial Sand Association (NISA), Photo provided by the R. T. Vanderbilt Company, Inc.

> ***Note: At the stipulated optimal air flow rate (1.7 liters per minute for the 10-millimeter nylon cyclone), the cyclone allows particles 10 micrometers or less in size to impact the 37-millimeter membrane filter for later analysis. Particles larger than 10 micrometers fall out and are deposited in the grit chamber.***

The purpose of these size-selective devices is to separate particles that are 10 micrometers or less in aerodynamic size (respirable particulates) from particles that are larger. Some particle size-selective devices can divide this respirable dust fraction into still smaller size fractions. All size-selective devices are designed to operate with a specific airflow rate, must be maintained clean of debris and all parts must fit tightly.

***Filter and filter holders**:* The cyclone size-selective device is designed to operate in conjunction with a preassembled plastic cassette that contains a pre-weighed 37-millimeter, low-ash polyvinyl chloride (PVC) filter with a 5.0-micrometer pore size. A backup pad is used to support the PVC filter inside the cassette (see typical dust sampling cassette shown in Figure 2-3).

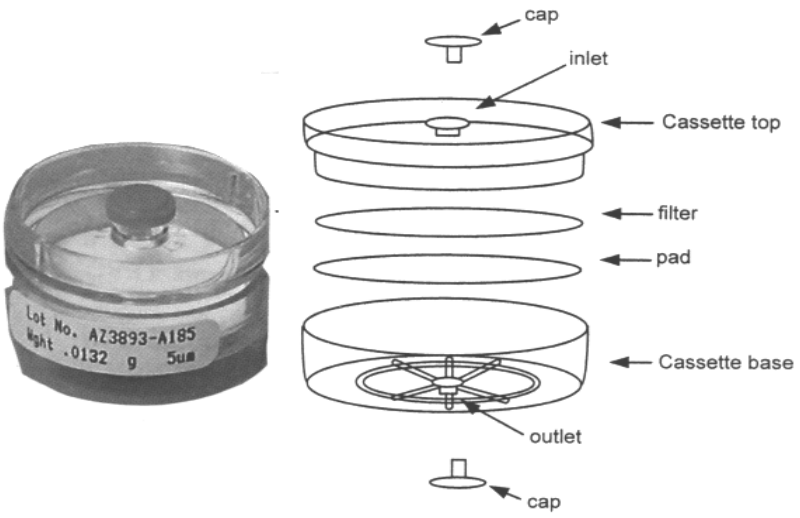


Figure 2-3 Filter-Cassette

Source: *Figure adapted from Omega sales brochure catalog, and IMA-NA*

> ***Note: Some size-selective devices are designed to work with various filter-cassette assemblies. If other than a 10-millimeter cyclone selective device is used, <u>follow the manufacturer's assembly requirements</u> carefully.***

Typically, the filter-cassette assembly is prepared by a qualified laboratory to which the entire intact cassette will be returned after sampling. The inlet and outlet cassette openings will be plugged before and after use. The color of the plugs has no meaning unless the sample taker wishes to use the colors to indicate used versus unused cassettes.

It is very important that the filter-cassette assembly be inserted properly into the size selective device after the cassette caps are removed because air must be drawn through the cassette assembly in only one direction. Note from Figure 2-2 that the cassette inlet faces down towards the cyclone base and grit chamber. The back of the cassette (outlet) typically shows raised radiating lines along the plastic base. Failure to insert the filter-cassette assembly into the cyclone properly (wrong side or loose seal) will result in a wasted sample.

Duplicate filter-cassettes will be used as ***controls***. These controls are subject to identical handling, but do not have air drawn through them and the plugs are not removed. Control filter-cassettes must have been assembled at the same time the other filter-cassettes were prepared by the laboratory and be of the same filter lot. All the filter-cassettes provided by the laboratory will be numbered. The user will need to mark the filter-cassettes used as "controls" so that they can be later identified at the laboratory and used in the analysis to confirm that no contamination of the sampling media has occurred (**2-5**).

Air sampling pump: A number of portable, battery-operated, rechargeable personal air sampling pumps are on the market. All have similar construction and operate in a similar manner.

Dust sampling pumps must reliably draw air through the cassette assembly over a full work shift at a constant flow rate. For personal dust sampling, airflow rate is typically expressed in liters of air per minute (L/min). ***When using the 10-millimeter nylon cyclone respirable fraction device, the ideal flow rate is 1.7 L/min.***

Today's sampling pumps are equipped with flow-compensating features that automatically maintain the desired flow rate as dust loading on the filter increases. Other features now common on air sampling pumps include: time recording devices, automatic shut offs, anti-tampering features, intrinsically safe design for use in potentially flammable/explosive atmospheres and a built-in rotameter or digital flow rate indicator, for spot checks of airflow rate and pump failure.

Sampling pumps have specific requirements for cleaning, general maintenance, battery maintenance and charging. The manufacturer's upkeep recommendations should be carefully reviewed to ensure long pump life and proper operation. A commonly used personal air-sampling pump is depicted in Figure 2-4

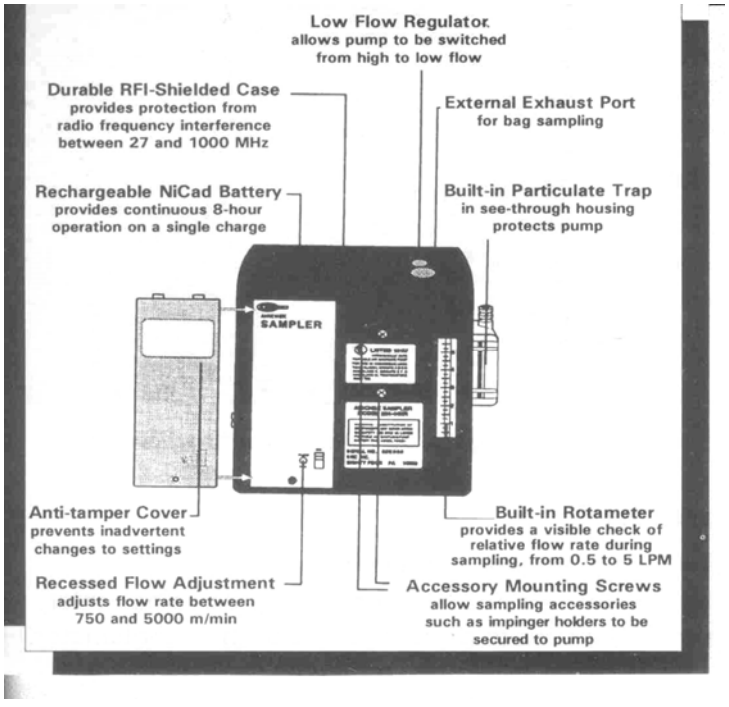


Figure 2-4 Air Sampling Pump

Source: U.S. Department of Labor, Mine Safety and Health Administration, National Mine Health and Safety Academy. Industrial Hygiene: Sampling for Silica and Noise. Metal and Nonmetal Specialized Training-Student Text Material. IG 13a. 1999. Page T-35.

Respirable Dust Sampling Train

The respirable dust sampling equipment is connected as shown in Figure 2-5 below. Flexible PVC tubing is used to make the connection between the filter-cassette assembly (cyclone in this example) and the air-sampling pump. The tubing must form a good seal between the pump and the filter-cassette assembly and be the same type/size of tubing used in calibration. Note how the cyclone and filter-cassette assembly are commonly attached to a worker's lapel to obtain a breathing zone sample (see additional discussion under "Personal Respirable Dust Sampling Steps" pages 22 - 25).

Figure 2-5 Respirable Dust Sampling Setup

Source: MSHA National Mine Health and Safety Academy.

Calibration

The accuracy of dust sampling is dependent upon correctly measuring the volume of air sampled. Proper airflow calibration through the sampling train is therefore essential. Any error in recording the airflow rate will result in a corresponding error in the final calculation of the dust concentration. In addition, when obtaining a respirable dust sample with the aid of a size-selective device like the 10-millimeter cyclone, a specific flow rate is required in order for the size selector to operate properly and separate respirable from non-respirable sized particles. The importance of proper calibration cannot be overstated.

Just before each sample is taken, the pump with its entire sampling train must be calibrated to the desired flow rate. Upon completion of the sampling, the pump flow with the sampling train (used in the calibration) is checked to ensure the accuracy of the desired airflow. This is done to ensure that the flow rate did not vary through the sampling period by more than plus or minus 5% (field tolerance) of the desired flow rate (i.e., 1.615 - 1.785 for 1.7 L/min). As earlier noted, the desired flow setting using the 10-millimeter nylon cyclone is 1.7 L/min. Sampling at this flow rate ensures that the 10-mm cyclone properly separates respirable from non-respirable sized particles.

Barometric pressure and temperature can affect pump operation and flow rate so calibration should occur as near to the sampling site elevation and temperature as possible. Formulas exist to compensate for these factors and some pumps automatically adjust, but it is always best to calibrate as close to the sampling location and conditions as possible.

Sampling train calibration may be manual, that is, measuring the movement of a soap bubble up a 1-liter (1000 milliliter) graduated burette. This procedure is relatively simple, inexpensive and considered extremely accurate when applied correctly. It is however, cumbersome, time-consuming, and the burette is fragile. It is not the most practical approach for field use. A detailed procedure for calibration utilizing the manual burette method can be found in **Appendix B.**

Electronic digital-read out calibration devices are also available though they, too, may be factory calibrated using the manual glass bubble burette method. While more expensive than the burette method, these devices are simple to use, field-friendly and are an acceptable and more commonly employed calibration alternative. A detailed procedure for calibration utilizing one commercially available electronic device can be found in **Appendix C.**

An accurate log of the calibrations performed on each sampling unit should be kept as a permanent part of the dust survey record. This *calibration log* supports the reliability of the dust sampling results and can indicate problems with the sampling train (most often, the air pump). An example of a calibration log can be found in **Appendix D.**

Because calibration plays such a pivotal role in sample reliability, extreme care should be exercised in performing all calibration procedures. The following summarizes the philosophy of air sampler calibration:

1. Use care and pay attention to detail and cleanliness of the equipment.
2. Ensure that all sampling and calibration connections are as short and free from constrictions and resistance as is possible.
3. Exercise care in reading scales and timers and in making adjustments.
4. Obtain enough data to provide confidence in the calibration measurements such as using the average of three flow measurements.
5. Maintain complete, permanent records.
6. When post flow rate differs significantly (i.e., more than plus or minus 5%) from the initial calibration, determine the cause of the discrepancy (e.g., the calibration device, the pump, connections, etc.). If a cause is not immediately identified and corrected, the sample should be invalidated and the equipment should not be used again. It is wise to consult an industrial hygienist in this instance.

Personal Respirable Dust Sampling Steps

Conducting representative personal sampling for respirable crystalline silica, and for that matter other respirable dusts, involves a series of basic steps and documentation requirements. The following lists these steps, provides summary guidance, and identifies minimum documentation requirements.

A sampling record form should be used in conjunction with these sampling steps. **Appendix E-1** contains examples of sampling record forms. The sampling steps listed below highlight the entries that should be included on these forms. Other recording requirements appear as well.

1. **Select** the worker(s) to be sampled. Determine where to sample (Pages 16-17). As a general rule, worker monitoring should progress from those workers who are most exposed to those less exposed until representative exposure results for each job are consistently found to be within established safe limits.

2. **Calibrate** the sampling train and record the initial flow rate on a calibration form or log (page 21 "Calibration", and **Appendix D** form). Note: *Do not use the calibration media for sampling purposes.*

3. **Assemble** the final sampling train as shown in Figure 2-5 and ***Record*** *the filter-cassette number and the pump number on a sampling record form such as an* ***Appendix E-1*** *form (individual sample record).*

4. **Explain** to workers being sampled why they are being sampled, not to tamper with the sampling train or cover the cyclone inlet, what to do if a problem is encountered, and when and where the sampling equipment will be removed. ***Record*** *the worker's name, job activity, and location (at a minimum) on the sampling record form. Be sure the date and time (or shift) is recorded as well, such as on an* ***Appendix E-1*** *form.*

5. **Attach** the sampling train to the worker's clothing as indicated in Figure 2-5 (lapel). Be sure the filter-cassette and cyclone are in the worker's breathing zone, the cyclone air inlet is not obstructed, and the cyclone assembly hangs in a vertical orientation. Affix the pump to the worker's belt with adequate PVC tubing to ensure free range of motion and that the tubing will not fold or crimp. Be sure all connections are tight (especially the cyclone sections).

6. **Collect** the air sample by switching the air pump on and ***Record*** *the start time on the sampling form – such as an* ***Appendix E-1*** *form.* Allow the pump to run through the worker's entire work shift whenever possible. Check back with the worker throughout the workday (ideally each hour or two) to ensure the sampling equipment is working properly. Changes in work activities throughout the sampling period should be recorded. A form similar to ***Appendix E-2*** *form* can be used for this recording purpose.

   Note 1: Remember the use of ***control*** filter-cassettes. Carry these cassettes into the sampling areas but do not remove the caps on these cassettes. Good practice supports the use of one control cassette for each set of ten or fewer sample filters for each day of sampling. Control cassettes must come from the same batch/lot as those used for the sampling. ***Record*** *the control filter-cassette number that corresponds to each sample on the sampling form, such as in* ***Appendix E-1***.

   Note 2: Remember to collect *bulk* samples **if** requested by the laboratory in sealable clean containers, such as plastic bags or vials. Date and record the source of each bulk sample for the laboratory.

7. **Stop** sampling by switching the air pump off at the end of the sampling period. ***Record*** *stop time on the sampling record, such as an* ***Appendix E-1*** *form.*

8. **Remove** the sampling train from the worker then remove the cassette assembly from the cyclone and immediately recap the inlet and outlet openings. Do not tip the cyclone in a way that allows particulate in the grit chamber to fall back through the cyclone onto the filter. Caps (usually red and blue) can be used to identify cassettes used from those not yet used. Note: Do not open the filter-cassette. Continue to handle and process the entire filter-cassette as a whole.

9. **Check** the pump flow rate with the same sampling train and procedure used in the initial calibration and record the ending flow rate on the calibration log (see pages 21-22 and **Appendix D** form).

10. **Determine** the *sampling's "**final flow rate**"* which is the average of the starting and the ending flow rate values. ***Record*** *this final flow rate on the sampling record such as an* ***Appendix E-1*** *form.* The *final flow rate* should not vary more than plus or minus 5% from the original starting flow rate recorded on the calibration log. If it does, consider the sample invalid.

    Example**:** $\frac{\text{1.72 end + 1.70 start}}{2}$ *= 1.71 L/min (**final flow rate**).*

11. **Deliver** the cassette samples, cassette controls, and bulk samples (if any) to the laboratory**.** Pack the sealed cassettes with cushioning packing material to minimize jarring. Be sure to include information required by the laboratory performing the analysis. Pack bulk samples (if taken) separately. Some laboratories will provide a laboratory information form to be completed and submitted with the samples. The information, at a minimum, will typically include the following:

    - *Contact information of the sample taker.*
    - *The analysis desired (e.g., crystalline silica by x-ray powder diffraction – NIOSH Method 7500).*
    - *The volume of air drawn through each sample cassette in liters is obtained by multiplying the **final flow rate** by the sample duration in minutes.*

    Example: *1.71 L/min flow rate (from above) X 480 minutes (if an 8 hour sample) =* ***820.8 liters volume (for the sample)***

    Note: If there is no laboratory form to record this information, a sampling summary or log form can be prepared for the laboratory from the individual sampling record (such as **Appendix E-1** form). Examples of such summaries or logs can be found in **Appendix E-3** and **E-4.**

Summary logs are also used as a primary record of the sampling by the sample taker. Personal sampling forms (e.g., **Appendix E-1**) are often permanently filed in the employee's records and may also be used in communicating sampling results to the employee (see page 35, "Communicate Sampling Results to Impacted Workers").

For further assistance, guide users are encouraged to view the MSHA produced DVD entitled "Respirable Dust Sampling." If not enclosed with a copy of this guide, this DVD may be obtained through the National Mine Health and Safety Academy as DVD # 011 at email MSHADistributionCenter@dol.gov or by calling 304-256-3257.

Area Sampling

In addition to personal air monitoring, fixed work area sampling may also be part of an effective dust-monitoring program. Utilizing the same sampling equipment used for personal sampling, area sampling might be employed for the following reasons:

1. For certain job activities, it may be impractical to use sampling equipment on the worker (e.g., confined or constricted work space). In such cases, a reasonable estimate of potential exposure can be made on the basis of general area sampling and observation of the worker's activity.

2. When a single full-shift personal dust sample indicates an excessive exposure to respirable crystalline silica, it may not be clear which dust emission source(s) contributed most to this exposure. Fixed area sampling can aid in the identification of key exposure sources along with direct observation of worker tasks.

Fixed area sampling can be extremely useful in evaluating the effect of work area equipment changes in regard to dust generation. Fixed sampling reduces sampling result variation caused by worker activity and, therefore, provides a more reliable dust level comparison that is specific to areas and equipment.

High volume dust sampling is a form of area air sampling for the purpose of obtaining an elevated loading of total dust (all sizes) on a filter. The particulate collected can be used by the laboratory, as a bulk, to check for analytical (x-ray diffraction) interferences. Such sampling requires the use of high flow rate pumps and larger filters (no cyclone involved). If high volume samples are requested, the sample taker must be familiar with obtaining these samples, seek experienced help, or obtain detailed assistance from the requesting laboratory.

Direct-Reading Instruments and Area Sampling

Sampling devices other than the traditional pump and cyclone assembly are available for evaluating workplace area dust concentrations. These devices can be calibrated for respirable dust (or other preset size fractions) and no laboratory analysis is required. However, these instruments do not determine the crystalline silica content of the dust recorded and measure only all dust of a preset particle size specification.

Because of its direct-readout capability, this device can be effectively moved around in an area to locate "hot spots", permitting the identification of key dust sources (providing the device is of a manageable size). Some models allow the continuous recording of dust levels plotted over time and present such data in graphic form. This is useful in the identification of activities, equipment cycles, or general area variations that most contribute to overall dust generation.

Direct-reading dust meters are not acceptable by MSHA for compliance sampling, although they are used by regulatory agencies as diagnostic tools. Use by untrained personnel is not recommended.

Additional information on direct-reading dust sampling devices can be found at:

www.coleparmer.com, and www.tsi.com

Engage a Qualified Laboratory for Sample Analysis

Commercial laboratories perform two analytical procedures required for respirable crystalline silica samples:

- Determination of the amount of dust collected on the filter; and
- Determination of the amount of crystalline silica in the dust.

This section covers selecting a laboratory for analyzing samples and specifying the method for determining the amount of crystalline silica. A detailed discussion of the analytical procedures can be found in the NIOSH *Manual of Analytical Methods, Chapter R, (see* www.cdc.gov/niosh/nmam*)* or obtained from the laboratory performing analyses for your organization**.**

Laboratory Selection

For quality assurance purposes, it is strongly recommended that analyses be conducted by an AIHA (see www.aiha.org) accredited laboratory that is a participant in the Proficiency Analytical Testing (PAT) program for crystalline silica analysis. Under the PAT program, spiked samples of known quantities of a contaminant (crystalline silica in this case) are sent to participating laboratories for analysis. Four times a year, the laboratories report results to the AIHA PAT program, and the data are subjected to statistical analyses for precision and accuracy. Laboratories whose results are outside of acceptable proficiency limits are removed from the program.

Crystalline Silica Analytical Method

The analysis of crystalline silica should be performed in accordance with NIOSH Method 7500, which is an x-ray powder diffraction technique (**2-5**) (www.cdc.gov/niosh/nmam/pdfs/7500.pdf). Although other acceptable methods such as infrared analysis are available, the x-ray method is considered most appropriate for crystalline silica. When procuring analysis of crystalline silica, NIOSH Method 7500 should be specified.

Dust sampling filter-cassettes are normally purchased from an analytical laboratory, and each is labeled with a unique identification number (ID) affixed by the laboratory. This ID is a reference link to the initial weight of the filter. Each filter is pre-weighed at the servicing analytical laboratory and post-weighed at the same laboratory (on same balance) after sampling and noting the net weight difference. Filters **must** be sent to

the same laboratory for analysis since this is the only facility that has the initial weight of each filter.

> ***Note:*** While it is acceptable to assign your own sample number to cassettes, new numbers must always be linked to the assigned laboratory number. For this reason, it is often wise to use only the assigned laboratory number to identify each sample.

The key information returned to you from the laboratory should be the concentration of respirable dust expressed as milligrams of dust per cubic meter of air (mg/m^3) and the amount of crystalline silica (typically quartz) on each filter expressed as a percent of the total respirable dust. The concentration of the respirable crystalline silica in mg/m^3 may also be reported.

The amount of respirable dust is determined by noting the before and after sampling difference in the weight of the PVC filter then dividing that difference by the total volume of air drawn through that filter, which is converted to cubic meters of air from the liter volume (see formula below). The weight difference is adjusted if necessary by any weight difference noted on the control filters. See example below for determining a respirable dust exposure concentration.

> **Example:** *Assume an 8 hour sample was taken at a flow rate of 1.70 L/pm flow rate and the difference in filter weight (before and after sampling) was determined to be 0.110 milligrams (the total amount of respirable dust collected).*

Formula

$$\frac{\text{respirable dust weight}}{\text{flow rate X sample minutes X units conversion value}} = \text{respirable dust concentration}$$

Application

$$\frac{0.110 \text{ mg}}{1.70 \text{ L/pm} \times 480 \text{ minutes} \times .001 \text{ m}^3/\text{L}} = 0.13 \text{ mg/m}^3$$

To determine the amount of crystalline silica, another laboratory procedure is required. In addition to being weighed, the filter is subjected to x-ray diffraction analysis that will measure the amount of crystalline silica (typically quartz) on the filter. The result is often expressed as the percent crystalline silica (e.g., quartz) in the total respirable dust. The amount of quartz may be expressed as a percentage of the total weight of the respirable dust. For example, if 50% of the respirable dust was quartz and we had a respirable dust exposure of 0.13 mg/m^3 (from the above example), the quartz concentration/exposure would be 0.065 mg/m^3. It is calculated by multiplying the respirable dust concentration by the percentage of quartz:

respirable dust concentration X % quartz = quartz concentration

$$0.13 \text{ mg/m}^3 \times 50\ \% = 0.065 \text{ mg/m}^3$$

Interpret Standards and Sample Results

Once sample results are returned from the laboratory, the next step is evaluation of these results. What do they mean?

As earlier noted, one purpose of dust sampling is to determine if a worker's exposure to respirable crystalline silica is below, or, at or above established occupational exposure limits. Indeed, most worker exposure assessments are conducted for this purpose. To properly interpret sampling results, it is important to understand not only what the established permissible exposure limits are for crystalline silica, but also the strengths and weaknesses of these limits as well as the variability of results.

There are a number of groups that establish occupational exposure limits for respirable crystalline silica**. Some limits are mandatory, while others are recommended.** *Regardless of which limit is used (mandatory or recommended), the steps and mechanics of respirable crystalline silica air sampling are the same.*

With one exception (NIOSH), all federal mandatory and recommended limits for respirable crystalline silica are based on a time-weighted average (TWA) concentration for a normal 8-hour work shift and a 40-hour workweek. TWA concentrations are most typically expressed in milligrams of respirable dust or crystalline silica (as quartz, cristobalite or tridymite) per cubic meter of air (mg/m^3). Formulas exist to establish acceptable limits for work exposures that are shorter or longer than the normal 8-hour work shift (see "*Other than 8-hour work shifts:*", page 30 and **Appendix F**).

Exposure limits are often adjusted over time as additional health risk information is obtained. The following reflects the most broadly recognized U.S. exposure limits in effect as of the end of 2007. Guide users are advised to always check the most up-to-date status of exposure limits.

Mandatory Standards (Exposure Limits)

The Mine Safety and Health Administration (MSHA) and the Occupational Safety and Health Administration (OSHA) within the U.S. Department of Labor have established the same mandatory crystalline silica workplace air exposure limits, but they differ in their enforcement protocols (see OSHA websites http://www.osha.gov/Firm_osha_data/100007.html and http://www.osha.gov/dcp/index.html). These mandatory limits are derived from adjustable formulas linked to the percentage of free silica in the respirable dust. The formulas for these standards were adopted as part of the Code of Federal Regulations in the early 1970s.

The following formulas are used to establish the OSHA and MSHA mandatory permissible exposure level (PEL) for respirable dust containing crystalline silica in workplace air:

Quartz: $\dfrac{10\ mg/m^3}{\%\ Respirable\ Quartz + 2}$

Cristobalite: **Use one-half the value calculated from the formula for respirable quartz.**

Tridymite: **Use one-half the value calculated from the formula for respirable quartz.**

As can be seen above, the allowable exposure limit is based on the percentage of quartz in the respirable sample. The following examples show the worst-case scenario with 100% respirable quartz and a scenario with 1% respirable quartz:

$$\frac{10\ mg/m^3}{100\%\ Quartz + 2} = \frac{10\ mg/m^3}{102} \approx 0.1\ mg/m^3$$ **allowable limit 8 hour PEL**

$$\frac{10\ mg/m^3}{1\%\ Quartz + 2} = \frac{10\ mg/m^3}{3} = 3.33\ mg/m^3$$ **allowable limit 8 hour PEL**

If the laboratory does not provide the percentage (%) of crystalline silica (typically quartz) in the respirable dust sample, it can be obtained with the following formula provided the silica on the sampling filter (in milligrams) is given.

$$\frac{mg\ silica}{mg\ respirable\ dust} \times 100 = \%\ crystalline\ silica\ (typically\ quartz)$$

Correction factors: Given the variability inherent in the calibration, sampling, and analytical process, MSHA currently applies a sampling and analytical "***error factor***" (correction factor) of plus 20% to their permissible exposure level (PEL). If the 8 hour TWA concentration of respirable dust containing crystalline silica sample is above the PEL times the error (correction) factor, the sample would be treated as exceeding the mandatory standard, and a citation is issued.

This factor ensures 95% confidence that the actual exposure is above the PEL. This means that a citation would not be issued unless the sample result exceeded the **adjusted PEL**. Another way to look at this would be that *the sample result must be 20% higher than the PEL before a citation is issued (i.e., PEL multiplied by 1.2).*

Example: *Assume the laboratory reports a respirable quartz weight of 0.122 mg with a total respirable dust weight of 0.628 mg. The flow rate was 1.7 liters per minute for 480 minutes. You wish to compare that result with the MSHA PEL.*

***Calculate % quartz*:**

$$\frac{mg\ quartz}{mg\ total\ respirable\ dust} \times 100 = \%\ respirable\ quartz$$

$$\frac{0.122\ mg}{0.628\ mg} \times 100 = 19.4\ \%$$

Calculate PEL:

$$\frac{\textbf{10 mg/m}^3}{\textbf{\% respirable quartz + 2}} = \textbf{PEL}$$

$$\frac{10\ mg/m^3}{19.4\ \% + 2} = 0.467\ mg/m^3$$

Calculate adjusted* PEL *using 20% error factor:

PEL X error factor = adjusted PEL

$0.467\ mg/m^3 \times 1.2 = 0.560\ mg/m^3$

Calculate Exposure:

$$\frac{\textbf{total respirable dust weight}}{\textbf{flow rate X sample minutes X units conversion value}} = \textbf{concentration}$$

$$\frac{0.628\ mg}{1.7\ L/pm \times 480\ (min.) \times .001\ m^3/L} = \frac{0.628}{0.816} = 0.77\ mg/m^3$$

In this example, the 8-hour TWA of the exposure concentration (0.77 mg/m^3) is above the adjusted PEL of 0.560 mg/m^3. If this sample was obtained by MSHA, it would be in violation and would be cited.

Note: It is possible to be at or above the PEL and <u>not</u> receive a citation if the result is less than or equal to the adjusted PEL (i.e., 0.467 mg/m^3 – 0.560 mg/m^3). This is known as: "compliance by error factor".

Other than 8-hour work shifts: For regulatory compliance purposes, only an 8 hour equivalent time-weighted average PEL is used, <u>regardless of the actual sampling time</u>. For regulatory compliance, sample results for longer or shorter work shifts are adjusted for comparison to the 8-hour PEL standard. To help make this clear, MSHA uses the term "shift-weighted average" (SWA) to show that the results were obtained following a shorter or longer work shift and have been adjusted. They are then compared to the 8-hour (480 minute) PEL standard.

The shift-weighting approach serves two functions: contaminant exposure concentrations during unsampled periods of an 8 hour shift are assumed to equal zero. And, exposures for work schedules greater than 8 hours are proportionately adjusted to allow direct comparison with the 8-hour PEL.

Example: *Assume you sampled the same activity as above for a 10-hour shift (600 minutes) and obtained a respirable quartz weight of 0.152 mg with a total respirable dust weight of 0.785 mg. Also assume the flow rate was the same (1.7 L/pm) and you wish to compare the result with the MSHA PEL:*

***Calculate % quartz*:**

$$\frac{\textbf{mg quartz}}{\textbf{mg total respirable dust}} \textbf{ X 100 = \% respirable quartz}$$

$$\frac{0.152 \text{ mg}}{0.785 \text{ mg}} \text{ X } 100 = 19.4\ \%$$

Calculate PEL:

$$\frac{\textbf{10 mg/m}^3}{\textbf{\% respirable quartz + 2}} \textbf{ = PEL}$$

$$\frac{10 \text{ mg/m}^3}{19.4\ \% + 2} = \frac{10 \text{ mg/m}^3}{21.4} = 0.467 \text{ mg/m}^3$$

Calculate adjusted* PEL *using 20% error factor:

PEL X error factor = adjusted PEL

$0.467 \text{ mg/m}^3 \text{ X } 1.2 = 0.560 \text{ mg/m}^3$

Calculate SWA Exposure:

$$\frac{\textbf{respirable dust weight}}{\textbf{flow rate X sample minutes X conversion value}} \textbf{ = concentration}$$

$$\frac{0.785 \text{ mg}}{1.7 \text{ L/pm X } 480 \text{ min. X } .001 \text{ m}^3/\text{L}} = \frac{0.785 \text{ mg}}{0.816} = 0.96 \text{ mg/m}^3$$

Note: 480 minutes is used regardless of the actual sample time of 600 minutes.

In the above example, note that the exposure concentration (0.96 mg/m^3) is significantly greater than the exposure concentration in the prior example while the adjusted PEL of 0.560 mg/m^3 remains the same. In this example, the 10 hour exposure would also be considered in excess of the adjusted PEL, and citable.

A few common sense observations regarding other than normal 8-hour shift sampling are listed below (also see "Unusual Work Shift Hours: **Appendix F**):

- Sample the worker's entire work shift.
- It can be more difficult to be in compliance for a longer than 8-hour exposure period.
- You will be in compliance if a shorter than 8-hour work period shows a TWA exposure below the established 8-hour standard.
- If the shift sampling time is close to 8 hours, the more directly comparable the TWA result is to the established 8-hour PEL. [In addition, the more 8-hour samples obtained for a given work period, the more reliable the average of those samples is relative to the 8-hour limit].

Multiple samples for single exposure period: In very dusty environments, excessive dust on a single filter presents analytical difficulties and can reduce the airflow rate as accumulated dust creates more and more resistance (even for self-adjusting air sampling pumps). Under these circumstances, it is often necessary to consecutively change out filter-cassettes in series to cover a full work shift sampling period.

If more than one filter cassette is used to cover a single work shift, the sample taker will need to consolidate the sample results in order to compare the work shift exposure to an exposure limit. When multiple samples in a single shift are taken for regulatory purposes, this is done by summing the amounts of silica and respirable dust for calculation purposes. An example is presented below.

> **Example**: *Assume three respirable dust air samples were taken consecutively to cover an 8 hour work shift. One sample covered 210 minutes with a respirable dust mass of 0.24 mg, and 0.024 mg of crystalline quartz. A second sample covered 100 minutes with a respirable dust weight of 0.32 mg, and 0 .026 mg of crystalline quartz. And a third sample covered 170 minutes with a respirable dust weight of 0.60 mg, and 0.066 mg crystalline quartz was reported. The final flow rate was 1.75 L/pm.*
>
> silica amount: .024 + .026 + .066 = 0.116 mg X 100 = 10 % quartz
> respirable dust weight: .24 + .32 + .60 = 1.16 mg

Calculate the respirable dust concentration, and then compare that shift exposure result to the adjusted PEL.

$$\frac{1.16}{1.75 \times 480 \times .001} = \textbf{1.38 mg/m}^3 \textbf{ Shift Exposure Concentration}$$

$$\frac{10}{10\ \% + 2} = 0.83\ \text{mg/m}^3\ \text{PEL}$$

$$0.83 \times 1.2 = \textbf{1.00 mg/m}^3 \textbf{ Adjusted PEL}$$

Recommended Exposure Limits

In addition to mandatory respirable dust exposure limits for workplace air, there are a number of ***recommended respirable crystalline silica limits.*** Two commonly referenced occupational exposure limits for respirable crystalline silica are those issued and periodically updated by the American Conference of Governmental Industrial Hygienists (ACGIH) and by the National Institute for Occupational Safety and Health (NIOSH). While not subject to rulemaking, recommended limits may provide a valuable additional tool in the evaluation of workplace air monitoring results.

As of 2007, these organizations recommended the following exposure limits:

- **ACGIH** (see www.acgih.org)

  Threshold Limit Values (TLVs®) expressed as an 8-hour time weighted average (TWA). The values below are based upon the respirable dust fraction.

TWA	8 Hour	Quartz	0.025 mg/m^3
TWA	8 Hour	Cristobalite	0.025 mg/m^3

- **NIOSH** (see www.cdc.gov/niosh/npg/npg.html)

  Recommended Exposure Limits (RELs) are 0.05 mg/m^3 and they include tridymite. These levels are expressed as a 10 hour time weighted average (TWA) not exceeding a 40 hour week.

Comparing sampling results to recommended exposure limits: When the laboratory reports a mg/m^3 concentration of respirable crystalline silica for quartz, cristobalite or tridymite for an 8 hour sample, that result is directly comparable to the 8 hour TWA based limits listed above. The result will:

a. exceed the recommended limit,

b. exceed ½ the recommended limit, ("action level"), or

c. be less than ½ the recommended limit.

Example: *Assume an 8-hour sampling result is reported by the laboratory to be 0.029 mg/m^3 quartz. This could be directly compared to the ACGIH TLV for quartz of 0.025 mg/m^3. This sample result would exceed the recommended limit.*

Recommended exposure limit additional considerations: Recommended exposure limits may incorporate elements beyond 8 hour TWA levels that aid in the evaluation of results. These additional considerations include action level, short term and ceiling limits, unusual work shift hours, and multiple consecutive samples for single exposures.

Several of these considerations (unusual work shift hours and multiple samples) were discussed in the mandatory standards section. There are, however, some differences in how the regulatory and non-regulatory results are managed due to the use of respirable dust weight and the percent crystalline silica in the regulatory area versus exposure expressed directly as the concentration of respirable crystalline silica (mg/m^3) in the non-regulatory arena. Extended discussion of non-regulatory sample result considerations can be found in **Appendix F*.***

Regarding the increasingly important issue of unusual work shift hours and recommended standards, guide users are encouraged to consult the latest ACGIH Threshold Limit Values for Chemical Substances and Physical Agents booklet (and can be obtained through www.acgih.org.) and references **2-6, 2-7** and **2-8**. Also, see the "*Other than 8-hour work shifts:*" discussion above.

Occupational Exposure Limit Reliability Considerations

Whether mandatory or recommended, occupational exposure limits are based upon known health risks associated with estimated or known exposure levels. The ability of an exposure based health standard to reliably reflect risk is directly influenced by how fully past exposure levels have been measured and linked to disease endpoints. Unfortunately, records of early dust exposures in most industrial environments are often sparse, if not altogether absent. As noted in Section 1, individual employee sensitivity to workplace and general environmental exposures (including crystalline silica) is also known to vary.

Given this uncertainty, it is unwise to view respirable crystalline silica standards (or most any occupational health standard) as "bright lines" above which adverse health effects are assured or below which they are not. Instead, occupational exposure limits should be viewed as a best available guide and a level that must not be exceeded for regulatory purposes. When training employees in the use of occupational exposure limits, it is important that this perspective be communicated.

Sampling reliability considerations: For sampling results to be viewed as adequately reflective of a worker's long term exposure, they must be taken frequently in order to reflect the typical full work shift day-to-day exposure variability. The most reliable way to achieve this ideal is to obtain enough air sampling results over the long term to observe the "range" for a given work exposure. Subsequent individual sampling results can then be contrasted to this range (i.e., they are typical of the range values, or they are not). See the following additional discussion regarding sampling strategy considerations.

Communicate Sampling Results to Impacted Workers

Once the results of respirable crystalline silica sampling are known, the next step is to communicate these results to impacted workers in a meaningful way. The most commonly applied tool used to communicate specific individual sampling results is an individual notice form. An example of such a notice form can be found in **Appendix G**. The individual sampling form example, **Appendix E-1**, is also suitable as an employee notice.

Dust sampling results obtained by regulatory agencies that exceed a mandatory permissible exposure limit typically require posting for general employee review as a means of result communication. Copies of sampling result notice forms should be placed in an employee's personnel record, medical record, a separate sampling result file or a data base system. Exposure monitoring results themselves should never be discarded regardless of the source.

As earlier noted, when communicating dust sampling results to impacted workers, it is important that these results be placed in proper perspective. Workers recognize the variability of most work environments and their individual duties. The concept of how representative a single sampling result may or may not be to day-to-day exposures over weeks, months and years is often an easy concept for workers to grasp. This also promotes acceptance of periodic monitoring.

An understanding of the significance of sampling results is best achieved through periodic employee training. Although appropriate precautionary statements on a worker's notice form should appear, they are generally not sufficient to achieve the desired level of understanding.

All sample result notices should reflect what actions (if any) will be taken as a result of the sampling results. Sample results and proposed corrective measures (when needed) should be shared with all workers who have the same or similar exposures.

Establish Dust Controls When Sampling Indicates the Need

Inadequate dust control may be indicated when elevated dust levels are recorded during workplace dust sampling. In addition, if adverse pulmonary effects are observed during routine medical surveillance from exposure to respirable crystalline silica, this is an indication that past dust controls may not have been adequate. Although a detailed discussion of dust control is beyond the scope of this guide, Section 3 provides a general overview of commonly applied dust controls in approximate order of desirability.

Determine Need, Frequency and Type of Re-Sampling

While initial dust sampling is used to identify jobs, areas and equipment that may need dust control attention, in most work environments initial dust sampling is rarely sufficient to reliably reflect actual long-term worker exposure. To compensate for variation in dust levels, re-sampling (typically on some routine basis) is most always required. Re-sampling is conducted for a variety of reasons, such as gauging the efficiency of dust controls when introduced or modified, documenting the effect of process changes, and as a means to more reliably document worker exposure over time. Only periodic monitoring can accomplish these objectives. Information collected during periodic sampling becomes more meaningful as a database of sampling results develops.

Throughout this guide, the variability of workplace dust exposure has been stressed. Exposure variability is influenced by the amount, particle size and rate of any dust generated from the material being handled. Differing air currents, employee work practices, housekeeping, leaks and spills, temperature and humidity fluctuations, work area configuration, and processing equipment most influence this variation. Variations must be addressed (compensated for) in order to reliably describe actual, day-to-day crystalline silica dust exposure to workers.

Until exposure results for each job are consistently found to be within established limits, worker protection is less assured. While air sampling by a regulatory inspector typically occurs over a single work shift, it may not adequately quantify long-term worker exposure. Generally speaking, a structured sampling program should be established and maintained until enough samples are obtained to reasonably confirm the range of exposure for a given job. This range or "**job exposure profile"** must be representative or typical of that job.

Because the variability of exposures are unique to each workplace, there is no single, "one size fits all" re-sampling strategy. However, there are sampling strategies that reflect generally accepted good practice approaches. Finding an appropriate re-sampling strategy for each workplace and establishing a job exposure profile is rarely a simple task.

Re-Sampling Statistical Considerations

Several basic statistical tools are often applied to determine the need and frequency of re-sampling. To use any of these statistical tools, multiple work shift samples need to be collected. Statistics can be used to quantify the exposure and the variability of the measurements. Depending upon the level of analysis desired, these statistical tools can be complex or simple. The following discussion will address only the most fundamental statistical concepts the reader should consider when establishing a re-sampling strategy.

Two basic statistical considerations are commonly applied when determining the need and frequency of re-sampling. The first is a measure of ***central tendency*** and the second is a measure of ***variability.***

Central tendency: The term, "central tendency", means that in any set of numbers or data points (such as a set of respirable crystalline silica dust sampling results, as shown below) we can observe the following: the data points which appear most frequently (***mode)***, the data point that is larger than or equal to half of the other data points ***(median)***, and the arithmetic average of all the data points ***(mean)***. These concepts are illustrated in the following set of six full shift respirable crystalline silica dust sampling results:

$$\text{mg/m}^3 \text{ Results: } \frac{0.124 + \mathbf{0.234} + \mathbf{0.245} + 0.254 + \mathbf{0.234} + 0.351}{6} = \mathbf{0.240}$$

In this example: The ***mode*** is 0.234, the ***median*** is 0.245, the ***mean*** (average) is 0.240 and 6 is the number of full shift sample results (statistically described as "n").

Note that each measure of central tendency is different (though two can have the same value).

When we are addressing dust sampling results, each of these measures of central tendency can be compared to an occupational exposure limit (mandatory or recommended). These measures of central tendency generally provide a more reliable indication of routine exposure than does a single data point for a single work shift.

Depending on the purpose, each of these central tendency measures may have a different value to the user. If a store owner, for example, wished to know what price his/her competitors are typically charging for a sales item he/she wishes to sell, the store owner might be most interested in the mode (the most frequent price charged). In industrial hygiene sampling, it is generally agreed that the mean (arithmetic average) is the most useful measure when making comparisons to an occupational exposure limit or as a way to more reliably compare one set of sampling results to another set.

The more the mean (arithmetic average) exceeds an occupational exposure limit, the more the need exists for dust controls and subsequent re-sampling to evaluate the effectiveness of the controls. Also, the closer this average is to exceeding the limit applied, the more important re-sampling often is to better identify exposure variability. Thus, we will want to know if more sample results yield a higher or lower average as a way to determine if the original average included enough samples (data points) to be a true average (closer to actual routine exposure).

It is important to note that some regulatory requirements (e.g., MSHA rules for metal and nonmetal mining – 30 CFR 56/57.5001) consider a single shift weighted average (SWA) sample result that exceeds the permissible exposure limit as a violation of a mandatory health and safety standard. The mean (average) of a series of sampling results is ***not*** considered for compliance purposes. Still, the more samples averaged for each job exposure profile, the more reliable it is as an indicator of the chronic long-term exposure risk for that job. And, as noted above, averages consistently below an established occupational limit reliably indicate compliance on any given day.

Variability: This brings us to another statistical consideration, measures of variability. Measures of central tendency do not adequately address variability. As illustrated

below, two sets of sampling results may have the same mean (arithmetic average), but one set may vary dramatically from the other.

Sampling results **SET 1** (mg/m^3)		Sampling results **SET 2** (mg/m^3)	
0.124		0.002	
0.234		0.005	
0.245		0.020	
0.254		0.178	
0.351		1.003	
1.208 / 5	= 0.242 average (mean)	1.208 / 5	= 0.242 average (mean)

If the lowest exposure data point is contrasted to the highest in each of the example sets, the variability in the sets is seen to be much different even though the arithmetic mean is the same. That comparison can be obtained by simply subtracting the lowest exposure from the highest exposure. This is known as the ***"range"***. Using the above sampling result sets, this is expressed as follows:

SET 1	**SET 2**
0.351 – 0.124 = **0.227** (range)	1.003 – 0.002 = **1.001** (range)

The much higher variation in SET 2 is now apparent (approximately 5 times greater). However, this simple measure of difference does not take into consideration the variability of all the sample results (data points) in each set because only the highest and lowest data points were considered. To address this deficiency, a more commonly applied measure of variability known as the "**standard deviation*"*** is used. This calculation requires more effort and like any measure of variability also requires one set of at least two sample results.

The standard deviation is defined as the square root of the sum of the squared differences from the mean divided by the number of data points (samples taken) minus 1. Another commonly applied measure of variability in industrial hygiene monitoring utilizing the standard deviation is the **"coefficient of variation"**. *The coefficient of variation is the ratio of the standard deviation to the mean expressed as a percentage (obtained by dividing the standard deviation by the mean and multiplying the result by 100).* **(2-11)**

Applied to the two dust sampling set distribution examples (above), the standard deviation and coefficient of variation calculated for each set would be obtained as follows*:*

Sample Results SET 1 (mg/m^3):

Sample Results	Average (mean)	Difference from Average	Squares of Differences
0.124	0.242	- 0.118	0.01392
0.234	0.242	- 0.008	0.00006
0.245	0.242	0.003	0.00001
0.254	0.242	0.012	0.00014
0.351	0.242	0.109	0.0118
			0.02601 (sum)

Standard Deviation: = **0.0806**

sum of sq. differences (0.02601) divided by # of samples minus 1 (4) then sq. root of this result

Coefficient of Variation: = **33.3%**

Standard deviation (0.0806) divided by the mean (0.242) then multiply this result by 100

Sample Results SET 2 (mg/m3):

Sample Results	Average (mean)	Difference from Average	Square of Differences
0.002	0.242	- 0.240	0.05760
0.005	0.242	- 0.237	0.05616
0.020	0.242	- 0.222	0.04928
0.178	0.242	- 0.064	0.00409
1.003	0.242	0.761	0.87235
			1.03948 (sum)

Standard Deviation: = **0.5098**

sum of sq. differences (1.03948) divided by # of samples minus 1 (4) then sq. root of this result

Coefficient of Variation: = **210.7%**

Standard deviation (0.5098) divided by the mean (0.242) then multiply this result by 100

The important concept to remember is that the variance of different data sets can be compared in a numerical way (i.e., the standard deviation and coefficient of variation of SET 2 above is approximately 6.3 times greater than that of SET 1). The statistical expression of variability itself might also be used to prompt action in a particular application. In regard to crystalline silica sampling results, a standard deviation greater than 0.1 might be set, for example, as a bench mark tool to prompt more frequent sampling, especially if the mean or arithmetic average is also just below the occupational exposure limit selected.

In terms of measures of central tendency and variation, re-sampling is influenced by the following factors:

- The fewer samples used to establish an average (mean), the more sampling is generally indicated.
- The higher the variability (e.g., standard deviation) in a set of dust sample results, the more sampling is indicated.
- Averages (means) based upon sparse sample results that also show wide variation (see above) are most subject to re-sampling.
- Average sampling results that show little variability and routinely fall well below an established occupational exposure limit require little re-sampling (unless work area changes likely to increase dust exposure occur).

The calculation of these statistical measures can be cumbersome (especially measures of variability), but many calculators and computerized spread sheets are preprogrammed to calculate them. More complex statistical tools are available to better test the reliability of sampling results but are beyond the scope of this guide. A statistician or knowledgeable industrial hygienist should be consulted. Perhaps the most complete review of sampling strategies and statistical tools can be found in an informative NIOSH manual entitled "Occupational Exposure Sampling Strategy Manual" (previously mentioned). A copy of this manual can be found at: http://www.cdc.gov/niosh/docs/77-173/ (**2-1**). Further guidance on statistical applications is available as well (**2-9, 2-10, 2-11**).

It is important to remember (and a regulatory requirement) that when changes in the work environment impact dust emissions, re-sampling must be conducted to establish the resultant exposure (greater, lesser or the same) for a particular job. At least two sampling results below an established occupational exposure limit are typically required to confirm that the change in the work environment has not presented an excessive exposure.

Re-Sampling Strategies: An Example (illustrative)

Using the basic principles and statistical tools discussed above, effective re-sampling strategies can be designed. The following ***is merely one hypothetical example*** of how the concepts and tools described above might be used to establish an in-house re-sampling strategy to address different exposure circumstances. Such a guide involves good practice considerations, so care should be taken to ensure such strategies do not conflict with any applicable regulatory standard.

- Conduct re-sampling once every 12 months for a job exposure profile if: no prior full shift sample exceeds an established occupational exposure limit and the mean (average) of samples for the job exposure profile is less than 50% of that limit and there are no operational, engineering, or administrative changes likely to increase dust exposure. If at least 4 samples have been obtained (or any other specified number) and the standard deviation of the dust sampling results falls

below 0.1, re-sampling may be extended to once every 18 months (or other specified frequency) unless a change likely to increase dust levels occurs.

- Conduct re-sampling once every 6 months for a job exposure profile if: a single full shift sample has exceeded an established occupational exposure limit and been abated and the mean (average) of samples for the job exposure profile is between 50% - 100% of that limit and there are no operational, engineering, or administrative changes likely to increase or decrease dust exposure. If the standard deviation of prior dust sampling results falls below 0.2, re-sampling may be extended to once every 12 months (unless a change likely to increase dust level occurs). Re-sampling should be conducted if any full shift exposure measurement exceeds the exposure limit after engineering, operational, or administrative process change has been instituted. *When an excessive dust exposure is determined, additional dust controls must be implemented in a timely manner until subsequent sampling shows the exposure is within acceptable limits.* At least two consecutive sample results confirming the effectiveness of dust controls to reduce exposure below an acceptable limit must be obtained before any other re-sampling strategy is adopted. Until an acceptable reduction can be achieved, an effective respiratory protection program must be applied.

It is wise to establish some structured periodic re-sampling plan consistent with the above considerations, unless an occupational health professional familiar with respirable crystalline silica dust monitoring and control is retained to provide advice on re-sampling.

Industrial Hygiene Assistance

Many industrial facilities with crystalline silica exposures may not feel comfortable conducting their own respirable crystalline silica sampling and/or may not wish to purchase the equipment necessary to properly sample. In these cases, assistance is available that can provide advice, conduct air sampling for you, and provide rental equipment. Common assistance sources are listed below.

Insurance Companies

Most industrial facilities are covered under some form of workers' compensation (WC) insurance. Most WC insurance carriers have industrial hygienists on staff (or on contract retainer) who can provide air monitoring services or assist in your own monitoring program. Some insurance carriers maintain AIHA-certified laboratories and can rent or loan air-sampling equipment. Some insurance brokers who retain insurance coverage for companies may have similar resources. Industrial hygiene services obtained through the insurance industry are often covered under a premium "service" charge and require no extra fees or charges. The availability of these services should be checked through your WC insurance carrier or insurance agent.

American Industrial Hygiene Association (AIHA)

The AIHA periodically publishes a list of industrial hygiene consultants as well as accredited laboratories. This list may be obtained from the AIHA web site: www.aiha.org

Regulatory Agencies

Regulatory agencies such as MSHA and OSHA do not provide contract industrial hygiene services, but will provide guidance if asked. Manuals, training aids and guides (such as this guide) are also available through these agencies and can be found through their websites www.msha.gov www.osha.gov and MSHA reference (**2-12**).

Trade Associations

A number of industry trade associations have staff safety and health personnel, safety and health committees and member company resources available to provide industrial hygiene guidance if you are a member. If you are a member of a trade association, you can contact your association for assistance in this area. The Industrial Minerals Association – North America can be reached at www.ima-na.org

Section 3 – Dust Control Methods

The elimination or control of hazards such as respirable crystalline silica is the primary reason for developing an occupational health program and for learning how to sample for these hazards. There would be little point to dust sampling if the results of that effort did not prompt necessary controls.

Dust controls encompass any device, equipment or procedure that, in some way, reduce or eliminate a hazardous crystalline silica exposure. Every work environment is unique so the most effective controls (singularly and combined) are often those designed specifically for the space, machinery, process flow, work schedule and other variables that differ from one work environment to the next. Though controls will vary, effective controls do share the following characteristics:

- The control adequately protects the worker from the hazard – that is, the hazard must no longer pose a health threat.
- With the control in place, workers are able to work in relative comfort.
- All workers who are potentially exposed to the hazard are protected.
- The control itself does not create a hazard.

Control Points

Workplace hazard controls are always applied to specific points associated with the hazard. Very basically, these points include the **source** and **path** of the exposure as well as the **exposed worker**. Dust is generated from sources such as drills, sanders, shakers, blasting, crushing, packing, sweeping, etc. The list is very long. Once the dust is released into the work environment, this environment becomes the path that conveys the dust to the worker. These three points can be viewed as the primary points at which controls can be applied either singularly or in a combined fashion (see Figure 3-1).

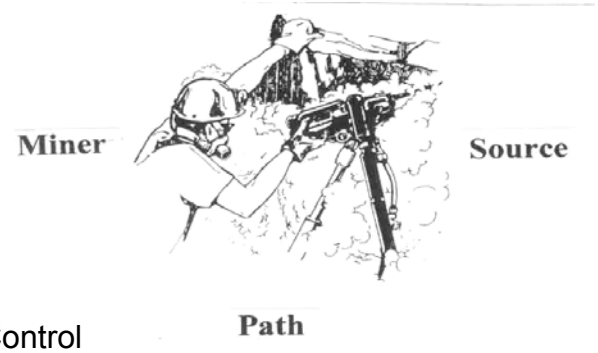


Figure 3-1 Points of Control

Source: U.S. Department of Labor, Mine Safety and Health Administration, National Mine Health and Safety Academy. Industrial Hygiene: Sampling for Silica and Noise. Metal and Nonmetal Specialized Training-Student Text Material. IG 13a. 1999. Page T-58.

Hierarchy of Controls

Occupational health professionals often refer to a "hierarchy" of controls. In its basic form, this hierarchy (in order of desirability) is described as engineering controls, administrative controls and personal protective equipment (PPE). For the purpose of this guide, a more detailed list of controls keyed to this hierarchy is listed below.

- ***Substitution*** to non-toxic or less hazardous materials when possible.
- ***Engineering controls*** such as isolation, equipment redesign or replacement to reduce or avoid generation of dust at the source or path.
- ***Ventilation*** to eliminate or reduce dust in the pathway (an engineering control highlighted here to emphasize its importance).
- ***Work practices*** that reduce the generation of dust at the source.
- ***Good housekeeping*** practices that reduce accumulation of settled dust that may later lead to resuspension of this dust into the workplace air.
- ***Administrative controls*** designed to reduce individual exposure time.
- ***Personal protective equipment*** (PPE) for the worker in the form of respiratory protection - as a last resort.

Each of these will be discussed in more detail below. Additional discussion on specific mining dust control techniques can be found at the following websites:

http://www.cdc.gov/niosh/mining/topics/topicpage3.htm

http://www.cdc.gov/niosh/mining/pubs/programareapubs9.htm

Substitution

The logic of using the least hazardous material to accomplish a job or produce a product cannot be disputed. As a first step in the control of crystalline silica exposure, substitution to a non-toxic or less hazardous material *when feasible* should always be considered. Feasibility, however, includes such important considerations as risk level, product functionality, quality, and cost.

In many work environments like mining and construction, crystalline silica is an inherent, unavoidable potential exposure because crystalline silica is a common and integral part of the earth's crust. As described above, crystalline silica has many important and beneficial applications in our society as well. In many (if not most) of these applications, there are no known substitutes (e.g., the manufacture of glass).

When substitution (or avoidance in the case of many mining or construction activities) is not feasible, it is important to remember that the risks associated with crystalline silica exposure (as well as other much greater risks) are managed safely each day in our society.

Perhaps the best example of substitution in regard to respirable crystalline silica is the radically decreased use of silica sand as a blasting agent to clean surfaces (most commonly applied in metal corrosion control). Propelling large amounts of silica sand at high velocity against a solid object produces copious, freshly broken fine respirable crystalline silica particles. Switching to a lower risk abrasive material (e.g., steel shot, walnut hulls, etc.) for this application is an example of a substitution that was prompted by an exceptionally high risk (i.e., acute silicosis).

Engineering Controls

One commonly employed and effective means of dust control involves changes in material handling, process equipment and/or isolation of the worker or dust emissions that eliminate or reduce worker dust exposure. Such changes are referred to as engineering controls and cover a broad range of dust reduction opportunities. *The most commonly applied engineering control for dust, ventilation, is covered separately in the next section*. The diversity of some commonly applied engineering controls is reflected below:

- Automation of dust generating processes such as crushing, bagging, mixing, milling, sifting, bag stacking, bulk loading, etc. so that these processes can be isolated (walled or partitioned off) or workers themselves can be isolated from the dust inside a closed control room or booth and view processes on a video screen.

Figure 3-2 Control Booth

Source: Courtesy Unimin Corp.

- The redesign, maintenance or additions to process equipment that eliminates or reduces dust escape at the source. Examples include closure and leak prevention of mineral conveying systems and the use of equipment that reduces dust emission through slower operating speeds, less vibration, secondary containment (container within a container), lower operating pressures, the use of

positive or negative air pressure to hold dust in systems and basic design configurations that restrict dust generation.

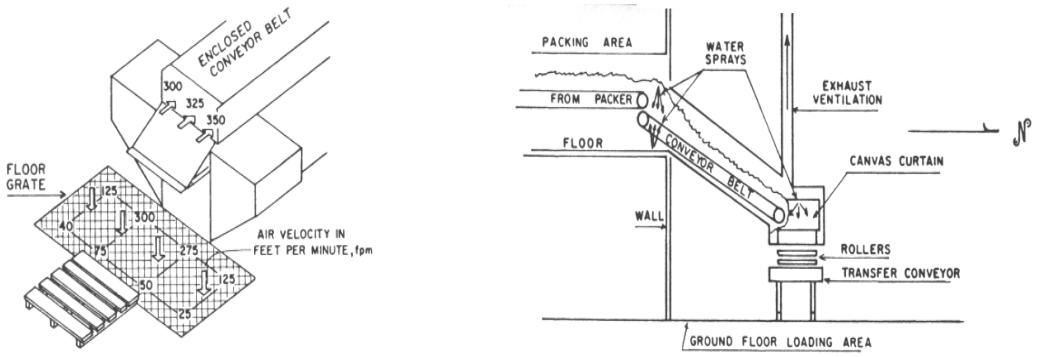


Figure 3-3 Examples of Engineering Controls

Source: NIOSH research report "Health Hazard Control Technology Assessment of the Silica Flour Milling Industry". U.S. Department of Health and Human Services, Cincinnati, Ohio (Oct. 1984) DNNH (NIOSH) Pub. # 84-110.

- The use of water mist or fog sprays to suppress dust from open sources such as crushers, screens, drills, open material conveyers and roadways.

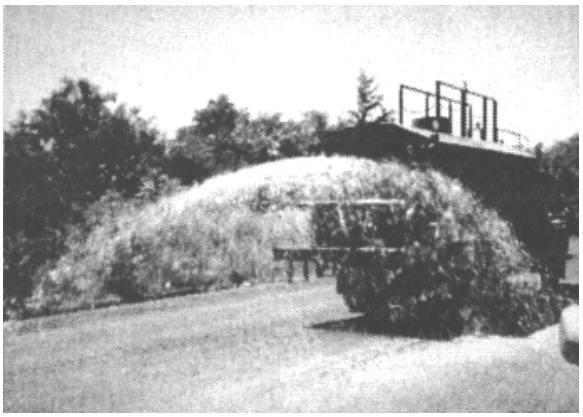


Figure 3-4 Water Truck Control of Road Dust

Source: U.S. Department of Labor, Mine Safety and Health Administration, National Mine Health and Safety Academy. Industrial Hygiene: Sampling for Silica and Noise. Metal and Nonmetal Specialized Training-Student Text Material. IG 13a. 1999. Page T-59.

- Tarps or other physical barriers over other open sources such as loaded dump trucks and dry ore piles subject to wind disturbance.

- Cabs on mining machinery equipped with environmental controls and filtration.

Figure 3-5 Environmental Cab

Source: MSHA inspections archives file.

- Combination controls specific to a process system. An excellent example would be a mineral bag filling process in which effective dust control is linked to a series of considerations which would include the following: how efficiently the bag releases air as it fills (bag type and particle size consideration), the speed of fill (fill pressure), nozzle seal (nozzle configuration, bag connection configuration), bag weight release settings (when used), design of the bag filling station to optimize ventilation applications, positioning of the worker, ergonomics, etc.

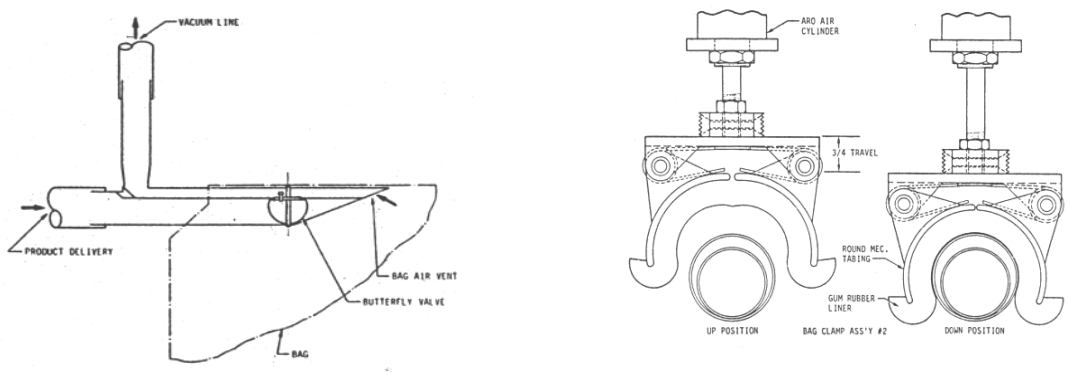


Figure 3-6 Engineering Controls, Bag Fill Nozzles

Source: Bureau of Mines "Bag Machine Dust Controls and Bag Sealing". U.S. Department of the Interior. A mining research contract report (May 1985) PB 86-153558 (BuMines OFR 8-86).

Increasingly, equipment manufacturers are paying attention to worker safety and health in the design of their equipment (i.e., less generation of noise, dust, vibration and improved ergonomics). Older equipment and long-established practices, however, remain an engineering challenge. With a commitment to reduce dust and the application of common sense, the ability to engineer out or dramatically reduce many dust emissions is possible.

One final example demonstrates well how one engineering dust reduction solution may have a significant impact on a long-standing exposure problem.

- Workers in the dusty trades are familiar with the problem of soiled clothing. Many workers feel the most effective way to clean dust-laden clothing is to blow the dust off with pressurized air. Unfortunately, while efficient, this cleaning technique releases a cloud of dust directly into the worker's breathing zone and poses additional safety concerns (e.g., eye injury). Federal regulations prohibit use of compressed air for this purpose. Clothing is expected to be cleaned by vacuuming which is time-consuming and not always particularly effective.

- To address this problem, a team composed of government and industry representatives developed a clothes' cleaning booth that utilizes a series of fixed compressed air nozzles. Workers wearing a respirator and with dust-laden clothing can enter this booth and in seconds, have their clothing blown clean. The booth contains and removes dust blown from the clothing efficiently through a dedicated, down draft ventilation system. Use of this device has been approved by MSHA and details can be found at the following website:

  http://www.cdc.gov/niosh/mining/products/product21.htm

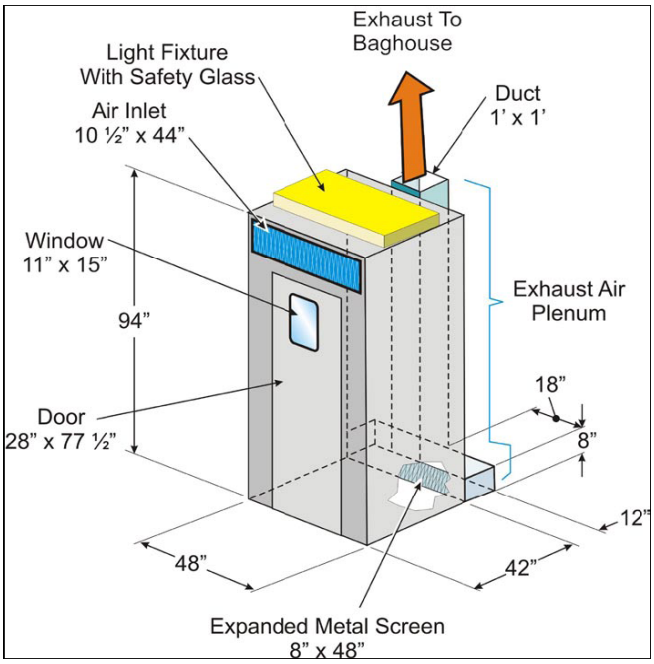


Figure 3-7 Clothes Cleaning Booth

Source: Clothes Cleaning Process. NIOSH Instructional Materials. CDC Workplace Safety and Health. 2004.

Ventilation

Ventilation is commonly viewed as an "engineering" control, but is addressed separately here given its expansive use in dust control. Ventilation is intended to keep airborne hazards such as respirable crystalline silica from reaching the breathing zone of the worker at a hazardous concentration (e.g., above an established exposure limit). Ventilation is an example of dust control at the source of emission and pathway. There are two general types of ventilation used to control airborne dust: *General Ventilation* and *Local Exhaust Ventilation*. Additional information related to ventilation can be found at www.aiha.org , www.cdc.gov/niosh , and www.acgih.org .

General ventilation: General ventilation systems are used to dilute contaminated air by bringing uncontaminated air (or less contaminated air) into the workplace. Air conditioning systems, heating systems and open doors and open windows commonly perform this dilution function and provide a more comfortable work environment by controlling temperature and humidity. The concept of air "dilution" is most appropriately applied to gases and vapors. The role of general ventilation in dust reduction is more an issue of "displacement". Air containing more dust is replaced by air containing less dust.

In enclosed work areas where fine dust remains suspended in the air for extended time (and potentially re-suspended after settling), periodic "dirty" to "clean" air exchanges have been advanced as a dust control approach when properly applied (**3-1**). Commonly, general exhaust systems are used in conjunction with local exhaust systems (discussed next).

To control general work area dust effectively through a general ventilation system, three critical engineering considerations are cited:

1. The system must reliably supply clean makeup air (typically to the base of a work area). Air intakes that are located close to exhausts, for example, can reintroduce dust into a work area and increase, rather than diminish the exposure. When locating air inlets and exhausts, prevailing wind direction should be carefully considered for this reason.

2. The general exhaust system should provide an effective air flow pattern to ventilate an entire work space while providing a "sweeping" action in major dust generating areas within that space. The desired flow pattern is achieved by the proper positioning of both the fans that pull air from the work area and the makeup air intakes (wall louvers or other openings including doors, etc.) that supply the air.

3. The work area shell should have no or minimal air intakes or outlets other than those intended. Exhaust ventilation systems draw makeup air into a structure from the points of least resistance. If the point(s) of least resistance are open or broken windows, holes or cracks in a wall or roof, or any openings near the exhaust fan(s), the designed air flow pattern (the "sweeping" action) will be compromised and will not be effective.

Most general building exhaust involves multiple exhaust points and does not carry enough dust to fall under an environmental emissions standard. Dust collection/filtration systems (e.g., bag houses, scrubber systems, etc.) are therefore rarely required. Applicable environmental emission standards should always be checked, however, as in some instances, they may apply.

In regard to crystalline silica, the principal emission consideration is likely to be a general dust opacity limit applied by a local or state environmental agency. Opacity is merely a visual estimate of the density of dust being emitted from a facility (typically from an exhaust stack).

There are some disadvantages of exchanging air in a large workspace. For example; exchanging air in a large workspace can involve elevated costs (i.e., energy costs, the cost of air movers, air exhaust filtering systems when needed, air temperature tempering systems, etc.). Also, because general ventilation helps control general workplace airborne dust, it does not protect workers well at localized dust generation sources. It provides no effective dust control intervention between specific dust generation sources and the breathing zone of the employee exposed to that source. In addition, care must also be applied to avoid creating air currents or "dead zones" in one work area when attempting to remove air from another. This could result in a worsening of airborne dust levels in another work space.

Local exhaust ventilation: The objective of a local exhaust system is to remove the contaminant (respirable crystalline silica) as close to the generating source as possible and before the contaminant reaches the breathing zone of the worker. Local exhaust systems are most often fixed to specific dust generation or source equipment such as drills, bagging machines, material conveying systems, crushers, saws, etc. Because local exhaust systems are designed for specific emission points, they vary widely in design. However, local exhaust systems are essentially composed of the following parts:

- **A hood** or collector designed to efficiently captures the substance;
- **Ducts or hoses** to carry the substance away from the work area;
- **A fan** which moves the air through the ducts;
- **An air cleaner**, such as a filter, bag house or cyclone which removes the substance from the air before the air is released to the atmosphere.

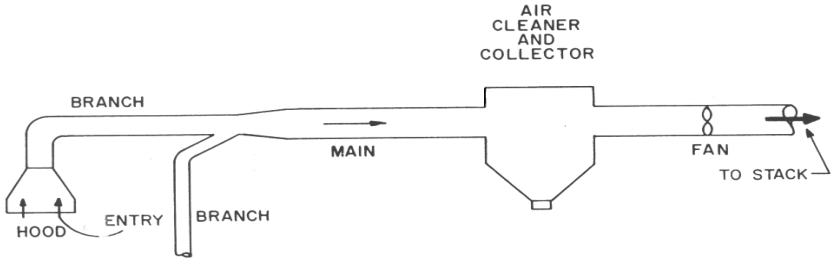


Figure 3-8 Basic Local Exhaust System

Source: R. T. Vanderbilt Company, Inc. – Work Guide Booklet

Although the basic principles of an effective local exhaust system are not theoretically complex and considerable guidance in their design and use is available, poor design and misuse is legendary. Many design and upkeep flaws can significantly hinder the effectiveness of these systems. Considerations most key to system efficiency include the following:

- The longer the ductwork, the more air resistance (friction loss) the fan or air mover must overcome.
- The more the number and the more abrupt the bends in the ductwork (e.g., > 45 degrees), the more the air resistance to be overcome.
- The rougher the surface of the duct (e.g., sheet metal versus rippled flex duct), the more air resistance to be overcome.
- The more entry points in the duct system (including leaks) the more exhaust capacity needed.
- Dust collection segments (filters, cyclones, scrubbers, etc.) present different air resistances and upkeep. Resistances from dust collection segments change over time, such as when dust accumulates on filters.
- Poor hood design or the absence of a hood.

Even when properly designed, local exhaust systems still require periodic upkeep and checking due to a variety of factors. For example, leaks in the system may develop. Crystalline silica, being extremely abrasive, can wear holes in duct work and bags. Also, fans may no longer be operating properly, dust collectors may not have been emptied on time, additional ducts and pick-up points may have been added that the system was not designed to handle, and ducts may be clogged and hoods may be broken, missing or poorly modified. In addition, work stations and equipment may have changed and new air currents may have compromised the system.

Local exhaust system checking: Practices for checking the adequacy of local ventilation systems are fully described in other texts (**3-2**). In general, many of the efficiency considerations listed above, in addition to general dust accumulation around exhaust pick-up points, can be visually observed (a qualitative assessment).

Beyond visual inspection, local exhaust systems can also be quantitatively tested. Air flow velocity at the hood or pick-up point, known as the ***capture velocity***, can be checked by a number of air velocity measurement devices (e.g., rotating and swing vane anemometers, heated thermocouple anemometers). Flow readings can then be checked against recommended minimum standards for the contaminant of interest. Recommended capture velocities depend upon the nature of the contaminant. These would include the form of the contaminant, (e.g., mist, dust, fume), as well as its size and weight. The velocity at which the contaminant is released (e.g., high, medium, or low) must also be taken into account in determining appropriate capture velocity.

If the capture velocity of a local exhaust system is very poor, little if any of the contaminant may be drawn into the system. It might be argued then that the entire local exhaust system is useless.

Once a contaminant is in a system, air velocity through the system must be sufficient to carry the contaminant to the dust collector (if one is used). This velocity is known as the ***transport velocity***. Once again, recommended air velocity standards for different contaminants exist as are ways to measure this velocity. **Appendix H** contains a listing of recommended minimum capture and transport air velocities for assorted contaminants generated in the workplace.

A common capture velocity recommended for respirable crystalline silica, generated at relatively low velocity in moderately still air, ranges between 100 and 200 feet per minute (fpm). Once in the system, a transport velocity of between 3000 to 4000 fpm is commonly needed (depending on particle size) (3-2).

Perhaps the most practical and widely used means of routine system checking is the use of a fixed system monitor typically located on each critical hood showing pressure within the system (i.e., the static pressure plus the velocity pressure expressed in inches of water displacement). When a system is working in accordance with design and controlling exposure, that effective operating pressure can be identified and routinely checked on a gauge.

The most common and best known of these gauges is the magnehelic gauge. Though this gauge needs periodic calibration, is small, vibration-resistant, and easy to read, it is not as accurate as some other means of measuring internal system pressure. But it can generally provide an acceptable indication of system performance. When it is regularly checked and reported to an engineer familiar with the acceptable operating range, it is an extremely effective means to monitor system performance adequacy.

Local exhaust system design: To design an effective local exhaust system requires considerable training. Although a discussion of design is well beyond the scope of this guide, a few general observations can be made.

It is essential to understand what the system is being designed to control. Key parameters such as capture and transport velocity should be recognized design objectives. In effect, the sum of all frictional and dynamic losses in the system (includes resistances from collection devices and the exhaust stack) should not preclude adequate capture velocity at the most distal collection hood. System features that minimize these losses (e.g., fewer and less severe duct bends, shorter duct runs, fewer branches, good hood design, etc.) are key system design considerations.

An alternative ventilation approach: While the principal ventilation control systems involve general and local ventilation, an additional ventilation approach does exist.

A local exhaust system has been designed specifically for the control of crystalline silica that moves only the finest particles through the system to a dust collector or filter. This design reduces energy and repair costs (less abrasion in the system), bag house change out and better controls loss of product. The system is referred to as a *low velocity containment system*. This design can be found at the following web site:

http://www.ima-na.org/about_ima_na/documents/Unimin2.doc

The low velocity containment system provides adequate capture velocity through differently sized orifices at dust pick-up points (the smaller the hole, the higher the velocity). Once in the system, however, only the fine dust particles are carried to a dust collector. The lower air velocity in the duct system is achieved through the use of much larger than normal diameter ducts. This larger duct work is also pitched in steep inclines (saw tooth) so that larger particles drop out more easily to collection pots for possible reprocessing. A larger initial cost and more space are the principal disadvantages (see **Appendix I** for additional detail).

Recommendations: Though the basics of ventilation may not be complex, the problem points are numerous and more often than not, interconnected. For this reason, it is strongly recommended that professionals knowledgeable in the design, installation and monitoring of local exhaust systems be consulted when a new system is contemplated or an existing system needs evaluation and/or modification. Typically these professionals include ventilation engineers and certified industrial hygienists specializing in ventilation.

In work environments in which general and local ventilation are principally relied upon to control exposures to respirable crystalline silica (or other elevated risk contaminants), appropriate in-house engineering personnel should be trained specifically in this area. NIOSH and the AIHA periodically offer courses on industrial ventilation design, problem recognition and problem correction. The following websites can be consulted: www.cdc.gov/niosh/training and http://www.aiha.org/Content/CE/ce.htm

Work Practices

In every workplace, examples can be found of employees who work more safely than others. Workers who perform the same crystalline silica linked jobs, for example, may generate significantly different levels of airborne dust due to different work practices.

One worker may lean closer to bags (s)he is filling than another or pull bags away from a filling nozzle faster than another. One worker may spray the floor with water before sweeping or use a vacuum system to clean dust while another may not. One worker may choose to clean his/her clothing more frequently, or make it a practice to stand upwind of visible dust while another may not. One worker may use controls such as ventilation more effectively than another or make adjustments to dust generating equipment more frequently or more effectively than another. The list of possible differences in dust-linked work practices is dependent upon the work environment. In some cases, work practices can influence a worker's dust exposure as much or more than the presence or absence of engineering controls.

In the discussion on respirable crystalline silica sampling, the importance of job observation was stressed. When personal air sampling results for workers with the same or similar jobs differ significantly, work practice is often the root cause. The sample result will not tell us about those practices, observation will.

Work practices that decrease exposure to respirable crystalline silica should be encouraged. The correction of work practices that increase exposure to respirable crystalline silica obviously begins with recognition of those practices followed by effective intervention to change those practices or behaviors. Intervention most typically involves training and increased supervision. In some instances, intervention may mean switching workers to less hazardous jobs.

Housekeeping

Many occupational health and safety professionals consider poor housekeeping in the work environment to be a tell-tale sign of more significant health and safety problems. Above average worker injury experience in these workplaces more often then not, bears this out.

In regard to respirable crystalline silica, poor housekeeping practices that allow excessive build-up of crystalline silica-containing dust on work surfaces, floors, beams, and equipment pose a distinct health threat through the re-suspension of this dust back into the air. “Settled” dust on vibrating equipment, dust on floors that is disturbed by foot traffic or the wheels of a lift truck are examples of this.

The finer, respirable particles will most often be the particles most easily re-suspended. These finer, respirable particles will also remain suspended in the air longer (hours in some cases) than larger, heavier particles. As the workday progresses (unless removed by general ventilation), the airborne concentration of re-suspended fine particulate will increase.

Keeping dust generation contained at the source is the best way to protect against excessive dust build-up in the workplace. Short of that, frequent cleaning is the next best defense. Unfortunately, it is difficult to clean settled dust without re-suspending some dust into the air in the process. Frequent cleaning is also time-consuming, labor intensive, and not directly linked to the manufacture of product.

When cleaning, dry sweeping and blowing dust are not recommended. Such practices can, however, be accomplished safely if strictly enforced precautions are taken. These precautions may include conducting the cleaning during shut down periods and only by employees protected by proper respiratory protection.

Cleaning surfaces through the use of a vacuum is recommended, as is the use of water sprays, to reduce dust re-suspension into the air when cleaning, during foot traffic, or during lift truck use in a building. Care should be taken to avoid creating slipping hazards when using wet cleaning methods.

Housekeeping considerations may also include the avoidance of placing/storing materials or equipment in locations that diminish dust control. An example would be the storage of materials in front of ventilation exhausts or air intake vents. Additional information can be found at: http://www.cdc.gov/niosh/mining/topics/topicpage3.htm (see Information Circular/2003 IC 9465).

Administrative Controls

Administrative controls most commonly involve a reduction in a worker's exposure time. Since respirable crystalline silica risk involves the time and intensity of the exposure, control is accomplished by adjusting the exposure time versus the intensity of the exposure. This is most often accomplished by rotating workers in and out of a respirable crystalline silica exposed job throughout the workday to reduce the exposure time of any one worker.

Less direct contact time at a dust generating source can also be achieved through the use of cabs and control booths, video cameras to monitor processes or the automation of processing equipment that reduces worker exposure time. These examples can also be viewed as engineering controls and are more desirable solutions than worker rotation. Rotation can be disruptive and does not diminish the intensity of the exposure for other area workers. It should not be used as an alternative to other more preferable controls.

Personal Protective Equipment (Respiratory Protection)

Personal protective equipment (PPE) is a control measure of last resort and should be employed only when all other controls do not adequately protect the worker, are not feasible, or when controls are not yet in place. With respect to crystalline silica, PPE essentially means respiratory protection.

Routine, full-shift use of respiratory protection should be avoided whenever possible for a variety of reasons. Respiratory protection is typically uncomfortable to wear (especially in warm work environments) and places additional physical stress on the employee (depending on the type or respirator employed and the worker's physical condition). Like administrative controls, PPE does not remove the hazard from the workplace so respiratory protection must be selected and used properly. Using respiratory protection properly involves ongoing attention and a formalized program that is often more expensive than commonly thought. For these reasons, personal respiratory protection is at the bottom of the hierarchy of controls.

Beyond good occupational health practice, MSHA policy requires that:

"When the exposure limit is exceeded, standard 56/57.5005 mandates that operators install all feasible engineering controls to reduce a miner's exposure to the [exposure limit]. Respiratory protection is required when controls are not feasible, as well as when establishing controls, and during occasional entry into hazardous atmospheres to perform short-term [non-routine] maintenance or investigations." Refer to the MSHA Program Policy Manual Vol IV, which can be found at the following website: http://www.msha.gov/REGS/COMPLIAN/PPM/PMVOL4C.HTM#35 .

These policies set forth a number of sound occupational health principles relative to respiratory protection. Some basic elements of an effective respiratory protection program are listed below (consult with the regulatory agency having jurisdiction over your operation for applicable requirements):

- Use only NIOSH approved respiratory protection for the intended purpose (e.g., protection against respirable crystalline silica).
- Prepare and maintain Standard Operating Procedures (SOP) that address the selection, use, and upkeep of respirators, the required respiratory use areas, and activities.
- Instruct and train the respirator wearer in the proper use and upkeep of their respirators as well as their limitations.
- Issue only the proper respirator to the respirator wearer. This is usually accomplished by assigning respirators to workers for their exclusive use where possible.
- Clean and disinfect respirators as frequently as necessary.
- Store respirators in a convenient, clean and sanitary location.
- Inspect respirators routinely, before and after each use, and replace worn or deteriorated parts.
- Inspect and evaluate the formal respiratory protection program on a regular basis to determine effectiveness.
- Administer the program through one person with sufficient knowledge of respiratory protection requirements.
- Confirm periodically proper respirator fit through fit testing when factors affecting the fit are observed.
- Consider physical factors (e.g., facial characteristics), and the ability of each worker to wear a respirator and perform his/her assigned work, in the selection of a respirator.
- Determine medical clearance and review status at least annually.
- Maintain records that reflect fit testing results for each wearer and the respirator assigned or issued to each wearer.
- Determine respirator filter change-out criteria (when applicable), because each respirator has distinct limitations on its use.

MSHA's requirements for an effective respiratory protection program can be found at: http://www.msha.gov/readroom/handbook/PH06-IV-1(1)MNMHealthInspectionProc.pdf

OSHA's requirements for an effective respiratory protection program can be found at: http://www.osha.gov/SLTC/etools/respiratory/oshafiles/require.html and at http://www.osha.gov/dcsp/ote/trng-materials/respirators/faq.html

Additional discussion concerning the more important elements of an effective respiratory protection program appears below:

Written respiratory protection programs that include the above elements should be developed to ensure consistency of approach and compliance to regulatory and good practice requirements. A sample respiratory protection program can be found in **Appendix J.**

Medical clearance to ensure workers are physically able to wear respiratory protection is standard practice. Requirements for obtaining medical clearance are detailed in Section 4 (Medical Surveillance) of this guide under "Medical Assessment of the Ability to Wear a Respirator" (see pages 75-78).

Respirator selection often poses a problem for those who are not familiar with respiratory protection programs because there are so many types of respirators on the market. Respirators fall into two basic categories: ***positive pressure*** respirators are those in which air is supplied to the respirator wearer from an outside source (e.g., fan, gas cylinder, compressor) and ***negative pressure*** respirators in which the wearer must pull air through an air-purifying filter media with their own lung power. Figure 3-3 provides some idea of the diversity of respiratory protection available.

Figure 3-9: Types of Respirators

Source: Composite of NIOSH "The Industrial Environment-Its Evaluation and Control" U.S. Department of Health, Education and Welfare. U.S. Government Printing Office (1973) and 3M Occupational Health and Safety Products respirator sales brochure. 3M Company, 220-7W, 3M Center. St. Paul, MN 55144. (800-242-4630). **Note:** Some respirators pictured are outdated/upgraded. Photo intended to show diversity only.

The type of respirator selected is dependent upon the exposure. Key variables include the nature, type, and concentration of airborne contaminant (i.e., dust, mist, fume, etc.), the inherent risk of the material (i.e., high, medium, low toxicity) and the work environment in which it must be worn (i.e., confined space, low oxygen level, elevated temperature, etc.). Each respirator is ranked in accordance with how protective it is relative to these variables.

In regard to respirable crystalline silica exposure, the respirator most often recommended is a NIOSH approved half-mask ***negative pressure*** particulate cartridge or disc filter respirator (99.97 efficiency – Figure 3-10), previously known as the "HEPA" filter. Another respirator used very commonly is the disposable filtering face-piece respirator (see Figure 3-11). Although some disposable dust respirators are approved for respirable crystalline silica, they must be fit-tested and used like any other half face-piece respirator. For brief low level exposures or for use by plant visitors, disposable dust masks are generally viewed as acceptable.

Figure 3-10 Half-mask negative pressure respirator

Figure 3-11 N95 filtering face-piece respirator (disposable)

Sources: 3M Occupational Health and Safety Products respirator sales brochure. 3M Company, 220-7W, 3M Center. St. Paul, MN 55144. (800-242-4630).

Fit testing for negative pressure respirators is mandated by both regulation and good occupational health practice. It is essential that the respirator form a tight seal against the face, or the protective function of the respirator is significantly compromised. Several types of respirators should be made available from which employees may choose to aid in comfort, fit, and acceptance.

Fit testing can be conducted ***qualitatively*** in which the respirator wearer reports detection of an odorous test material directed at the respirator (i.e., banana oil or Bitrex ^{TM} aerosol) or ***quantitatively*** in which fit is measured with an instrument. Fit testing is required when a worker is first assigned a respirator and each time a new respirator is

used by that worker. To test for leak problems due to poor respirator upkeep or changes in the physical structure of the worker's face (i.e., weight loss, injury, etc.), annual fit testing (at a minimum) is recommended.

Quantitative fit testing is generally considered the desired form of testing although qualitative fit testing (especially for half-mask face pieces) is most common. Electronic quantitative fit testing devices are available which can be used to test changes in the integrity of the respirator seal through various exercises such as turning the head, speaking aloud, nodding, etc. Test data (i.e., fine particle counts outside versus inside the respirator) is electronically stored and can be printed from a computer as a permanent record of the test. **Appendix K** contains an example of a quantitative fit testing protocol and recording sheet. Figure 3-12 shows one popular quantitative respirator fit tester.

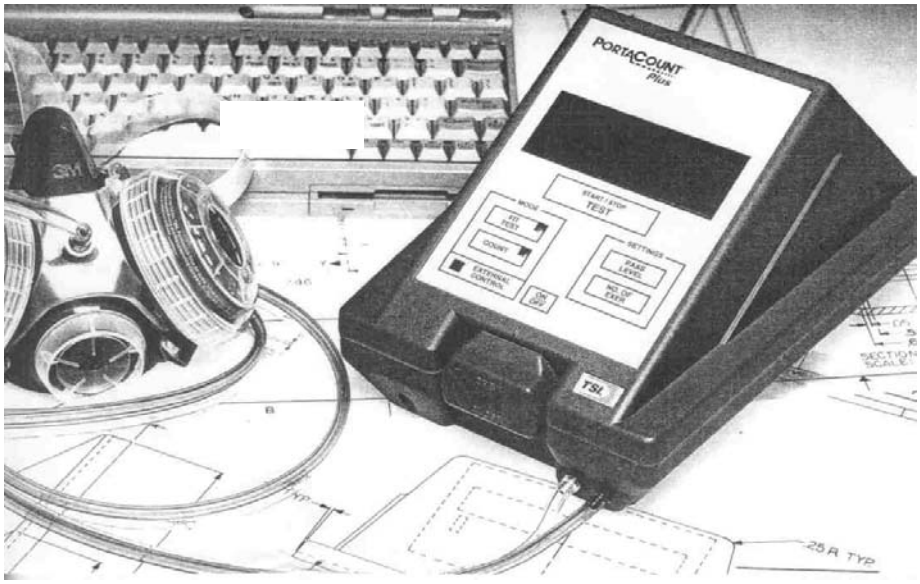


Figure 3-12 Quantitative Fit Testing Machine

Source: Operation instruction manual. FitPlus Fit Test Software-TSI Incorporated Oct. 1993 P/N 1980091 Rev. D. TSI Incorporated, 500 Cardigan Rd., Shoreview, MN 55126. (800-926-8378)

Often overlooked in negative pressure respirator fit testing is the importance of a restrictive facial hair policy. Next to facial configuration/size, facial hair is generally considered the leading cause of poor respirator fit. **Appendix K** contains a simple pictorial reference that may aid in the understanding and development of such a policy.

Positive pressure respiratory protection for respirable crystalline silica exposures is generally limited to fabric hoods or helmets that supply air to the worker by pulling or pushing it through a NIOSH approved HEPA filter via a fan or air compressor (compressor use is now generally discouraged). The filtered air is then released inside the hood or blown across the wearer's breathing zone from the top of the helmet (behind an affixed face shield). Figures 3-13 and 3-14 are examples of positive pressure respirators.

The advantage of positive pressure respiratory protection is that fit testing is not critical and facial hair typically does not pose a problem. The cost of these respirators, however, is much higher.

Sand Blasting

Figure 3-13 Abrasive Blasting Helmet

Helmet Respirator

Figure 3-14 Helmet/Loose Fitting Face Shield Respirator

Sources: 3M Occupational Health & Safety Products respirator sales brochure. 3M Company, 220-7W, 3M Center. St. Paul, MN 55144. (800-242-4630).

Employee training and recordkeeping*:* These are essential parts of an effective respiratory protection program. Those required to wear respiratory protection must understand their limitations, how to check for proper seal, when/where respiratory protection is required, proper storage and upkeep, which filter to use and when filters should be changed-out (see listed references below for details on training considerations).

Reference sources: The development of an effective respiratory protection program requires considerable time and cost. It is important that regulatory and good practice policies are in place and maintained. Additional reference sources that will assist you in the understanding, development and upkeep of an effective program to include worker training; respirator selection and fit testing are as follows:

American Industrial Hygiene Association: www.aiha.org

NIOSH: www.cdc.gov/niosh

See also; NIOSH Pub. # 2005-100, and NIOSH Pub. # 96-101, which can be accessed through the web site.

OSHA: www.osha.gov/dcsp/ote/trng-materials/respirators/respirators.html and

http://www.osha.gov/

MSHA: www.msha.gov/30cfr/56.5005.HTM

http://www.msha.gov/readroom/handbook/PH06-IV-1(1)MNMHealthInspectionProc.pdf

Section 4—Respiratory Medical Surveillance for Silicosis

Purpose

The objective of this recommended medical surveillance program is to prescribe baseline and periodic health evaluations of workers exposed to respirable crystalline silica. The guidance in this section is modeled after an official American Thoracic Society (ATS) statement, adopted in 1982 **(4-1)** and that is substantially unchanged **(4-2).**

This guidance manual section should be provided to physicians and allied health professionals who conduct medical surveillance for company employees but who may not be familiar with occupational health surveillance programs for exposure to respirable crystalline silica. For this reason, much of the information in this section is detailed. Consideration should be given to specifying appropriate standards in this section in contracts and procurement agreements with medical providers.

Medical surveillance is accomplished by performing screening examinations, which are not necessarily the same as diagnostic tests. The key distinction is that medical surveillance is performed on a worker because the worker is at risk from a specific occupational exposure, whereas a diagnostic test is performed on a patient because of a specific medical complaint or finding. Abnormal findings detected by screening examinations must be confirmed and then referred for diagnostic studies to determine their relationship to occupational exposure and their true significance.

The respiratory medical surveillance program has the following objectives:

1. To establish a baseline from which to assess changes that may develop in the individual at a future date. Thus, each worker serves as his or her own control, and the ability to recognize early change is greatly enhanced.
2. To detect abnormalities that might be consistent with silicosis in an early stage and take corrective actions (i.e., medical follow-up, exposure reduction) to possibly prevent disease progression.
3. To help to prevent the development of silicosis that could produce pulmonary impairment and irreversible pulmonary damage in the worker.
4. To disclose to the worker occupationally and non-occupationally related abnormalities for appropriate medical follow-up.
5. To help identify unrecognized potentially hazardous working conditions for which improved control measures may be needed (if unchanged over time).
6. To develop data on which future epidemiological studies of the health effects of respirable crystalline silica exposure can be based.

Respiratory Surveillance Program

A respiratory surveillance program for silicosis consists of the following components:

1. ***A medical history*** that focuses on the presence of respiratory symptoms, but also includes questions regarding personal habits such as smoking, hobbies, secondary jobs, and family history.

2. ***A comprehensive occupational history*** that details exposure to potentially harmful dusts, chemicals, and other physical agents at prior jobs. Any adverse effects related to these exposures must be recorded.

3. ***A 14-by-17-inch posteroanterior (PA) chest x-ray*****,** preferably obtained using a high-kilovoltage technique. For pneumoconioses, films should be interpreted by qualified board-certified radiologists or pulmonologists who are NIOSH-certified B readers. Films should be classified in accordance with the 2002 *Guidelines for the Use of ILO International Classification of Radiographs of Pneumoconioses* (**4-4)**.

4. ***Medical examination of the thorax as indicated.***

5. **(*Optional) pulmonary function tests*** that include spirometric measurements of forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC). Such tests should be performed, calculated, and interpreted in accordance with the most recent ATS/European Respiratory Society (ERS) standards (**4-5).**

6. **(*Optional) tuberculosis (TB) skin tests*** for new hires at the time of the baseline examination and for workers with x-ray evidence of silicosis who have not been tested. A positive skin test is evidence of tuberculin infection, but the result does not indicate whether the infective process is active or inactive. Further medical study is required to evaluate a positive test. The tuberculosis test should be an intradermal skin test using a purified protein derivative (PPD). Administering the test requires skill since the injection needle must stop between layers of the skin. In your location it may be appropriate to have the test performed by the state or local health department since medical personnel at these locations may have more experience administering the PPD test. A blood test for latent TB infection has more recently been introduced (QuantiFERON®).

Medical and Occupational History

A trained interviewer such as a physician, physician's assistant, or nurse-practitioner should compile a medical history focusing on the presence of respiratory symptoms, pre-existing conditions (e.g., asthma), and personal factors (e.g., smoking, hobbies, family history). If a trained interviewer is not available, the forms can be completed by the worker to the best of his or her ability. However, if this latter approach is used, it may be necessary to provide guidance (i.e., supplemental instructions) in non-technical terms to ensure comprehension of employees who will complete the forms. Sample

medical and occupational history forms are provided in **Appendix L-1** and **2**. The forms have been developed as guidelines for obtaining medical and work history information specific to chest and related lung disorders. The examining physician or health professional can provide suitable forms for obtaining medical and work history information on other organ systems.

As a minimum, the lung information in **Appendix L-1** should be gathered as part of the occupational health program, either by administering this portion of the examination separately or by including these items in the questionnaire used by the examining health professional. If the worker is uncertain about a response, the question should be initialed by the worker to show it was not overlooked.

A separate record detailing the subject's occupational history and potential exposures should be obtained. Such a record consists of a chronological entry of all jobs, setting forth the specific duties of the person and the nature of potential occupational exposures. The job history should contain questions regarding hobbies that might affect the respiratory system. All jobs up to the present employment—even part-time work—should be accounted for. If the employer cannot ascertain from personnel records the jobs held by a worker, then this information should be included on the occupational history form. A form for obtaining an occupational history is included as **Appendix L-2**.

Chest Radiographs (x-rays)

Radiographic changes in workers exposed to respirable crystalline silica are the most sensitive means of early detection of silicosis; that is, abnormalities are usually seen radiographically before pulmonary function loss can be detected spirometrically or before symptoms appear. Periodic chest x-rays are therefore a vital part of medical surveillance.

Chest radiography (i.e., chest x-ray) is one of the most commonly performed radiographic examinations. Through the 1990's technological improvements have generally improved radiographic quality and in more recent years digital imagining systems linked to computer programs have further improved image quality and reproducibility. However, it may still be difficult to consistently obtain high-quality radiographs in some locations.

The valid interpretation of the subtle findings of pneumoconiosis depends on a technically superior chest radiograph (**4-4, 4-6**). Radiographs should be produced using the best current techniques. Films produced under any lower standard are not acceptable. See discussion below.

Specifications: Although other x-rays may be ordered by an examining physician, a PA projection on a film no less than 14 by 17 inches and no more than 16 by 17 inches at full inspiration is essential to the program for detection of pneumoconioses (**4-6)**. The film must be exposed for a very brief duration to avoid blurring as a result of motion and must use factors adequate for optimum penetration without "graying" caused by scattered radiation. Ancillary measures, such as the use of a grid, may be necessary. A high-kilovoltage technique with a grid is the preferred method, but adequate films can in most instances be obtained by a lower voltage method.

Guidelines providing comprehensive discussion of the importance of proper equipment and technique in producing radiograms for evaluating pneumoconioses have been published (**4-1, 4-4, 4-6, 4-7, 4-8 and 4-9**)**.** Detailed specifications for chest x-rays for the NIOSH Underground Coal Miner X-ray Surveillance Program can be found in the *Code of Federal Regulations,* Title 42, Part 37, which describes factors important in obtaining high-quality x-rays at Section 37.41. These specifications should be brought to the attention of the medical facility or providers contracted to perform the x-rays and are reproduced in **Appendix M** for convenience. Questions concerning the suitability of a facility to perform x-rays and exceptions to these specifications should be brought to the attention of the radiologist or pulmonologist performing the interpretation.

Interpretations: In clinical practice, it is customary for physicians reporting radiological findings from chest films to do so in nonquantitative, narrative form. For most clinical purposes, this is satisfactory. However, when information is to be used epidemiologically or for medical surveillance purposes, the reporting must be more quantitative (**4-8**)**.**

ILO classification system: For occupational surveillance, the radiographic changes associated with pneumoconioses must be classified according to the 2000 *Guidelines for the Use of ILO International Classification of Radiographs of Pneumoconioses* (**4-4**). The interpretation must be recorded on a form, as shown in **Appendix N.** All pertinent observations must be recorded on the interpretation forms. These documents should be provided as a requirement for lung specialists engaged to interpret x-rays. See http://www.cdc.gov/niosh/topics/chestradiography/ilo.html

The ILO system is designed to classify the appearances of pneumoconioses on a PA chest radiograph. The classification system does not attempt to define specific medical diagnoses, but it is very important in recording the type and extent of radiographic changes, as well as in describing any progressive changes. It has been used extensively internationally for epidemiological research, the surveillance of those in dusty occupations, and clinical purposes (**4-4** and **4-8**).

The ILO classification system provides a means of systematically recording the radiographic abnormalities in the chest provoked by the inhalation of dusts (**4-4**). As noted in the ILO *Guidelines:*

> The object of the Classification is to codify the radiographic abnormalities of pneumoconiosis in a simple reproducible manner. The Classification does not define pathologic entities, nor take into account working capacity. The Classification does not imply legal definitions of pneumoconiosis for compensation purposes, nor set, nor imply a level at which compensation is payable.

The ILO classification system requires the codification of a chest radiograph according to its pulmonary and pleural findings and its technical quality (**4-9**). Pleural findings are not discussed in this manual because pleural changes are not considered to be associated with silica exposure but are instead regarded as a marker of exposure to fibers such as asbestos and possibly some other non crystalline silica particulates. Classification is performed by viewing a worker's x-ray, considering all affected zones of

the lung, and comparing the worker's film with a set of ILO standard radiographs. With respect to pulmonary findings, the system divides lung opacities (i.e., areas that are impervious to x-rays) into two categories, small and large, with each defined in specific quantitative terms.

Small opacities are recorded according to four characteristics—shape, size, profusion, and extent. **Figure 4-1** illustrates shape and size classification for small opacities. Two shapes are recognized—small rounded and small irregular. For each shape, opacity size is graded in three categories; for example, rounded opacities are grouped according to the approximate diameter of the predominant lesions as follows:

1. Opacities up to 1.5 millimeters in diameter.
2. Opacities > 1.5 millimeters and up to ~ 3 millimeters in diameter.
3. Opacities exceeding ~ 3 millimeters and up to ~ 10 millimeters in diameter.

Irregular opacities are classified according to the approximate width of the predominant lesions as follows:

1. Fine linear opacities up to ~ 1.5 millimeters.
2. Medium opacities >~ 1.5 millimeters and up to ~ 3 millimeters.
3. Coarse, blotchy opacities >~ 3 millimeters and up to ~ 10 millimeters.

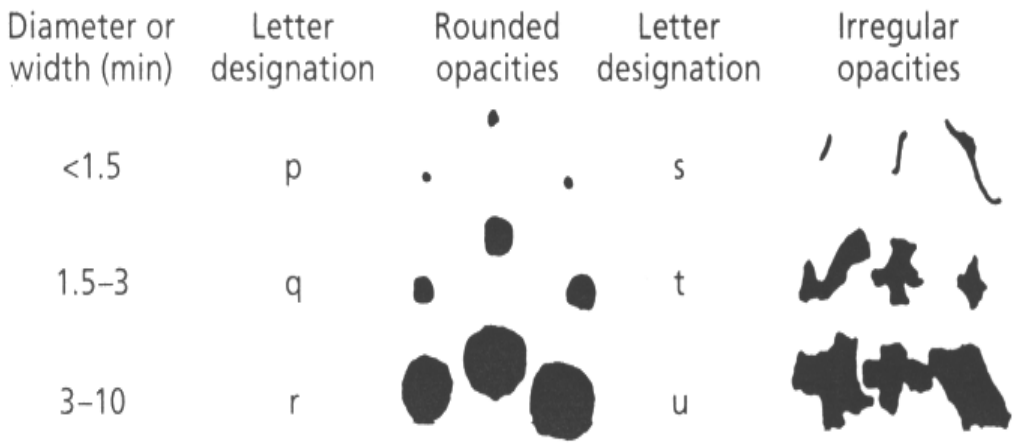


Figure 4-1 Shape and Size Classification for Rounded and Irregular Opacities

Source: NISA

Two letters (i.e., q, t) are used to record shape and size. If the reader considers that virtually all the opacities are of one shape and size, this should be noted by recording the appropriate symbol twice, separated by an oblique stroke (for example, q/q). If,

however, another, less predominant shape or size is observed, this should be recorded as the second letter (for example, q/t). Hence, q/t would mean that the predominant small opacity is round and of Size q but that significant numbers of small irregular opacities of Size t are present. Figure **4-2** illustrates recordings of shape and size classifications. In this scheme, no more than the two most prominent kinds of size and shape can be recorded.

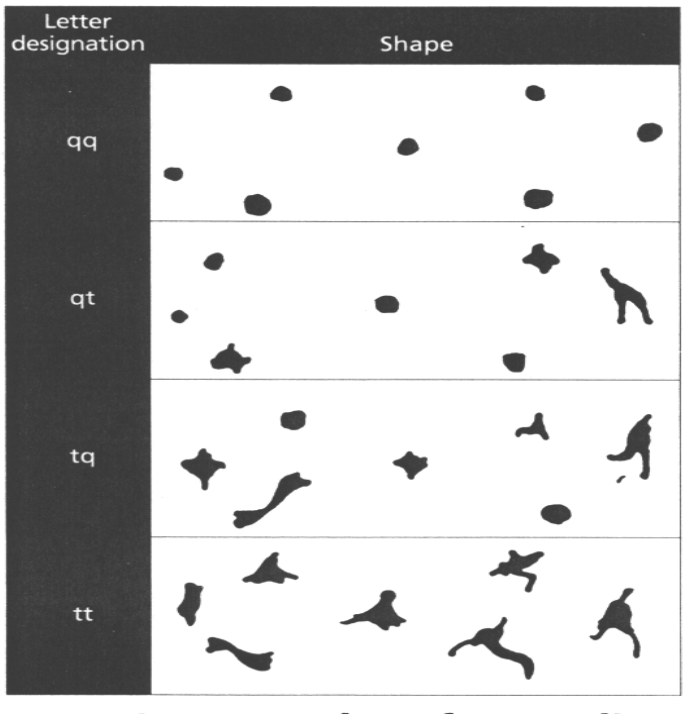


Figure 4-2 Examples of Recordings of Shape and Size Classifications

Source: NISA

The term *profusion* refers to the concentration or number of small opacities per unit observed within the lung fields. The observed opacities are compared with a series of ILO standard radiographs. The 22-film set of standard radiographs can be obtained from ILO. In early versions of the system, profusion was graded only in four major categories:

Category 0. Small opacities are absent or less profuse than in Category 1.

Categories 1, 2, and 3. Small opacities are increasingly profuse, as defined by the corresponding radiograph.

In 1968, the codification of small-opacity profusion was modified by the further division of each major category into three minor divisions to provide a 12-point scale. Figure 4-3 illustrates the scale as it relates to profusion of opacities. The current notation designating the divisions of the scale is as follows:

0/–	0/0	0/1
1/0	1/1	1/2
2/1	2/2	2/3
3/2	3/3	3/+

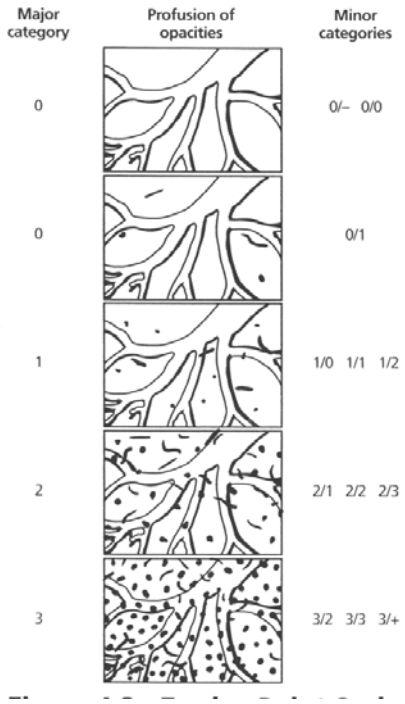


Figure 4-3 Twelve-Point Scale and Its Relationship to Profusion of Opacities

Source: NISA

The first number in each division indicates the major category to which the division belongs; the second number indicates whether the profusion level is judged to be somewhat less than, equal to, or somewhat greater than the profusion level corresponding to the major category indicated. Thus, the notation 2/1 is used to indicate a profusion level that is Category 2 but at less than the midpoint of that category.

Although the 12-point scale implies a high degree of quantification for the recording of profusion levels, the definition of the major profusion categories on which the scale is based is nonspecific. Hence, when the profusion levels of a series of radiographs are evaluated by a group of physicians, substantial differences of opinion can be expressed. To locate physicians with occupational medicine and radiological expertise, see:

www.acoem.org
www.acr.org
http://www.cdc.gov/niosh/topics/chestradiography/breader.html

The fourth characteristic of small opacities that must be recorded in the ILO classification system is the spatial distribution of pulmonary disease. To record this parameter, lung fields are divided into six zones, three on each side, corresponding to

the upper, middle, and lower thirds of the lung fields. Figure 4-4 provides an example of coding of the zones of lung involvement for small-opacity profusion. In reporting the extent of disease, the physician simply checks off the zones affected. The zones can be coded R or L for right or left lung; U, M, or L correspond to the upper, mid, or lower lung zone (RU = right upper).

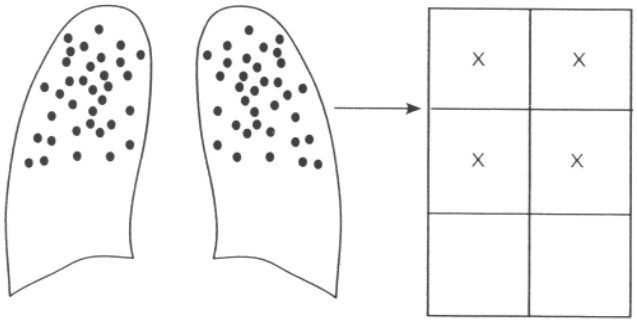


Figure 4-4 Example of Coding of Lung Zones of Involvement of Opacities

Source: NISA

Of the four characteristics of small opacities requiring codification, profusion is the most important, for it is the best indicator of the seriousness of any disease that may be present. When profusion levels vary from one portion of the lung fields to another, the category of profusion to be recorded is determined by considering the profusion as a whole, over the affected lung zones. Where there is a marked difference in profusion (three minor categories or more) among different zones, the zone or zones that show less profusion are ignored for classification purposes.

Large opacities are considered to be present when any large opacity is evident on a film in which there is sufficient evidence for a diagnosis of pneumoconiosis. The classification excludes nonpneumoconiotic large opacities due to other causes such as lung cancer. Simple silicosis is said to be present when a profusion of ***small opacities*** (1/0 to 3/+) exists, and complicated silicosis is said to occur when ***large opacities*** are present. Figure 4-5 illustrates the classification of large opacities. Most often, a background of small opacities will exist when dust-induced large opacities are present.

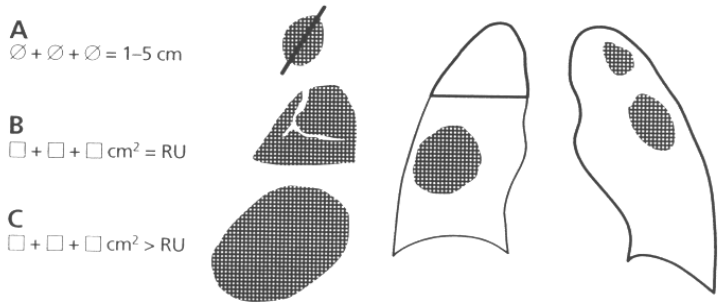


Figure 4-5 Classification of large Opacities

Source: NISA

Large opacities are codified in three categories, depending on the size of the lesions:

> ***Category A***. A single large opacity whose greatest diameter exceeds about 1 centimeter but is no more than about 5 centimeters, or several opacities, each greater than about 1 centimeter in diameter, the sum of whose diameters does not exceed about 5 centimeters.
>
> ***Category B***. One or more opacities larger or more numerous than those in Category A whose combined area does not exceed the equivalent of the right upper zone of the lung.
>
> ***Category C.*** One or more opacities whose combined area exceeds the equivalent of the right upper zone of the lung.

Narrative radiology report: Although it is not a requirement, companies may also wish to have films evaluated by a narrative method, as is customary among radiologists. It should be noted, however, that the standard ILO form (**Appendix N**) contains a blank section that may be used for narrative information as well. Use of the ILO form is encouraged in an occupational medical surveillance program.

In a narrative report, each facet of the film is noted, and a statement about it is included. A narrative evaluation can include adequacy of technique; soft tissues and bones of the thorax; position and shape of the diaphragm; costophrenic angles; the size and shape of the cardiac shadow; the appearance and distribution of the bronchovascular markings; the appearance of the pleura and the lung parenchyma, including a statement about whether or not unusual nodulations are present; a summary of the findings; and a statement about whether the film is normal or abnormal. If the film is determined to be abnormal, the narrative should describe the way in which it is abnormal and what the abnormality means. Comment on the technique and quality of the film if it may have influenced interpretation is also important (see "*Quality control:*" p 72). An example of a narrative report is presented in **Appendix O-1.**

Cumulative radiology report: Another approach to industrial surveys of chest x-rays is a cumulative radiology report (**4-10**). A cumulative radiology report contains a listing of serial interpretations and findings in chronological order, or reverse chronological order, analogous to clinical progress notes. Putting serial x-ray reports into a single- or multiple-page format improves the quality of the report and conveys the information to the industry client in an effective, understandable manner. This style of report can be produced on a personal computer, but some customization of a commercial word processing package will be necessary (**4-10**). An example of a cumulative radiology report is presented in **Appendix O-2.**

Reader variability, B readers, and consensus readings: Repeated classification of the same radiograph may vary considerably, not only from reader to reader (intervariability) but also among multiple readings by the same reader (intravariability). This variability has been reported in the medical literature (**4-11 & 4-12**) and is greatest when profusion levels are near the lower end of the ILO scale. Generally speaking, physicians have more difficulty distinguishing a series of radiographs at the boundary between Categories 0 and 1, namely, 0/1 and 1/0.

To improve the proficiency of readers and minimize the variability of readings, NIOSH, in conjunction with the American College of Radiology, www.acr.org has conducted training programs and instituted a proficiency examination for physicians who want to demonstrate competence in the classification system (**4-9).** Those who successfully pass the examination are certified as B readers and are periodically required to pass a recertification examination. Physicians who only attend a course on the ILO classification system or submit other documentation to NIOSH are called A readers and are not generally as proficient as B readers. An updated listing of currently approved B readers can be found at: http://www.cdc.gov/niosh/topics/chestradiography/breader-list.html

For the purposes of respirable crystalline silica medical surveillance, all x-rays should be interpreted by a physician who is certified as a B reader, is board-certified in radiology or pulmonary medicine, and has considerable experience in occupational lung diseases. Because of the inter- and intravariability in readings, the ILO Guidelines recommend that at least two, and preferably three, independent readings be made for each radiograph (**4-4**).

It is generally recommended that multiple interpretations of all films 1/0 or greater be obtained and that 5% – 10% of the films interpreted as 0/1 receive multiple interpretations, according to the decision logic shown in Figure 4-6. Such a system will allow a consensus interpretation or median reading to be noted so that the worker is provided the best possible interpretation. For companies with workers that have an elevated respirable crystalline silica exposure, it is wise to identify an expert panel of radiologists who are willing to participate in a consensus interpretation methodology. Selection of radiologists and other physicians proficient in ILO classification and experienced in dust disease is vital to the x-ray component of this medical surveillance effort.

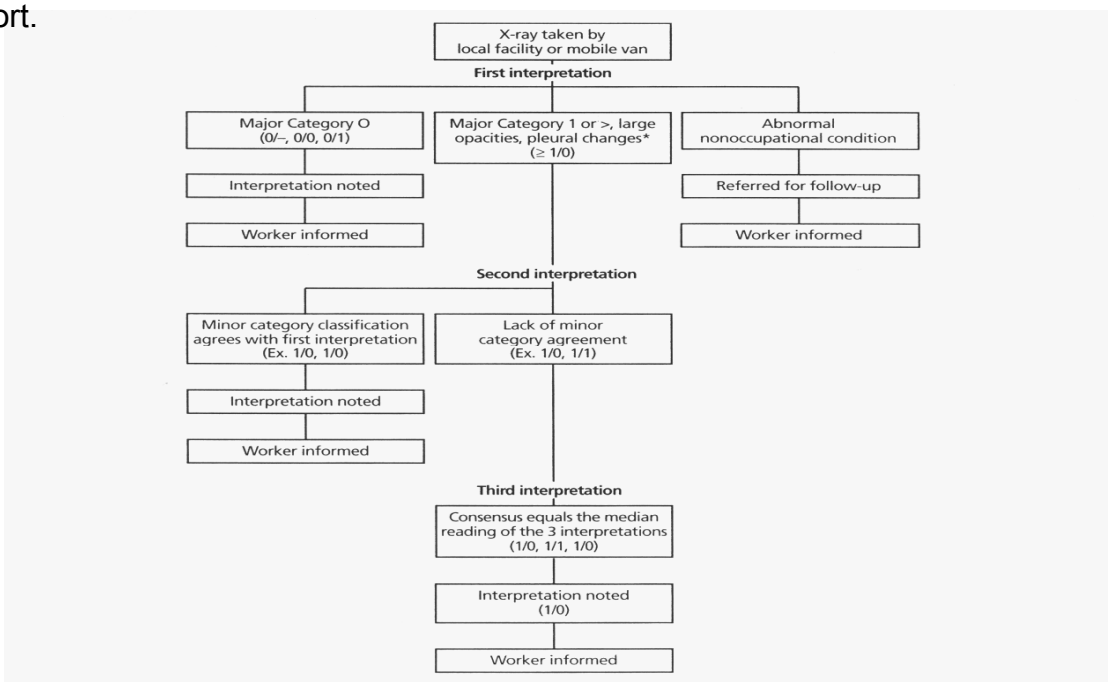


Figure 4-6 Consensus Procedure for X-Ray Interpretation

Source: NISA

Retention and storage of film and digital files: Chest x-rays *must* be stored safely for an indefinite period in a place from which they can be retrieved for subsequent comparisons. Copies are *not* acceptable for this purpose. Hospitals and x-ray facilities are known for purging old x-rays to relieve storage-space problems and to recover silver from the x-ray film's emulsion. Insist that your worker's x-ray films be kept for 30 years after the worker ceases employment, and consider taking possession and self-storing them to ensure that inadvertent destruction does not occur. It may be advisable to arrange for centralized storage of films at a medical facility, with a written agreement specifying storage conditions.

In recent years advancements have been made through the use of ***digital technology***. This technology avoids many of the storage pitfalls and "copy" film quality concerns. This technology also reduces storage space, maintains the quality of the films in a more protected format and allows original quality copies to be electronically transferred for outside review. Unless historical films can be transferred to this technology, storage concerns remain for earlier films. In some locations, digital technologies may not yet be available.

The American National Standards Institute (ANSI) www.ansi.org has developed standards for the storage and preservation of photographic film (see guidelines below). These documents may be obtained from ANSI, 1430 Broadway, New York, New York 10018, telephone (212) 642-4900.

One of the most important factors affecting the storage life of radiographs is the amount of residual thiosulfate left in the radiograph after processing and drying. Residual thiosulfate comes from the fixer chemicals, so thorough washing of the film after developing and fixing is important. Testing for residual thiosulfate is beyond the capability of most companies, so it may be advisable to confirm with the x-ray provider that processing of the films meets current ANSI criteria.

General guidelines for storing radiographs are as follows:

1. Store films at a temperature of 32°F–75°F and a relative humidity of 30%–50%. Peak temperatures for short time periods should not exceed 90°F, and relative humidity should not exceed 60%.
2. Avoid short-term cycling of temperature and humidity.
3. Avoid storage in the presence of chemical vapors.
4. Place each film in a protective folder, or if several films are stored in a single folder, place interleaving paper between films.
5. Never store unprotected films in sunlight or other bright light.
6. Avoid pressure damage caused by stacking a large number of films or by forcing more radiographs than fit easily in a file drawer or on a shelf.
7. Avoid storage locations in which water damage could occur.

Quality control: Technical quality control is an exceedingly important factor for chest radiographs, since it has a dramatic effect on the interpretation and categorization of pneumoconioses. Film quality ratings of Grades 1 and 2 are acceptable for the interpretation of pneumoconioses. Grade 4 or unreadable film is unacceptable, and occurrences of Grade 4 film should be reduced to zero. Grade 3 films, which are "poor," contain technical defects but are still thought acceptable for classification purposes. Generally speaking, poorly exposed films may spuriously increase markings as does poor employee inspiration. Overexposed or underexposed films may obliterate subtle interstitial markings/nodules.

Though not stated (**4-11**), it is implied that the technical defects associated with Grade 3 films could affect the ILO classification process. In occupational health surveillance activities, when more than 1 in 10 chest films are considered to be Grade 3 or worse, a review of the factors influencing technical quality is in order. This should serve as a minimum goal. One must bear in mind, however, that reader assessment of quality is somewhat subjective and that agreement among readers on quality grade is often poor. Thus, procedures for providing feedback to stationary and mobile x-ray facilities and x-ray technicians to upgrade quality and achieve high standards is a factor that must not be overlooked.

Medical Examination

The examination of the thorax and general respiratory fitness of a worker should be performed by a physician, preferably with occupational medicine expertise, when indicated during screening (chest x-ray, questionnaires, etc.). Where examination by a physician is not practicable, a physician's assistant or nurse-practitioner under the supervision of a licensed physician can conduct a routine examination and refer abnormalities to a physician for further evaluation. Alternatively, clinical data collected by a medical-evaluation van service and reviewed by a physician can be used for follow-up medical evaluation.

The physician or other person conducting the examination should be provided with a description of the duties and physical abilities required by the job, respiratory protective equipment used by the worker, an estimate of the respirable crystalline silica exposure level, and other information pertinent to the clinical assessment. If possible, the person conducting the examination should gain first-hand knowledge of the workplace conditions by visiting the work site to observe the job requirements. The examination should note whether observations relating to the chest, such as symmetry, expansion, percussions, breath sounds, palpitation, wheezes, rales, and rubs, are normal or not.

Spirometry Testing (Pulmonary Function Testing)

Spirometry is generally viewed as an ***optional*** component of the medical surveillance program because pulmonary function tests are nonspecific and one can seldom make a diagnosis based on spirometric findings alone (**4-3**). The total clinical presentation, including medical history, physical examination, chest x-ray, and appropriate ancillary laboratory studies, must be considered. Experience has shown that most abnormalities

on screening spirometry are not due to work-related disorders. Smoking, nonoccupational pulmonary disease, and other variables are more common causes of alterations in pulmonary function.

Serious obstacles have hindered the widespread use of spirometry in the industrial setting (**4-3**). Many technicians, nurses, and physicians have been inadequately trained and perform or analyze tests incorrectly. Certain spirometers have been demonstrated to be technically unsatisfactory. Test methodology and procedure have lacked standardization, rendering difficult the comparison of results obtained at different facilities. Surveillance information obtained under these circumstances can be worse than no information at all.

It is imperative that if spirometry is part of the medical surveillance program, it be conducted to meet stringent quality control parameters. The physician or health professional performing spirometry should be thoroughly familiar with and meet the guidelines in this subsection and the criteria of the American Thoracic Society (ATS). A discussion of spirometry practice appropriate for this program is included in **Appendix P**.

Recognizing the deficiencies associated with spirometric testing, the routine assessment of ventilatory function with a spirometer is still an increasingly common practice in occupational medicine (**4-3**). Properly conducted, spirometry is regarded as a useful component of respiratory medical surveillance programs for baseline evaluation and periodic monitoring. Routine follow-up studies of workers exposed to respirable crystalline silica can detect pulmonary function loss in its earliest stages, although radiographic changes consistent with silicosis will normally precede losses detected by spirometry that result from the inhalation of respirable crystalline silica.

ATS Standardization of Spirometry

In 1977 the ATS, http://www.thoracic.org , published the results of its Snowbird Workshop on the standardization of spirometry. Methodological principles and instrument specifications were approved by consensus and recommended for “both clinical laboratories and epidemiologic studies.” Although objections have been raised that certain provisions are too stringent for “office spirometry,” most occupational health professions have recognized the ATS standards as state-of-the-art recommendations applicable to the industrial setting.

The spirometry criteria were updated in 1987, 1994 and 2005 and can be obtained by contacting the ATS, 61 Broadway, New York, New York 10006-2755, telephone (212) 315-8600. A copy of the ATS criteria can be obtained at: http://www.thoracic.org . Through the ATS web site and other sources, copies of additional spirometry standardization and technician requirement documents can also be obtained (**4-13**).

It is imperative that spirometry performed on workers adhere to the ATS requirements. This is true for both stationary medical facilities and mobile medical vans. The ATS criteria should be cited in procurement agreements between companies and the spirometry provider.

A checklist, developed from the ATS criteria, of some of the items to assess in choosing a spirometry provider is provided in **Appendix Q**. Questions concerning the adequacy of spirometric testing should be directed to the company physician or independent pulmonologist who evaluates the spirograms. Manufacturers should provide documentation that their instruments have been tested by an independent laboratory. If such documentation is not available, the equipment should be approached with caution—it probably does not meet the ATS criteria.

Relaying Medical Information to Workers and Employer:

The examining physician or other health professional should provide both the employer and employee with the results of any medical examination that is pertinent to the employee's safety and health at work. Evidence of respirable crystalline silica linked abnormalities would certainly be pertinent to the employee's health.

Medical privacy standards can change over time but employers need to know confirmed or likely work related medical surveillance findings in order to better protect employees. Occupational linked medical abnormalities are therefore typically excluded from medical confidentiality rules although all medical records still need to be protected. Companies concerned about medical confidentiality should seek legal counsel and review current state and national medical confidentiality policies.

The term "occupationally linked" means medical conditions known or likely to have been caused by the work environment. An example of such conditions would be a chest radiograph that shows the signs of silicosis in a dusty work environment involving respirable crystalline silica. Occupationally linked can also mean medical conditions that may place a worker (or other workers) at risk in the work place even though the condition was not caused or aggravated by the work environment. Examples of this might be impaired vision, respiratory impairments that restrict respirator use, muscle-skeletal disorders which limit safe material handling, etc.

Physicians typically relay such findings to employers through some formal reporting process. One reporting tool used effectively by many companies is a physician's results summary form that is sent to both the employee and the company after the medical surveillance process is completed**.** Such notifications, however, can only reflect "occupationally linked" findings. Non-occupational linked findings should not be shared with employers. Employers can not discriminate against employees based on medical findings in regard to pay or job loss.

Medical observations and opinions shared with a company should:

- Assist the company in developing baseline information against which future occupational health observations can be compared.
- Inform the company about any medical condition or change in an employee's condition from a job-related exposure such as crystalline silica.

- Assist the company to better protect the worker by providing information on the worker's ability to wear respiratory protection, exposure restrictions (if any) and the need for medical follow-up.

In regard to employee notification, any medical abnormalities detected, whether occupational or non-occupational, must be disclosed to the employee with a recommendation for appropriate medical follow-up. The worker should be provided a copy of the examination results. Evidence that follow-up has been completed should be obtained and documented by the employer (if work related) or by the physician (if not work related).

Abnormalities that are not "occupationally linked", but noted during the course of an occupational medical surveillance examination, should not be shared with the company. Such observations must be relayed to the employee by the examining physician. Typically, for non-occupationally linked findings, employees are advised to follow-up through their personal physicians who should be provided a copy of the medical findings of concern.

Employers must follow medical confidentiality requirements as stipulated by the Health Insurance, Portability and Accountability Act (HIPAA) and other applicable standards. In general, occupational medical surveillance programs are intended to identify work linked abnormalities that may impact the health and safety of employees but medical records must be kept confidential. HIPAA rules can be found at: *http://www.hhs.gov/ocr/hipaa/FinalEnforcementRule06.pdf*

Medical Assessment of the Ability to Wear a Respirator

A worker should not be assigned to a job requiring the use of a respirator unless it has been determined that he or she is physically able to perform the work and use the respirator properly and safely.

The following medical evaluation guidelines are adapted from NIOSH Publication 2005-100, *NIOSH Respirator Selection Logic 2004.* This guidance should be provided to health practitioners who assess their workers' ability to use respirators.

These guidelines assume that workers are wearing air-purifying respirators under moderate exercise conditions, as typically found at most industrial facilities. If workers are required to wear heavy respirators, such as self-contained atmosphere-supplying types, or are required to perform tasks equivalent to heavy exercise, then the stress on the cardiovascular system can be significant. Under such conditions, NIOSH Publication 2005-100 and other respirator literature should be consulted (**4-13, 4-14, 4-15**)**.**

Physician's Evaluation

A physician should make the medical determination of the worker's fitness to wear a respirator by considering the worker's health, the type of respirator, and the work conditions. This recommendation satisfies ANSI standard practices and leaves the medical decision about an individual's fitness to wear a respirator to a person qualified

to evaluate the clinical variables. Much of the clinical and other data can be gathered by other personnel. It should be emphasized that the clinical examination alone is only one part of the fitness determination and that collaboration with foremen, industrial hygienists, and others may often be needed to better assess the work conditions and other factors that affect an individual's fitness to wear a respirator.

Medical History and Physical Examination

A medical history and at least a limited physical examination are recommended. The medical history and physical examination should emphasize the evaluation of the cardiopulmonary system and elicit any history of respirator use. The medical history is an important tool in medical diagnosis and can be used to detect most problems that might require further evaluation. The physical examination should confirm the clinical impression based on the medical history and detect any important medical conditions (such as hypertension) that may be asymptomatic.

The physician should consider the following in selecting or permitting the use of respirators (**4-14**):

- History of spontaneous pneumothorax (collapsed lung).
- Claustrophobia or anxiety reaction.
- Moderate or severe pulmonary disease such as chronic bronchitis with coughing.
- Angina pectoris, significant arrhythmias, or recent myocardial infarction.
- Symptomatic or uncontrolled hypertension.
- Age.

It seems unlikely that wearing a respirator would play any significant role in causing lung damage such as pneumothorax. However, without evidence that wearing a respirator does not cause such lung damage, it is prudent to prohibit an individual with a history of recurrent spontaneous pneumothorax from wearing a respirator.

Moderate lung disease is defined by ATS as forced expiratory volume in 1 second (FEV_1), divided by a forced vital capacity (FVC), that is, FEV_1/FVC, of 41%–59%, or an FVC of 51%–69% of the predicted FVC. Similar arbitrary limits can be set for age and hypertension. It seems more reasonable, however, to combine several risk factors into an overall estimate of fitness to wear respirators under certain conditions. Here, the judgment and clinical experience of the physician are needed. In many cases, even impaired workers are able to work safely while wearing respirators if they can control their own pace and are allowed adequate rest breaks.

Chest X-ray and Spirometry

Although a chest x-ray and/or spirometry may be medically indicated in some fitness determinations, these tests need not be routinely performed for assessing the ability to wear a respirator. The medical surveillance guidelines for silicosis prescribe periodic

chest x-ray examinations and optional spirometry for exposed workers. Because the results of these tests are available, they may be used by the physician in determining fitness to wear a respirator; however, chest x-rays and spirometry are not routinely recommended for respirator fitness evaluations. In most cases, if the worker's medical history and physical examination result in a negative clinical evaluation, x-rays and spirometry are unlikely to influence the fitness determination. In general, chest x-rays do not accurately reflect a person's cardiopulmonary status, and limited studies suggest that in most cases, mild to moderate impairment detected by spirometry does not preclude the wearing of a respirator. Spirometric values alone cannot be used to determine a worker's fitness to wear a respirator and may even give misleading indications of fitness.

Psychological and Physiological Problems of First-Time Wearers

In addition to medical considerations, the physician or another qualified person should consider if wearing a given respirator will cause extreme anxiety or a claustrophobic reaction in the individual. After respirator use training, the worker should be asked to report any physical or emotional stress while wearing the respirator during the first day of work. Reports of any physical or emotional stress during first time use in the work environment should receive further medical follow-up.

NIOSH recommends that a worker be provided the opportunity to wear the respirator "in normal air for a long familiarity period" (**4-15**) to evaluate the ability and tolerance of the worker to wear the respirator. This trial period need not be associated with respirator fit testing and should not compromise the vital fit-testing procedure. Instead, this "intermediary" test or trial would typically take place during use training. A "familiarity period" might cover at least one hour.

Frequency of Fitness Determinations

The periodicity of respirator fitness determinations recommended by NIOSH varies according to several factors, but can be as frequent as every 5 years. Adhering to a 2-year frequency for silicosis surveillance and incorporating respirator assessment as a periodic component of the medical surveillance program will satisfy the NIOSH recommendations for periodicity. These guidelines are based on clinical judgment and, like the other recommendations in this section, should be adjusted as clinically indicated.

The OSHA Respirator Standard (29 CFR 1910.134) includes a listing of situations that require respirator fit and use re-determinations. This list includes changes in job or work practices, facial changes caused by injury or weight shifts that may affect respirator fit, medical conditions, observation by supervisors, etc. See the OSHA respiratory standard.

http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12716

Summary

Individual judgment is needed in determining the factors affecting an individual's fitness to wear a respirator. Although many of the guidelines above are based on limited evidence, they provide a useful starting point for a respirator-fitness screening program. In general, if a worker is able to do his or her job safely without a respirator, he or she will usually be able to do it safely while wearing a respirator. It bears repeating, however, that in the hierarchy of dust controls, personal protective equipment such as respirators should not be the first or only dust control applied. The use of respiratory protection should be avoided or held to a minimum through engineering dust controls if at all possible.

Record Keeping

All occupational health linked medical records obtained on workers should be retained by the company (or held by a company contracted physician) for at least 30 years after the worker's employment. A provision to safeguard electronic medical records, when they exist (such as through back-up copies on discs), is similarly important. This is necessary because of the chronic nature and long latency of silicosis. Historical records are also useful in assessing the adequacy of occupational standards.

Frequency of Examinations

Baseline Examinations

Before a worker is assigned to a job with potential exposure to respirable crystalline silica, a medical examination should be completed to establish a baseline on the worker's respiratory health status. The examination should include, as a minimum, a medical history, including a respiratory symptom questionnaire and smoking history; a complete occupational and job history; a medical evaluation of the thorax, as indicated; a PA chest x-ray; and any additional tests ordered by the company or examining physician. TB testing and spirometry, including FVC and FEV_1, are an optional part of the Occupational Health Program (OHP), but they are encouraged by the American College of Occupational and Environmental Medicine (**4-17**).

Periodic Examinations

With the exception of chest x-rays, medical evaluations are often administered every 2 years. These should be comprehensive examinations that include the elements of the baseline examination. Follow-up after one year if an elevated crystalline silica exposure is known to exist has also been recommended but repeating the x-ray examination should be at the discretion of the healthcare provider (**4-17**).

The frequency of x-ray examinations depends on the number of years since first exposure to silica dust, the age of the worker, and whether any signs or symptoms are present. Dust exposure level (see Section 2) should be considered as well. One

recommendation suggests that during the first 8 years following a worker's exposure to silica dust, x-rays should be taken at 4-year intervals. After 8 years from the first job-related exposure to silica, the age of the worker will determine the frequency of x-ray examinations. Up until age 35, x-rays should be taken at 4-year intervals. After age 35 and a combined 8 years of silica exposure, x-rays should be taken every 2 years. Table 4-1 summarizes the recommended frequency of x-ray examinations under this scheme. Similar recommendations have been made by others (**4-16, 4-17).**

Companies may find this recommended frequency difficult to administer and may wish to seek a compromise schedule that can be more easily administered. After a baseline initial hire x-ray, for example, all such workers might receive an x-ray 4 years later, then at 2 or 3 year intervals thereafter. Such simplification will, however, typically lead to more x-rays than are medically indicated. Regulatory standards concerning respirable crystalline silica may also dictate minimum x-ray frequency and should always be consulted before an x-ray schedule is selected.

Workers who experience respiratory symptoms such as shortness of breath or a positive TB test should receive chest x-rays as determined by a physician. Likewise, workers whose x-rays show changes consistent with pneumoconiosis should receive x-rays and medical evaluations more frequently, as medically indicated, to monitor any progression of changes. Additional diagnostic tools such as CT scans and lateral x-ray views should be applied at the discretion of the physician. Routine application of these additional tools is not generally supported.

	Age of Employee	
Years Since First Silica Exposure	<35	>35
0–8	Every 4 years	Every 4 years
>8	Every 4 years	Every 2 years

Note: Workers experiencing signs or symptoms of pulmonary abnormality, or who have abnormal chest radiographs, should be x-rayed as determined by a physician.

Table 4-1 Frequency of Chest X-Rays

Source: NISA

References

Section 1

1-1 American Conference of Governmental Industrial Hygienists (ACGIH®): *2005 Threshold Limit Values (TLV®) for Chemical Substances and Physical Agents; Biological Exposure Indices,* Appendix C pp. 74. Cincinnati, Ohio (2005).

1-2 Morgan, W. K. C., and Lapp, N. I., "Diseases of the Airways and Lungs," in *Occupational Diseases – A Guide to Their Recognition,* (M. M. Key, A. F. Henschel, J. Butler, R. N. Ligo, and I. R. Tabershaw, Eds.). Washington, DC: U.S. Department of Health and Human Services, National Institutes of Occupational Safety and Health, U.S. Government Printing Office (1977).

1-3 Hendrick, D. J., et al., *Occupational Lung Diseases* (3rd ed.). Philadelphia: W.B. Saunders (1995).

1-4 Morgan, W. K. C., and Seaton, A., *Occupational Lung diseases* (3rd ed.). Philadelphia: W.B. Saunders (1995).

1-5 Chen, D. M., et al., "Diseases Caused by Silica: Mechanisms of Injury and Disease Development" *Int. Immunopharmacolo.* 2002 Feb:2 (2-3):173-82. Review.

1-6 Gulumain, M., et al., Mechanistically Identified Suitable Biomarkers of Exposure Effect, and Susceptibility for Silicosis and Coal-Worker's Pneumoconiosis: A Comprehensive Review. *Journal of Toxicology and Environmental Health, Part B,* 9:357-395, (2006).

1-7 National Institute for Occupational Safety and Health (NIOSH), "Silicosis and Related Exposures" Section 3. *The Work-related Lung Disease Surveillance Report, 2002* Center for Disease Control (2003) www.cdc.gov/niosh/docs/2003-111/2003-111.html .

1-8 Cohen C., et al., "Accelerated Silicosis with Mixed-Dust Pneumoconiosis in a Hard-Metal Grinder" *J Occup Environ Med.* 1999 Jun;41(6):480-5.

1-9 NIOSH Hazard Review, "Health Effects of Occupational Exposures to Respirable Crystalline Silica." US Dept. of Health & Human Services, CDC, DHHS (NIOSH), Publication No. 2002-129 www.cdc.gov/niosh/02-129A.html .

1-10 IARC Working Group on the Evaluation of Carcinogenic Risks to Humans: "Silica, some silicates, coal dust and para-aramid fibrils," IARC Monogr Eval Carcinog Risks to Hum.; 68:1-147 (1997).

1-11 National Toxicology Program (NTP), *9th Annual Report on Carcinogens:* Washington, DC: U.S. Department of Health and Human Services (2000).

1-12 Steenland, K., et al., "Interaction Between Tobacco Smoking and Occupational Exposures in the Causation of Lung Cancer," JOM/Vol. 28 No. 2, 11-118. Feb. 1986.

1-13 Goldsmith, D. F., et al., "Combined Silica Exposure and Cigarette Smoking: A Possible Synergistic Effect", In *Silica, Silicosis, and Cancer: Controversy in Occupational Medicine,* Goldsmith DF, Winn DM, ShyCM (eds) New York, Praeger, p 451-459 (1986).

1-14 Parkes, R. W., *Occupational Lung Disorders* (2nd Edition) Butterworths Pub., British Library Cataloguing ISGN0-407-33731-8 p. 49-50 (1982).

1-15 American Thoracic Society, *Adverse Effects of Crystalline Silica Exposure,* American Journal of Respiratory and Critical Care Medicine, Vol. 155, No. 3, pp. 761-768, Feb. 1997.

Section 2

2-1 NIOSH, "Occupational Exposure Sampling Strategy Manual," U.S. Dept. of Health & Human Services, CDC, DHEW (NIOSH), Publication No. 77-173, Jan. 1977.

2-2 Corn, M., *Strategies of Air Sampling* in Scandanavian Journal of Work, Environment and Health, Vol. 11, No. 3, pp 173-180 (1985).

2-3 Rappaport, S. M., *Exposure Assessment Strategies Exposure Assessment for Epidemiology and Hazard Control*, in Industrial Hygiene Science Series, S.M. Rappaport and T.J. Smith, Eds., Lewis Publishers, Chelsea, MI, pp 219-249, (1991).

2-4 Lippman, M., *Exposure Assessment Strategies for Crystalline Silica Health Effect*, Applied Occupational and Environmental Hygiene, Vol. 10, No. 12, pp 981-990 (1995).

2-5 NIOSH method 7500 – Manual of Analytical methods – 4th Edition March 2003 (www.cdc.gov/niosh/nmam/pdfs/7500.pdf).

2-6 Verma, D. K., "Adjustment of Occupational Exposure Limits for Unusual Work Schedules," *Am Ind Hyg Assoc J 61(3): 367-374* (2001).

2-7 Paustenback, D. J., "Pharmacokinetics and Unusual Work Schedules". In: Patty's *Industrial Hygiene, 5th ed., Vol. 3, Part VI, Law, Regulation, and Management.* Chap. 40, pp 1787-1901. RL Harris, Ed. John Wiley & Sons, Inc., New York (2000).

2-8 Armstrong, T. W., et al., "Occupational Exposure Limits: An Approach and Calculation Aid for Extended Work Schedule Adjustments," *J Occ & Env Hyg (2): 600-607* (2005).

2-9 Weinber, G., et al., "Statistics – An Intuitive Approach" 5th Edition, Wadsworth Publishing Co. Inc., Belmont, California (1966).

2-10 Armitage, P., "Statistical Methods in Medical Research," 4th Edition, Blackwell Scientific Publications, Oxford London Edinburgh Melbourne (1977).

2-11 Caravanos, J., "Quantitative Industrial Hygiene: A Formula Workbook", *American Conference of Governmental Industrial Hygienists (pub.)* ISBN: 0-936712-95-3 (1991).

2-12 Mine Safety and Health Administration: *Industrial Hygiene: Sampling for Silica and Noise, Metal and Nonmetal Specialized Training.* Student Text Material, US Dept. of Labor, National Mine Health and Safety Academy, IG 13a (1999).

Section 3

3-1 Cecala, A., et al., "Reducing Respirable Dust Concentrations at Mineral Processing Facilities Using Total Mill Ventilation Systems," United States Department of Interior, Bureau of Mines Report of Investigations (RI) 9469 (1993).

3-2 American Conference of Governmental Industrial Hygienists, *Industrial Ventilation: A manual of Recommended Practices, 25th Ed.* Cincinnati, OH (www.acgih.org) (2004).

Section 4

4-1 American Thoracic Society, "*Surveillance for Respiratory Hazards in the Occupational Setting,"* American Review of Respiratory Disease, Vol. 126, pp. 952-956 (1982).

4-2 Personal communication with Brian Boehlecke, MD – Professor of Medicine (pulmonary) of the University of North Carolina, Chapel Hill (2006).

4-3 Horvath, E. P., et al., *Manual of Spirometry in Occupational Medicine.* Cincinnati: U.S. Dept. of Health and Human Services, National Institute for Occupational Safety and Health.

4-4 *Guidelines for the Use of ILO International Classification of Radiographs of Pneumoconiosis. Occupational Safety and Health,* Revised Edition 2000, Series 22, Rev., Geneva: International Labor Office (2002).

4-5 ATS/ERS Guidelines for Pulmonary Testing – European Respiratory Journal; 26:319-338 for spirometry testing, and 948-968 for spirometry interpretation (2005).

4-6 Sargent, E. N., *"Technique for Chest Radiography for Pneumoconiosis".* Chicago: American College of Radiology (1982).

4-7 *Guidelines for Use of Routine X-Ray Examinations in Occupational Medicine; Committee Report,"* Journal of Occupational Medicine, Vol. 21, pp. 500-502 (1979).

4-8 Jacobson, G., et al., *"Essentials of Chest Radiology,"* Radiology, Vol 95, pp. 445- 450 (1970).

4-9 Morgan, R. H., *"Radiology"* in Occupational Respiratory Disease (J. A. Merchant, Ed.). Cincinnati: U.S. Dept. of Health and Human Services, National Institute for Occupational Safety and Health (1986).

4-10 Wheeler, P.S., et al., *"The Computer-Based Cumulative Report: Improvement in Quality and Efficiency,"* Radiology, Vol. 182, No.2. 355-357 (1992).

4-11 Morgan, R. H., "*Decision Processes and Observer Error in the Diagnosis of Pneumoconiosis by Chest Roentgenography,"* American Journal of Roentgenology, Vol. 132. pp. 803-808 (1979).

4-12 Amandus, H.E., et al., *"Pneumoconiosis: Inter-Reader Variability in the Classification of the Type of Small Opacities in the Chest Roentgenogram,"* American Journal of Roentgenology, Vol. 122, No. 4. pp. 740-743 (1974).

4-13 Miller, M. R., et al., *"General Considerations for Lung Function Testing*,*"* Eur Respir J No. 26: pp 153-161 (2005).

4-14 NIOSH *Respirator Decision Logic* –DHHA Publication 87-108. Cincinnati: National Institute for Occupational Safety and Health (1987).

4-15 Harber, P. I., *Medical Evaluation for Respirator Use.* Journal of Occupational Medicine, Vol. 26, No. 7, pp. 496-502 (1984).

4-16 American National Standards for Respirator Protection – Respirator Use-Physical Qualifications for Personnel (ANZI Z88.6). New York: American National Standards Institute, pp. 7-15 (1984).

4-17 American College of Occupational and Environmental Medicine. *Medical Surveillance of Workers Exposed to Crystalline Silica.* Lead authors: L. Raymond, S. Wintermeyer, JOEM, Vol. 48, No. 1.

Appendix A

Respirable Crystalline Silica Sampling Selection Guide

Use this checklist to assist in the selection of areas and work activities to be sampled. Determine your reason(s) for the sampling as this will influence which considerations are most important in selecting the type of sampling (i.e., personnel, area or both) and the frequency of sampling. Reasons for sampling include determination of regulatory compliance or company policies, the effectiveness of dust controls, and/or the need for medical surveillance, baseline sampling for a new process, etc.

Task or Work Area Elevated Dust Observations:

- Visible dust in the air _____
- Dust settled around equipment, floors, other surfaces _____
- Dust on worker's clothing _____
- Work practices that produce visible dust _____
- Process equipment emitting visible dust _____
- Number & proximity of workers to this equipment _____
- Dust respirator use is evident _____
- Lift trucks or other mobile equipment creating dust _____
- Dusty clean-up activities _____
- Other _____

Researched Information:

- Work-shift patterns (how variable, etc.)
- Worker dust complaints – concerns (interview)
- Condition of existing dust controls (isolation, ventilation, respirators, etc.)
- Prior sampling data available for review
- Nature of process equipment (open, does it produce fine particles, etc.)
- Other:

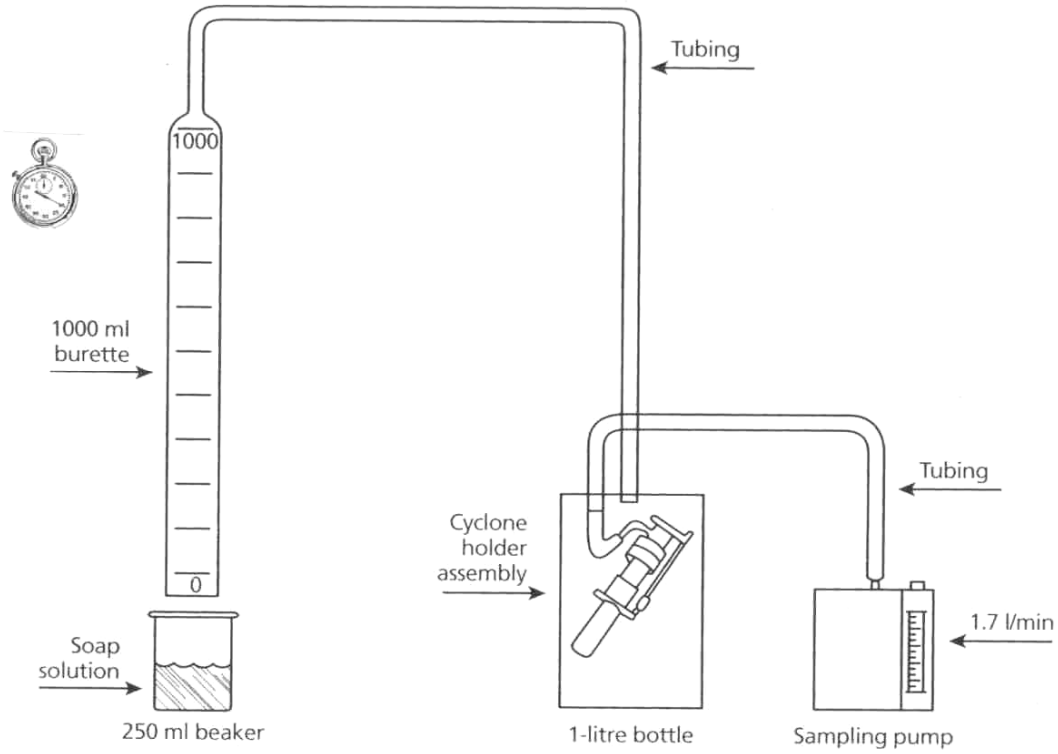
  _____
  _____
  _____
  _____
  _____

Source: Composite from MSHA (ref. 2-12) and NISA reference materials

Appendix B

Calibration of Cyclone Respirable-Dust Sampler Using a Bubblemeter

Setup:



Source: NISA diagram

Pump Calibration Using a Manual Glass Bubblemeter

A 1000 ml (1 liter) glass bubblemeter is used to calibrate air-flow pumps.

Materials Needed:

- 1000 ml glass bubblemeter (burette)
- Support (rectangular base with rod)
- Burette clamps (2)
- Utility clamp
- Beaker or dish capable of fitting over the large open end of the bubblemeter
- Soap solution or equivalent
- Stopwatch, graduated in 100^{th} of a minute or 10^{th} of a second
- Exact sampling train which will be used in sampling
- Hose or tubing

Bubble Travel Times

Using the formulas below, calculate the time required for the bubble to travel the length of the burette to obtain the desired flow rate.

➔ $\frac{\text{1.0 liter}}{\text{Desired flow rate (Lpm)}}$ = time (min)

➔ $\frac{\text{100 ml}}{\text{Desired flow rate (ml/min)}}$ = time (min)

➔ Time (min) x 60 sec/min = time (sec)

Procedure

1. Connect the calibration apparatus (sealed cyclone and filter-cassette) to the pump with the cyclone in line between the bubblemeter and the pump.

2. Check the seals on all hose connections. The entire system must be free from leaks.

3. Raise the beaker containing the soap solution and momentarily submerge the opening of the bubblemeter.

    - Repeat several times until a bubble travels the entire distance up the bubblemeter without breaking. This will be easier to accomplish if the inside of the burette has been wetted previously with diluted soap solution or water.

- Raise the beaker to form only one bubble, after the inside of the bubblemeter is properly treated.

4. Using a stopwatch, time the travel of the bubble from the zero to the 1000 ml mark.

5. Increase or decrease the flow rate, as necessary.

6. Repeat steps 3, 4, and 5 until the bubble travel time is correct for two consecutive timings.

7. If the pump is equipped with an external rotameter, mark the correct position of the ball on the rotameter tube. Make sure that the pump is not tilted when marking ball position.

8. Turn the pump off. Record the following:

   - Pump ID number
   - Date/time of calibration
   - Name of person performing calibration
   - Calibrated pump flow rate
   - Location of calibration
   - Calibration ID number

Flow rates are calculated using the formula:

$$\text{Flow rate} = \frac{\text{Bubble tube volume (ml)}}{\text{Elapsed time (sec)}} \times \frac{60 \text{ sec}}{1 \text{ min}} = \text{ml/min}$$

For example:

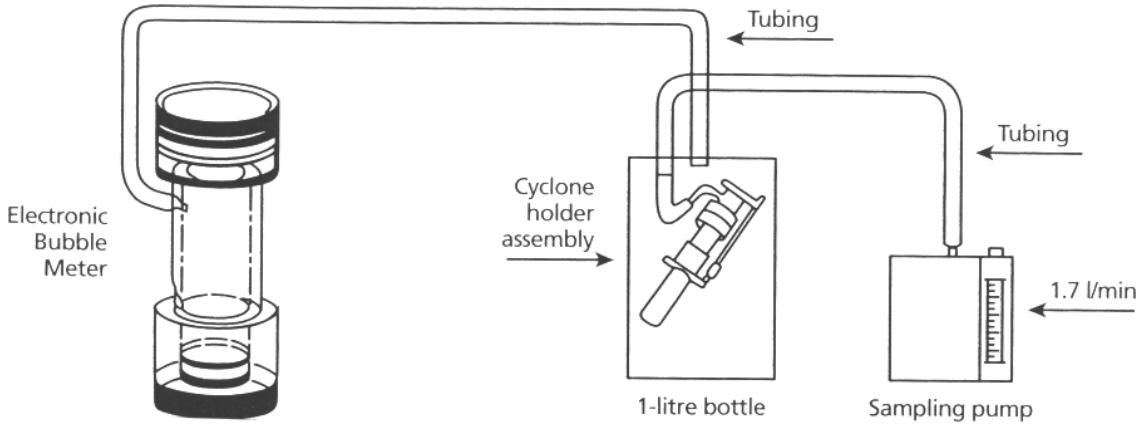
	Stopwatch	**Graduation Mark**
Start	0 sec	0 ml
Stop	17.5 sec	500 ml

$$\frac{500 \text{ ml}}{17.5 \text{ sec}} \times \frac{60 \text{ sec}}{\text{min}} = 1714 \text{ ml/min}$$

Appendix C

Calibration of Cyclone Respirable-Dust Sampler Using an Electronic Flow Calibrator

Setup:



Source: NISA diagram. Procedure from MSHA Sampling for Silica and Noise Student Text Material, IG-13a, 1999.

Gilibrator Pump Calibration (Electronic)

Initial Setup

Charging the Gilibrator

- Plug in the charger and connect to the charging jack on the right side of the control unit. The unit's charging LED will light indicating that the unit is charging properly.
- Allow the battery system to charge for 14 hours prior to operation. The unit can be used while being charged.

Mounting the Flow Cell Assembly

- Select the flow cell assembly to cover the flow range required.
- The bottom of the flow cell assembly has a quick mount feature. The base of the flow cell assembly is positioned onto the mounting plate of the control unit.
- Engage the pin of the cell assembly base into the mounting plate of the control unit. When the flow cell assembly is properly engaged, the base of the cell will be flush with the mounting plate and the cell assembly will face toward either the right or left side.
- Grasp the bottom cell chamber and rotate the cell until it clicks in.

CAUTION: Always engage and disengage the cell by grasping and rotating only the bottom cell chamber. The cell assembly will now face forward.

- Insert the control unit's cable assembly into the sensor block connecting jack located on the back of the sensor block.

Adding the Gilibrator Soap Solution

- Remove the storage tubing from the upper outlet boss of the upper cell.
- Fill the dispenser bottle provided with Gilibrator soap solution. Using the rubber storage tubing as a funnel, slowly add soap solution from the dispenser.
- The amount of soap needed is determined by depressing the BUBBLE INITIATE button and holding it down in the lower position.
- Continue to add enough soap solution until the angled edge at the bottom of the bubble generator ring is immersed in the solution. **DO NOT OVERFILL.**
- After the solution is added, the rubber storage tubing may be removed completely. Recap the soap dispenser bottle for later use. **NOTE:** If the flow cell assembly is not to be used for a prolonged period of time, reinstall the rubber storage tubing between the inlet and outlet bosses. This will prevent evaporation, which may cause the solution's concentrations to alter.
- Connect the air sampler to be calibrated to the upper outlet boss of the flow cell assembly with ¼-inch ID tubing. **NOTE:** An auxiliary liquid trap between sampler and flow cell is recommended to prevent moisture carry over into the sampler during the continuous calibration periods.

Operation

Conditioning the Flow Tube

- Turn on the sampler. Depress the **BUBBLE INITIATE** button several times to wet the inner walls of the flow tube. You will not be able to initiate a timing bubble without first priming the flow tube. Practice will make bubble generation easier.

Electronic Startup

- After the flow tube walls have been primed, turn on the power switch of the Gilibrator control unit. Wait approximately 10 seconds while the system runs through its check sequence. The Run LED will light at this time as well as a Low Battery indication and a series of five dashes displayed on the LCD readout.
- Do not operate the Gilibrator until the Run LED signal goes off. Ready operation is indicated by a series of 4 dashes.

Bubble Generation

- For optimum bubble generation, depress the **BUBBLE INITIATE** button and hold to initiate one bubble up the flow tube. Release the button to initiate a second bubble up the flow tube. This will be the standard procedure for making clean, consistent bubbles at high and medium-flow ranges.
- As the bubble rises up the flow tube it initiates a timing sequence when it passes the lower sensor (Run LED lights) and ends the timing sequence upon passing the upper sensors (Run LED light goes out). The timing information is then transmitted to the control unit which performs the necessary calculation. A flow reading instantaneously appears on the LCD display.

If a bubble breaks before the time sequence is completed, timing will continue until another bubble is generated to trip the second sensors. This will cause an erroneous reading and should be subtracted from the average by pushing the DELETE button.

Flow Readout

The control unit will display the actual flow for each sample and will accumulate and average each successive reading.

- **Average.** To display average and number of samples, depress and hold the AVERAGE button. Releasing the button will display the last flow reading. Repressing the button will display the number of samples accumulated for that averaging sequence and releasing will once again display the last flow reading. Additional pressing and holding will repeat the sequence.
- **Delete.** To delete obvious false readings, push the DELETE button which will automatically delete the false information from the average and reset the average and sample number back to the previous reading.

- **Reset.** To reinstate the sequence for additional pumps, push the RESET button. This will zero out all samples and average registers within the control unit indicating the start of a new sequence. The RESET button is also used if a malformed bubble is generated and has not been subtracted from the average by use of the DELETE function.

Storage

Daily Use

If the Gilibrator is to be used daily, it is recommended that the storage tubing be replaced between the upper and lower cell chambers. Plug in the charger and connect into the control unit charging jack. Recharge overnight for next day usage.

Long-Term Storage

If a Gilibrator is not to be used for long periods of time, the following steps should be taken to keep the unit in proper working order.

- Disconnect the cable assembly from the back of the sensor block on the flow cell assembly.
- Remove the flow cell assembly from the control unit (base). Remove the cell from the base in the reverse order in which it was mounted.
- Pour soap solution out of the bubble generator through the lower inlet boss by holding bubble generator horizontally and, with the inlet boss facing down, tilting at a 45 degree angle. Continue until all of the soap solution is poured out. Then clean the cell.

Maintenance

The Gilibrator is designed so that little maintenance is required.

Cleaning – Interior

There are two methods used to clean the bubble generator.

- The unit may be flushed clean by connecting storage tubing to the upper outlet boss and continuously running water through the generator until water runs clear. Maintain a horizontal position with cell bosses facing down and flush for 15 to 30 seconds. Then remove tubing and rock the cell in a see-saw fashion to empty all excess water. Replace seal tubing between the upper and lower cell bosses; or

- Remove the sensor block assembly by loosening the two holding screws and sliding the block out from between the upper and lower cell chambers. Remove safety tape. Using a small flat-blade screwdriver, lift off the damper plate using the notch between the upper chamber and the lid. Remove the spacer and then the bubble breaker plate. This gives complete access to the interior of the flow cell tube.

Continue to run clear water through the cell until water runs clear. Rock cell to empty all excess water. Replace the bubble breaker plate and center the air outlet boss with the plate's largest hole. Next, insert the spacer. To replace the damper plate assembly, moisten the O-ring with soap solution and then press the damper plate into the top of the upper cell chamber. Using your fingers, firmly squeeze the plate into the upper flow cell chamber.

Cleaning – Exterior

To clean the exterior of the bubble generator use a mild detergent and warm water. NEVER USE ALCOHOL, ACETONE, OR ANY OTHER HARSH CLEANERS TO CLEAN THE BUBBLE GENERATOR.

Transportation

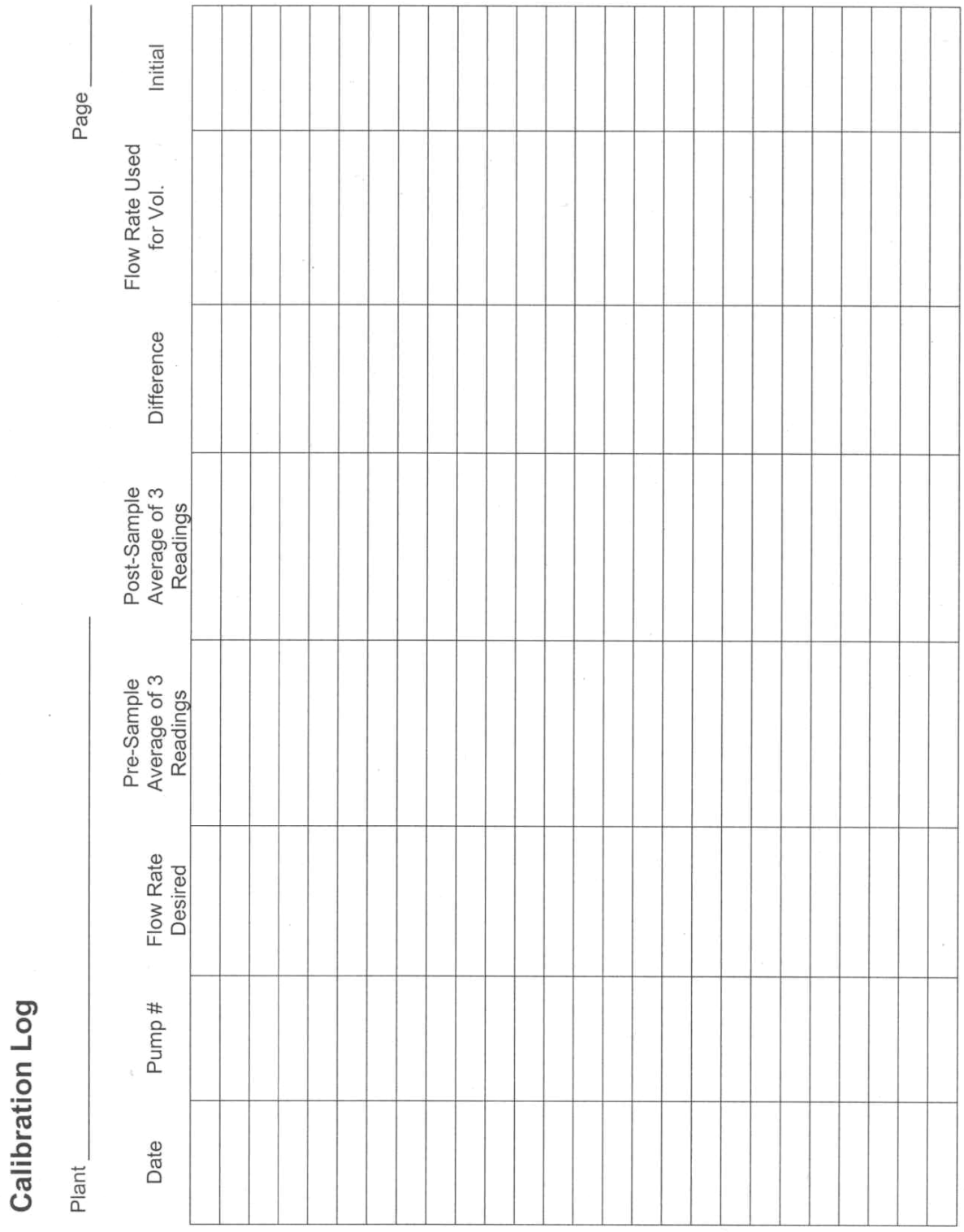
When transporting the Gilibrator, especially by air, it is important that one side of the seal tube that connects the inlet and outlet boss be removed. This will allow for equalizing internal pressure within the generator. Do not transport unit with soap solution or storage tubing in place.

CAUTION: Do not pressurize the flow cell! Excessive pressure may cause the cell to rupture, resulting in personal injury.

Post Sampling Calibration Check

- Adjust the pump so that the rotameter ball falls between the calibration marks or "operating" marks. The flow rate of constant flow pumps without rotameters must not be adjusted before performing post-sampling calibration.
- Time the bubble travel with sampling train in-line. The post-sampling calibration train must be the same as the pre-sampling calibration train.
- The sample is valid if the time or volume displacement agrees with the pre-sampling calibration within $\pm$5% for 3 consecutive timings. Otherwise, the sample is invalid.

Appendix D



Source: Supplied by the R. T. Vanderbilt Company, Inc.

Appendix E-1

Respirable Dust/Silica Sampling Data Sheet

Plant _____ Sample number _____

Type of sample: ☐ Personal breathing zone ☐ Work area ☐ Other
If breathing-zone sample; was respirator used? ☐ Yes ☐ No
Employee _____ Social Security no. _____
Date of sample _____ Obtained by _____
Description of job activity/work area: _____
_____

Weather conditions: ☐ Clear ☐ Overcast ☐ Rain/snow ☐ Windy
Filter no. _____ Pump no. _____ Calibration date _____
Time: Start _____ Stop _____
Rotameter reading (liters per minute): Start _____ Stop _____
Filter blank no. _____
Average flow rate (liters per minute) × Duration of sample (minutes) × 0.001 = Volume of air sampled (cubic meters)
_____ × _____ × 0.001 = _____

Analytical Results:
Respirable dust _____ (mg) Respirable silica _____ (mg) or _____(%)
Analytical method _____ Name of lab _____

$$\% \text{ Respirable silica} = \frac{\text{Respirable silica (milligrams)}}{\text{Respirable dust (milligrams)}} \times 100 = \_\_\_\_\_ \%$$

$$\text{Exposure limit} = \frac{10}{2 + \% \text{ Respirable silica}} = \_\_\_\_\_ \text{ milligrams per cubic meter}$$

(If % = 25, use 25, not 0.25.)

$$\text{Respirable dust concentration} = \frac{\text{Respirable dust (milligrams)}}{\text{Volume of air sampled (cubic meters)}} = \_\_\_\_\_ \text{ milligrams per cubic meter}$$

$$\% \text{ Exposure} = \frac{\text{Respirable dust concentration}}{\text{Exposure limit}} \times 100 = \_\_\_\_\_ \%$$

(If result exceeds 100%, the exposure limit is exceeded.)

% Exposure	Exposure Classification (Circle One)
<50	I
50–100	II
>100	III

Data approved and filed:

_____ _____
Signature Date

Source: All forms in Appendix E-1 to E-3 are from the NISA "Occupational Health Program for Exposure to Crystalline Silica in the Industrial Sand Industry" Manual, 1997.

Form E-1 (Sample)

Respirable Dust/Silica Sampling Data Sheet

Plant Number 1 Sample number _____

Type of sample: ☒ Personal breathing zone ☐ Work area ☐ Other
If breathing-zone sample; was respirator used? ☒ Yes ☐ No
Employee George Wilson Social Security no. 018-64-8192
Date of sample August 16, 1994 Obtained by O. K. Sampler
Description of job activity/work area: Cleaning screens

Weather conditions: ☒ Clear ☐ Overcast ☐ Rain/snow ☒ Windy
Filter no. 2692 Pump no. 03 Calibration date 8/16/94
Time: Start 8:00 a.m. Stop 4:00 p.m.
Rotameter reading (liters per minute): Start 1.7 liters/min Stop 1.7 liters/min
Filter blank no. 2693

Average flow rate (liters per minute) × Duration of sample (minutes) × 0.001 = Volume of air sampled (cubic meters)
1.7 × 480 × 0.001 = 0.816

Analytical Results:
Respirable dust 0.110 (mg) Respirable silica 0.040 (mg) or Respirable silica 36 (%)
Analytical method X-ray Name of lab Green Mount

$$\% \text{ Respirable silica} = \frac{\text{Respirable silica (milligrams)}}{\text{Respirable dust (milligrams)}} \times 100 = 36\ \%$$

$$\text{Exposure limit} = \frac{10}{2 + \% \text{ Respirable silica}} = 0.26 \text{ milligrams per cubic meter}$$

(If % = 25, use 25, not 0.25.)

$$\text{Respirable dust concentration} = \frac{\text{Respirable dust (milligrams)}}{\text{Volume of air sampled (cubic meters)}} = 0.13 \text{ milligrams per cubic meter}$$

$$\% \text{ Exposure} = \frac{\text{Respirable dust concentration}}{\text{Exposure limit}} \times 100 = 50\ \%$$

(If result exceeds 100%, the exposure limit is exceeded.)

% Exposure	Exposure Classification (Circle One)
<50	I
50–100	(II)
>100	III

Data approved and filed:

_____ Signature _____ Date

Appendix E-2

Employee Activity Log for Dust Sampling

Plant _____ Employee Wearing Sampling Pump_____
Dept. _____ Date _____ Shift _____

The descriptions below must accurately reflect ALL ACTIVITIES performed by the employee. Please note any SPECIAL CONDITIONS observed.

Hour 1 (ending _____:_____ a.m./p.m.)

Hour 2 (ending _____:_____ a.m./p.m.)

Hour 3 (ending _____:_____ a.m./p.m.)

Hour 4 (ending _____:_____ a.m./p.m.)

Hour 5 (ending _____:_____ a.m./p.m.)

Hour 6 (ending _____:_____ a.m./p.m.)

Hour 7 (ending _____:_____ a.m./p.m.)

Hour 8 (ending _____:_____ a.m./p.m.)

Form E-2 (Sample)

Employee Activity Log for Dust Sampling

Plant _Mauricetown_____ Employee Wearing Sampling Pump___Sam Smith_____
Dept. __Dryer_____ Date __2/10/07_ Shift _6:00 am – 2:00 pm___

The descriptions below must accurately reflect ALL ACTIVITIES performed by the employee. Please note any SPECIAL CONDITIONS observed.

Hour 1 (ending 7 : 00 (a.m.)/p.m.)	Checked bins 2 times 5 minutes each time
Hour 2 (ending 8 : 00 (a.m.)/p.m.)	Changed screens – 60 mesh 15 minutes
Hour 3 (ending 9 : 00 (a.m.)/p.m.)	Control room, entire hour
Hour 4 (ending 10 : 00 (a.m.)/p.m.)	Loaded 3 dump trucks With 60 sand
Hour 5 (ending 11 : 00 (a.m.)/p.m.)	Control room, 50 minutes Checked bins 1 time, 10 minutes
Hour 6 (ending 12 : 00 a.m./(p.m.))	Lunch room, 30 minutes Control room, 10 minutes
Hour 7 (ending 1 : 00 a.m./(p.m.))	Changed screens – 60 mesh 15 minutes
Hour 8 (ending 2 : 00 a.m./(p.m.))	Control room, 45 minutes Cleanup, 15 minutes

Respirable Crystalline Silica Sampling Summary

Company _____ Plant _____

Date	Sample Number	Description of Sample		Source	Percent Silica	TWA Concentration of Respirable Dust (mg/m^3)	Permissible Exposure Limit (mg/m^3)	% Exposure (concentration/ exposure limit)	TWA Concentration of Crystalline Silica (mg/m^3)
		Job	Area						

Note: TWA = a time weighted average

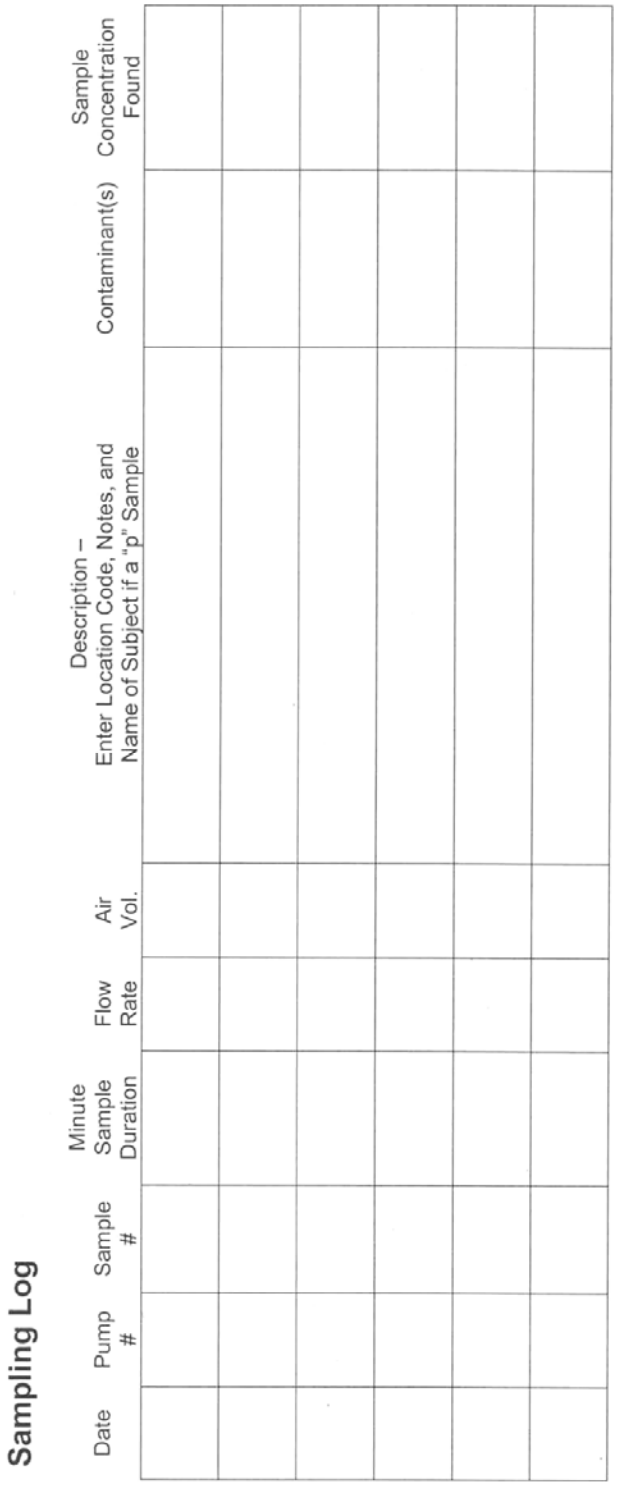
Respirable Crystalline Silica Sampling Summary

Company ABC Company Plant Anyplant

Date	Sample Number	Description of Sample		Source	Percent Silica	TWA Concentration of Respirable Dust (mg/m^3)	Permissible Exposure Limit (mg/m^3)	% Exposure (concentration/ exposure limit)	TWA Concentration of Crystalline Silica (mg/m^3)
		Job	Area						
6/16/07	0106169503	Dryer Oper		Dryer	50%	0.276	0.192	1435	0.138
6/16/07	0106169504	Bulk Loader		Dryer	40%	0.333	0.238	139%	0.135
6/16/07	0106169505	Load-out		Dryer	36%	0.171	0.263	65%	0.061
6/16/07	0106169506	Laborer		Bagger	25%	0.101	0.370	2%	0.024
6/16/07	0106169507	Loader Oper		Yard	27%	0.312	0.370	84%	0.085
6/16/07	0106169508		Bin Room	Dryer	32%	1.850	0.294	629%	0.590
6/16/07	0106169509		Bagger	Bagger	50%	0.070	0.192	36%	0.035

Note: TWA = a time weighted average

Appendix E-4



Sampling Log

Date	Pump #	Sample #	Minute Sample Duration	Flow Rate	Air Vol.	Description – Enter Location Code, Notes, and Name of Subject if a "p" Sample	Contaminant(s)	Sample Concentration Found

Source: Supplied by the R. T. Vanderbilt Company, Inc.

Appendix F

Additional Occupational Permissible Exposure Considerations Associated with Recommended Limits

Action Level: Many industrial hygienists consider sample results that are below a stipulated permissible 8 hour TWA but above ½ that value as a corrective action trigger level. Such action typically includes medical surveillance and a requirement for additional air sampling. As of 2007, there are no published regulatory action level requirements for crystalline silica. As standards are periodically updated, current standards should always be checked. Taking some corrective action at ½ the permissible limit is, however, good practice.

Short term and ceiling exposure limits: For workplace exposures that pose an immediate or "acute" hazard after a certain level is reached, standards often include short term or maximum ceiling levels that cannot be exceeded beyond a stipulated time duration or cannot be exceeded at all for any period of time (a ceiling). Respirable crystalline silica principally poses a chronic or long-term risk as well as an acute risk at highly elevated airborne dust levels. There are currently no short term or ceiling exposure limits applicable to crystalline silica.

Unusual Work Shift Hours: Acceptable workplace exposure limits are based upon a normal 8-hour workday exposure. However, exposure to respirable crystalline silica can occur during work shifts that are less than or more than a normal 8-hour workday. In these instances, a question arises as to the reliability of the 8-hour based acceptable limit as an appropriate gauge of safety. The concern essentially involves lung clearance.

Lung clearance is dependent upon many factors, including the concentration (dose), dust particle size, the durability or bio-persistence of the particle and time to clear the particle after exposure ceases (see Section 1 of this guide). Of principal concern is the possibility that a high dust level exposure during a short exposure period (or a continuous dust exposure over an extended period of time) may excessively tax lung defense mechanisms.

To address lung clearance uncertainties, many occupational health professionals advise adjusting recommended acceptable exposure levels. Several mathematical models exist to accomplish this adjustment but all involve some level of uncertainty due to the complexity of the pharmacokinetics involved (see Section 2 Refs 6, 7, 8). These adjustments result in a higher acceptable exposure limit for shorter than 8-hour work shift exposures and a lower exposure limit for longer than 8-hour work shift exposures.

Using the 2006 recommended ACGIH TLV for Quartz, the most commonly applied adjustment simply divides the typical 8 hour (480 minute) work shift by the actual work shift time. The calculation would be as follows for an 8-hour shift, a 6-hour shift, or a 10-hour shift.

Example:

8 Hr. 0.025 mg/m^3 TLV X $\frac{480\ (1)}{480}$ = 0.025 mg/m3 TLV

6 Hr. 0.025 mg/m^3 TLV X $\frac{480\ (1.3)}{360}$ = 0.035 mg/m3 Adjusted limit

10 Hr. 0.025 mg/m^3 TLV X $\frac{480\ (0.8)}{600}$ = 0.020 mg/m3 Adjusted limit

If a TWA respirable quartz concentration of 0.031 mg/m3 was obtained, this sampling result would exceed the 8 hour TLV and adjusted exposure limit for a 10-hour exposure period, but not the adjusted exposure limit for the 6-hour exposure period.

It is important to remember that the 0.031 mg/m^3 sample result is a time weighted average (TWA) already adjusted for the exposure period sampled. Thus, if a sampling result for an exposure period shorter than a standard 8 hour day is considered representative of an 8-hour exposure, that result can be directly contrasted to the 8-hour standard. An adjustment to the exposure limit (as in examples above) would not be calculated in that instance. *It should be noted that calculating the adjusted exposure limit is not a process that MSHA uses.*

Multiple samples for single exposure period: If consecutive filter-cassettes are used to cover a single work shift (versus a single filter-cassette), the sample taker will need to consolidate the sample results in order to compare the work shift exposure to a full shift exposure limit. This is accomplished by multiplying the concentration reported for each filter by the minute sampling duration of that sample. Those dust concentrations are then added together as well as the minute sample durations for each sample. The sum of the concentrations are then divided by the sum of the sample durations.

Example*: Assume three filters were used to cover a full 480 minute shift. Results reported by the laboratory show a concentration of 0.06 mg/m^3 for 210 minutes, TWA concentration of 0.08 mg/m^3 for 100 minutes, and TWA concentration of 0.15 mg/m^3 for 170 minutes:*

$$0.06 \times 210 = 12.6$$
$$0.08 \times 100 = 8.0$$
$$0.15 \times \frac{170}{480} = \frac{25.5}{46.1}$$

$$\frac{46.1}{480} = 0.096 \text{ mg/m}^3 \text{ Shift Exposure}$$

Source: Guide Authors and U.S. Department of Labor, Mine Safety and Health Administration, National Mine Health and Safety Academy. Industrial Hygiene: Sampling for Silica and Noise Metal and Nonmetal Specialized Training – Student Text Material. IG 13a. 1999. Page T-55.

Appendix G

Employee Sampling Result Notice Form: Example

To: _____ Date _____
Sampled_____
Dept./Activity: _____ Time _____
Sampled_____

Recently you were a participant in a work-place dust sampling study and wore monitoring equipment important to this study. As a courtesy, your dust sampling results are reported below.

The purpose of such studies is to reflect the level of dust exposure that exists in your work area. The results of such sampling help determine what additional protective steps (if any) might be required to protect your health. It is important to understand that the "result(s)" reflected here are for a single work shift and should be viewed as a guide only.

Equivalent 8 hr. time weighted average obtained by type of dust sampled:

_____

Interpretation:

_____ Within Standard Limits
_____ Elevated Exposure (still within standard limits)
_____ Excessive Exposure

Comment:

Follow-up:

_____ None Required
_____ Periodic Resample *
_____ Use Respiratory Protection
_____ Periodic Medical Review
_____ Engineering/Administrative Control

Comment:

*** Dust results represent only those obtained on the survey date. As daily work activities change, your dust exposure is likely to change as well. Periodic sampling may therefore be required as a way to measure your exposure over time.**

Dust Standard Applied:

Questions regarding this notification should be directed to: _____
Employee Signature:_____Date: _____

Thank you for your Cooperation:
Signed: _____ Date: _____

Source: Supplied by the R. T. Vanderbilt Company, Inc.

Appendix H

Range of Capture Velocities

Condition of Dispersion of Contaminant	Examples	Capture Velocity, fpm
Released with practically no velocity into quiet air	Evaporation from tanks, degreasing, etc.	50-100
Released at low velocity into moderately still air	Spray booths, intermittent container filling, low speed conveyor transfers, welding, plating, pickling	100-200
Active generation into zone of rapid air motion	Spray painting in shallow booths, barrel filling, conveyor loading, crushers	200-500
Released at high initial velocity into zone of very rapid air motion	Grinding, abrasive blasting, tumbling	500-2000

In each category above, a range of capture velocity is shown. The proper choice of values depends on several factors:

Lower End of Range	Upper End of Range
1. Room air currents minimal or favorable to capture	1. Disturbing room air currents
2. Contaminants of low toxicity or of nuisance value only	2. Contaminants of high toxicity
3. Intermittent, low production	3. High production, heavy use
4. Large hood – large air mass in motion	4. Small hood – local control only

Range of Duct Transport Velocities

Nature of Contaminant	Examples	Design Velocity
Vapors, gases, smoke	All vapors, gases, and smoke	Any desired velocity (economic optimum velocity usually 1000-1200 fpm)
Fumes	Zinc and aluminum oxide fumes	1400-2000
Very fine light dust	Cotton lint, wood flour, litho powder	2000-2500
Dry dusts and powders	Fine rubber dust, Bakelite molding powder dust, jute lint, cotton dust, shavings (light), soap dust, leather shavings	2500-3500
Average industrial dust	Sawdust (heavy and wet), grinding dust, buffing lint (dry), wood jute dust (shaker waste), coffee beans, shoe dust, granite dust, silica flour, general material handling, brick cutting, clay dust, foundry (general), limestone dust, packaging and weighing asbestos dust in textile industries	3500-4000
Heavy dusts	Metal turnings, foundry tumbling barrels and shakeout, sand blast dust, wood blocks, hog waste, brass turnings, cast iron boring dust, lead dust	4000-4500
Heavy or moist dusts	Lead dust with small chips, moist cement dust, asbestos chunks from transite pipe cutting machines, buffing lint (sticky), quick-lime dust	4500 and up

Source: Industrial Ventilation ACGIH, 25th Edition 2004.

Appendix I

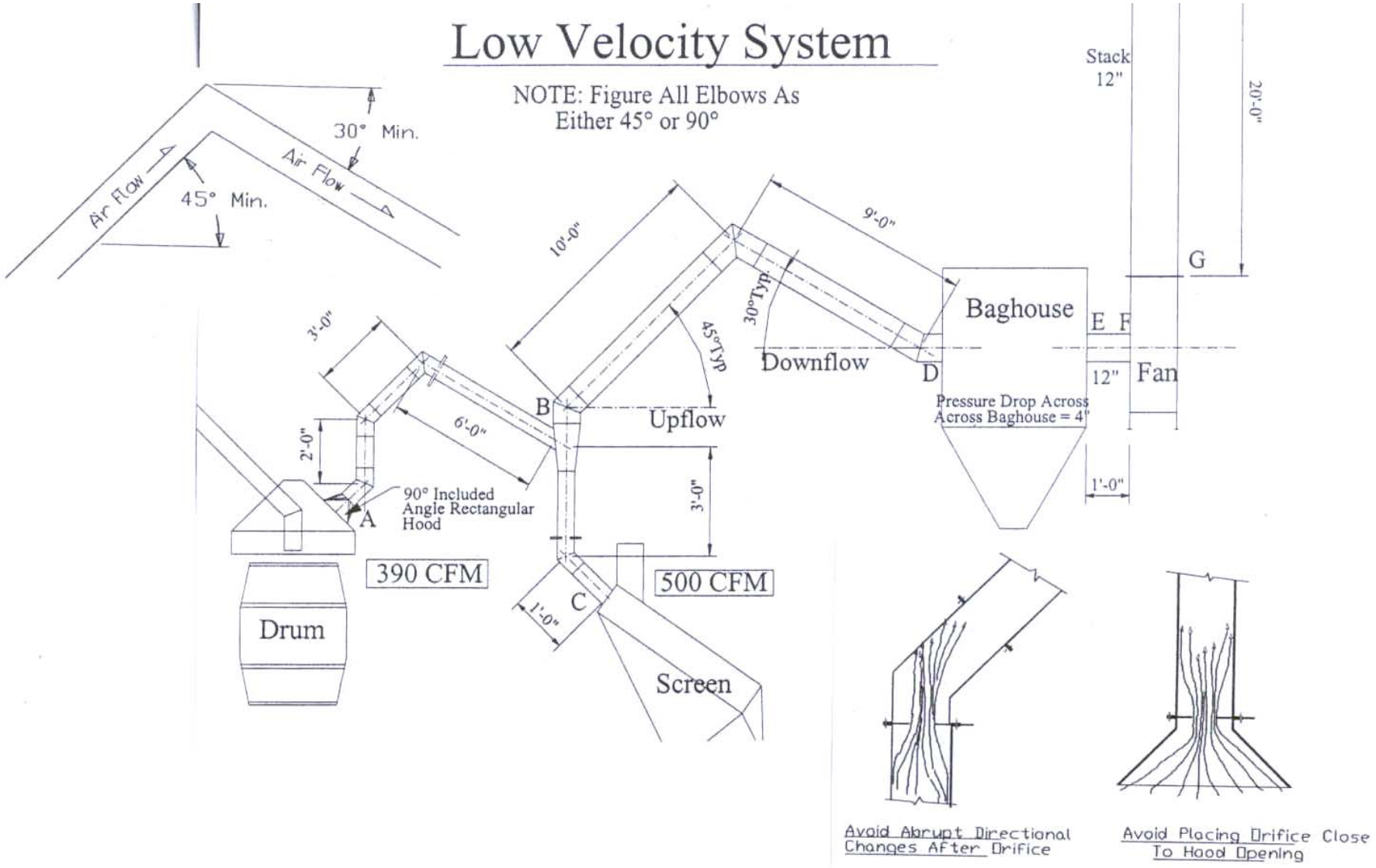
Low Velocity Dust Control

Two types of design for dust control systems are utilized in the mining industry. Most familiar is the ***high velocity*** design, where air velocities in the ductwork are in the range of 3,000 to 4,000 feet per minute (FPM). The other newer design is the ***low velocity*** system where transport velocities are less than 1,800 FPM. There are significant advantages to the low velocity transport design. A high velocity system carries all particles collected through ductwork to the dust collector. This system's disadvantages are that maintenance costs are higher, product is lost to the dust collector, and the system requires more energy to operate. The ductwork is subjected to highly abrasive blasting from the coarser dust particles. A single hole worn in a high velocity duct can imbalance the whole system, and dramatically reduce its effectiveness in controlling dust exposure. The low velocity design is a dust containment system where only the fine, primarily respirable size particles are moved to the collection device. Coarser particles, which are contained, rather than conveyed, are returned to the process stream. It is important to remember that low velocity does not mean low airflow. Pickup air flows, capture velocities, hood design and static pressures at the pickup points are the same in either a low or high velocity transport system. The term "low velocity" only refers to that part of the ducting system downstream from the pickup point. The advantages of the low velocity system are lower maintenance costs, lower energy consumption, and more reliable dust control. The system is less likely to lose effectiveness due to wear. Although the low velocity system has a higher initial capital cost, over the life of the system this is offset by lower energy and maintenance costs.

Source: U.S. Silica Corporation

Low Velocity System

NOTE: Figure All Elbows As Either 45° or 90°



Appendix J

Sample Respirator Program

I. Object

The object of this program is to control exposure to airborne contaminants in the air which may cause occupational disease or injury. This is to be accomplished to the extent feasible by accepted engineering control measures such as general or local ventilation, enclosure or isolation, and substitution of less hazardous processes or materials. When effective engineering controls are not feasible, or while they are being instituted, appropriate respirators may be required.

II. Purpose and Scope

The practices and procedures described here constitute the program under which respirators are effectively used at _____.

Underlined statements or blanks are to be filled in by management to fit the program to the specific needs of the operation or area where respirators are to be used.

III. Responsibility

A. _____ is the respirator program coordinator who is responsible for:

1. Provision of appropriate respirators.
2. Implementing the training and instruction program.
3. Administering the overall program.

Effective training and supervision are crucial to make this part of the program effective.

B. Supervisory personnel are responsible for:

1. Making sure that appropriate respirators are available when needed.
2. Ensuring that employees wear respirators as required.
3. Inspecting respirators on a regular basis.

C. The employee is responsible for:

1. Using the respirator in accordance with instructions and training.
2. Cleaning, disinfecting, inspecting, and storing his/her respirator.
3. Reporting a respirator malfunction to the supervisor.

If a specific person is responsible for cleaning and disinfecting the respirators, this section would be rewritten.

Source: MSHA text (ref. 2-12)

D. The _____ is responsible for ensuring that the written job procedure or other task outlines include the requirement for respirator use when necessary.

This is the person responsible for reviewing the process description in your operation and determining the point at which respiratory protection should be used.

E. Corporate industrial hygiene services is responsible for:

1. Technical assistance in determining the need for respirators and in the selection of appropriate types.
2. Providing surveillance of work area conditions.
3. Periodically evaluating the respirator program.
4. Providing educational materials to be used in employee training.

Surveillance of work conditions is essential to an effective respirator program. Air sampling and surveys are necessary to determine the proper application and safety of respirator use.

F. Corporate safety is responsible for:

Technical assistance in the selection of respirators for use in emergency reentry situations and the training and instructions necessary for their use.

The respirator program coordinator should discuss with the safety engineer the need for emergency respirators.

IV. Respirator Selection

Respirators are selected by the respirator program coordinator and industrial hygiene services. Their choice(s) is based on the physical, chemical and physiological properties of the air contaminants and on the concentration likely to be encountered.

Respirators have various capabilities and limitations. In addition to the toxicological properties and air concentrations of the chemicals encountered, the nature of work, as well as quality and fit of the respirator must be considered.

V. Fit Testing

Proper fit by qualitative fit tests will determine which respirator will be assigned to an employee.

Testing should involve simulation of actual work conditions.

Improper fit or interference with the face piece will bar an employee from working in an area where the use of respirators is required.

Glasses, beards or sideburns may prevent a good seal. The respirator can't be worn until the condition is corrected.

VI. Distribution

Respirators will be assigned to individuals whenever possible. Each assigned respirator will be identified in a way that does not interfere with its performance.

A tag system may be used.

VII. Inspection and Maintenance

A. Inspection

1. The user inspects the respirator before and after cleaning to check condition of face piece, head bands, valves and hoses, and canister, filler or cartridge.
2. The foreman or supervisor inspects all respirators regularly.

At least once per month is a suggested minimum.

B. Maintenance

Respirators which do not pass inspections are to be replaced or repaired immediately. The user may change canisters, cartridges, filters and head straps. All other replacements or repairs are performed by _____, a person experienced with parts designed for the respirator(s).

The experienced person should be a designated technician who is trained or experienced in the repair of all respirators used.

VIII. Cleaning

Individually assigned respirators are cleaned and disinfected as frequently as necessary to ensure that proper protection is provided for the wearer. Respirators not individually assigned and those for emergency use are cleaned and disinfected after each use. The following procedure is used for cleaning and disinfecting respirators:

The specific cleaning procedure selected should be included in the text of the respirator program.

A. Filters, cartridges or canisters are removed before washing the respirator and discarded as necessary.

B. Respirators are washed in a cleaner-disinfectant or detergent solution, rinsed in clean water and allowed to dry in a clean area.

IX. Storage

After inspecting, cleaning and necessary repairs, respirators are stored to protect against dust, sunlight, heat, extreme/excessive moisture or damaging chemicals.

It is recommended that respirators be stored in plastic bags in the original cartons and placed in specifically designated cabinets or lockers with other protective equipment. Cartridges or canisters and masks equipped with these components should be sealed in plastic bags to preserve their effectiveness. Improper storage will usually result in reduced service life and added cost.

X. Training

Every employee who may have to wear a respirator is trained in the proper use of the respirator. Both the employees and supervisors receive this training which includes:

A. Description of the respirator
B. Intended use and limitations of the respirator
C. Proper way to wear, adjustment, and testing for fit
D. Cleaning and storage methods
E. Inspection and maintenance procedures

Training is repeated as necessary, at least annually, to ensure that employees remain familiar with the proper use and care of respiratory protection.

XI. Records

The following records are maintained by_____.

A. The number and type of respirators in use
B. A record of employee training programs
C. Inspection and maintenance records
D. A record of fit testing
E. Medical certification that the employee is capable of wearing a respirator under the given working conditions.

Fill in the name and/or title of the person responsible for record keeping. The respirator program coordinator is a common choice.

A person should not be assigned to tasks requiring the use of respirators unless a physician has determined that the user is physically able to perform the work and use the equipment.

Appendix K

Portacount Plus® – Basic Fit Testing Procedure

Projected Time Per Test: 15 minutes

PREPARATION:

- Develop a test schedule (leave a few minutes between tests).
- Be sure employees understand there can be no smoking at least 30 minutes prior to test.
- Prior to each day of testing be sure Portacount is in proper operating condition – run through specified equipment checks (ambient particle count, zero check, and fit factor test with small HEPA filter).

SETUP

- Install alcohol soaked wick in machine (see instruction book if new wick is needed).
- Place HEPA filter on the clean sampling tube and push ON/OFF button. Allow to warm up for 60 seconds.
- Perform ambient particle count test. Remove small HEPA filter and press **COUNT** button. Number reflected must exceed 1000.
- Perform zero test. Place HEPA filter back on clear sampling tube. Number reflected should be 0 or no greater than 0.6.
- Perform Max. Fit Test. Push **FIT TEST** button and **TEST** button (with HEPA filter still on). Run through Exercise 1 (80 seconds) and let machine run into Exercise 2. Into Exercise 2 a fit factor number for Exercise 1 will appear. This number should exceed 50,000.

NOTE: If any of these tests are off, check alcohol wick and the manual for troubleshooting.

Push **TEST** button to STOP TESTS.

THE NEXT PUSH OF THE TEST BUTTON SHALL BEGIN EMPLOYEE TESTING (leave the HEPA filter on the sampling tube until respirator is connected).

Pass/Fail Fit Factor Standard to use:

100 for half masks
500 for full masks

Source: Procedure for the Use of Portacount Plus Fit Tester – TSI Incorporated.
Procedure, Form, and Facial Hair Guide provided by the R. T. Vanderbilt Company, Inc.

Respirator Quantitative Fit Test
Recording Data Sheet

Plant: _____ Test Date: _____

Employee Name: _____ Age:
Respirator Type: _____
Medical Respirator Use Approval Yes_____ No_____ No Record_____

QUESTIONS FOR EMPLOYEE

Have you smoked within the last 30 minutes? Yes_____ No_____
How long have you had this respirator? _____
Time since last training on respirator use? < 1 yr._____ > 1 yr._____

Note respirator condition problems (if any)

Was respirator put on properly (straps, etc.)? Yes_____ No_____
Positive and negative fit test performed properly? Yes_____ No_____

TEST EXERCISES	Fit Factor #	Check ✓	Pass	Fail
1. Normal breathing	_____		____	____
2. Deep breathing	_____		____	____
3. Head side to side	_____		____	____
4. Head up and down	_____		____	____
5. Talking out loud	_____		____	____
__ _____	_____		____	____
__ _____	_____		____	____
__ _____	_____		____	____
Fit Factor Standard Used_____ Average Fit Factor_____			____	____

IF FAILED –CHECK POSSIBLE REASONS: Facial Hair_____ Poor Adjustment_____
Poor Respirator Condition_____ Wrong Size_____
Change in Facial Shape (weight, dental, medical, etc.)_____

IF POSSIBLE – CORRECT PROBLEM AND RETEST

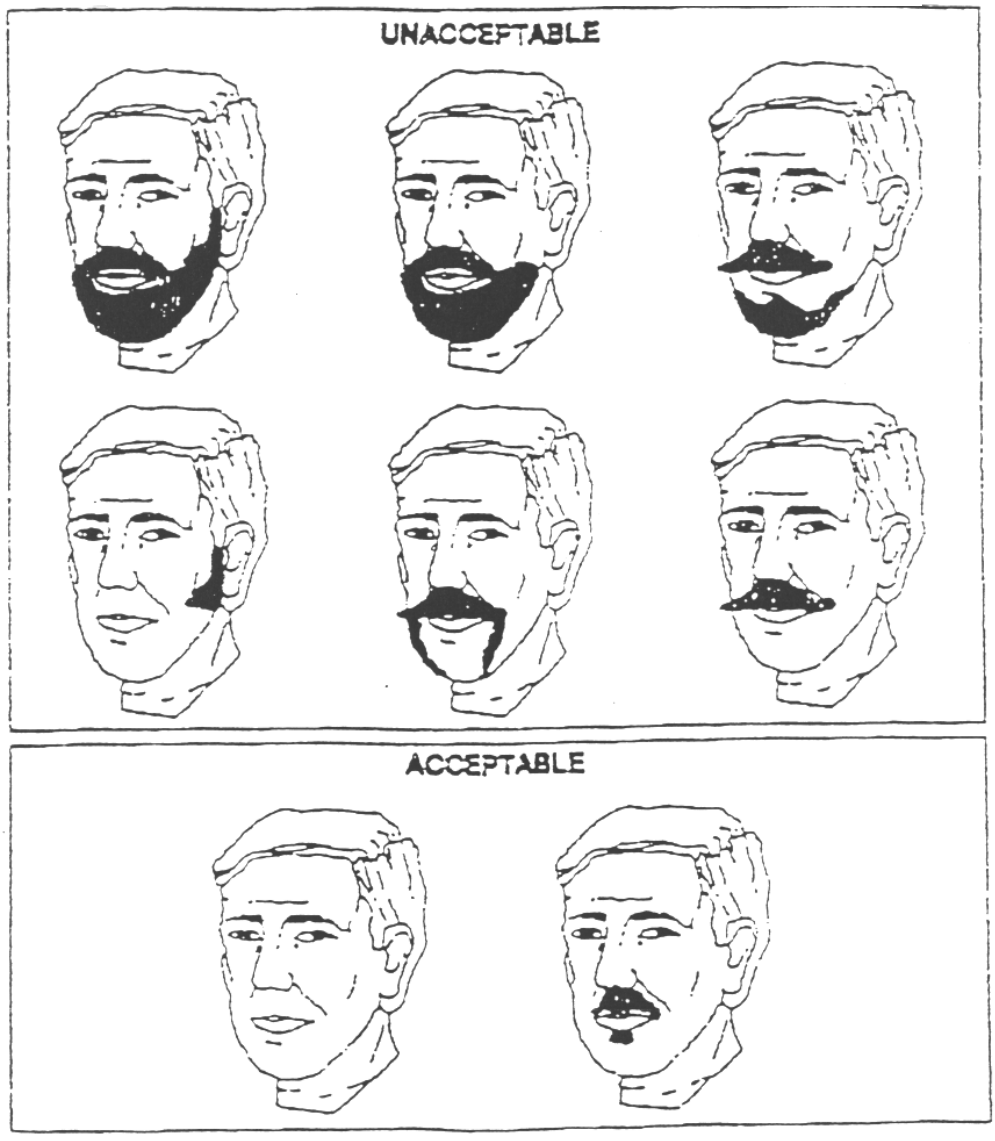
IS THIS A RETEST FOR A PROBLEM? Yes ____ No ____

ADDITIONAL COMMENTS:

TESTER NAME: _____
RETAIN TEST DATA IN FILE INDEFINITELY
ROUTINE RETEST ANNUAL _____ 6 MONTHS _____

Respirator Seal Requirements and Facial Hair

The shaded portions above are respirator seal areas.
Facial hair should not be grown in the shaded areas.



Appendix L-1

Respiratory System Medical and Work History

Respiratory occupational health screening examinations can only indicate the presence of a possible medical problem. Abnormal findings detected by screening must be confirmed and then referred for diagnostic studies to determine their relationship to occupational exposure and/or their true significance. An accurate and up-to-date medical and work history is an essential part of a health screening examination. Please answer the following questions as completely and frankly as you can. If you are uncertain of a response, leave the answer blank. Your answers will be held in strict confidence in your medical records and may be used in medical studies without public release of your name.

Name _____ Date of birth _____
Social Security no. _____ Home phone _____
Company name _____
Plant location _____
Job title _____
Physician's name _____ Physician's phone _____
Physician's address _____
City _____ State _____ Zip _____
Your height: _____ feet _____ inches
Race (optional): ☐ White ☐ Black ☐ Hispanic ☐ Asian/Pacific ☐ Alaskan/Indian
Sex: ☐ Male ☐ Female

Family History

Your family history plays a significant role in your medical health status. Please check the appropriate boxes to indicate if any member of your family has had any of the following conditions:

Respiratory problems, lung disorders:
☐ Father ☐ Mother ☐ Grandparent ☐ Brother/sister ☐ Children

Asthma, hay fever, allergies:
☐ Father ☐ Mother ☐ Grandparent ☐ Brother/sister ☐ Children

Emphysema or bronchitis:
☐ Father ☐ Mother ☐ Grandparent ☐ Brother/sister ☐ Children

Tuberculosis or consumption:
☐ Father ☐ Mother ☐ Grandparent ☐ Brother/sister ☐ Children

Lung or respiratory cancer:
☐ Father ☐ Mother ☐ Grandparent ☐ Brother/sister ☐ Children

Heart problems:
☐ Father ☐ Mother ☐ Grandparent ☐ Brother/sister ☐ Children

Collapsed lung:
☐ Father ☐ Mother ☐ Grandparent ☐ Brother/sister ☐ Children

Source: NISA Guide, "Occupational Health Program for Exposure to Crystalline Silica in the Industrial Sand Industry (1997)

Personal History

How many colds have you had in the past year?
☐ 1–3 ☐ 4 or more

Do you cough up sputum/phlegm?
☐ After getting up in the morning ☐ When lying down ☐ All day

What color is your sputum/phlegm?
☐ White or clear ☐ Yellow or green ☐ Bloody

Have you ever had asthma?
☐ Yes ☐ Yes (currently under treatment) ☐ Childhood only

Do you have:
☐ Chronic or dry cough not due to cigarettes or smoking ☐ Chronic or recurrent productive cough
☐ Blood being coughed up from chest or lungs ☐ Red, rusty, or foaming pink phlegm

Do you usually cough first thing in the morning (on getting up) in the winter?
☐ Yes ☐ No

Do you usually cough during the day-–or at night—in the winter?
☐ During the day ☐ At night ☐ At work

Do you cough like this on most days (or nights) for as much as three months each year?
☐ Yes ☐ No

Do you usually bring up any phlegm from your chest during the day—or night—in the winter?
☐ Yes ☐ No

In the past three years have you had a period of (increased) cough and phlegm lasting for three weeks or more?
☐ Yes ☐ No

Have you had more than one such period?
☐ Yes ☐ No

Have you coughed up blood:
☐ In the past year ☐ Before the past year

Are you troubled by shortness of breath:
☐ When hurrying on level ground or walking up a short hill ☐ When walking on level ground with people your own age
☐ During exercise ☐ At work

Does your chest ever sound wheezing or whistling?
☐ During the day ☐ At night

Have you recently had attacks of shortness of breath with wheezing?
☐ Yes, at home ☐ Yes, at work

If so, is your breathing absolutely normal between attacks?
☐ Yes ☐ No

What weather conditions affect your chest?
☐ Fog ☐ Damp ☐ Cold ☐ Heat

Do you usually have a stuffy nose in the winter?
☐ Yes ☐ No

Personal History (Continued)

Do you usually have a stuffy nose in the summer?

☐ Yes ☐ No

Do you have a stuffy nose for as much as three months each year?

☐ Yes ☐ No

During the past three years, has any chest illness kept you from your usual activities for as much as a week?

☐ Yes ☐ No

Did you bring up more phlegm than usual during any such illness?

☐ Yes ☐ No

Have you ever had:

☐ Chest injury	☐ Chest operation	☐ Heart trouble	☐ Bronchitis	☐ Pneumonia
☐ Pleurisy	☐ Pulmonary tuberculosis	☐ Bronchial asthma	☐ Emphysema	☐ Bronchiectasis
☐ Collapsed lung	☐ Black lung disease	☐ Asbestosis	☐ Pneumoconiosis	☐ Byssinosis
☐ Farmer's lung	☐ Other chest trouble			

Smoking history:

☐ Never smoked	☐ Ex-smoker	☐ Present smoker—do not inhale
☐ Present smoker—inhale slightly	☐ Present smoker—inhale moderately	☐ Present smoker—inhale deeply

Type of smoker:

☐ Cigarettes only ☐ Pipe only ☐ Cigars only ☐ Cigarettes, pipe and cigars ☐ Cigars and pipe

If you are an ex-smoker, how much did you smoke per day?

☐ ½ pack ☐ 1 pack ☐ 1½ packs ☐ 2 packs ☐ More than 2 packs

Do you use smokeless tobacco?

☐ Snuff ☐ Chewing tobacco

If you currently smoke, how much do you smoke per day (average, including weekends)?

Cigarettes:	☐ ½ pack	☐ 1 pack	☐ 1½ packs	☐ 2 packs	☐ More than 2 packs
Cigars:	☐ 1	☐ 2–5	☐ 6–10	☐ 11 or more	
Pipe:	☐ ½ oz.	☐ 1 oz.	☐ 2 oz.	☐ More than 2 oz.	

What age were you when you started smoking?

_____ years

For how many years have you smoked?

_____ years

Have you ever worked:

☐ In dusty places	☐ In a coal mine	☐ In a hard rock or uranium mine
☐ In a mill processing mined or quarried materials	☐ In any other mine	☐ In a quarry, including sand
☐ In a foundry	☐ In a pottery	☐ In abrasive blasting/sand blasting
☐ In construction, insulation, or shipyard work	☐ In welding	☐ With asbestos
☐ With X-rays or radioactive substances		

Personal History (Continued)

Have you ever worked where you often or daily breathed any of the following materials? (Check all appropriate.)

☐ Coal dust	☐ Silica or blasting sand	☐ Asbestos dust	☐ Talc, clay, diatomaceous earth
☐ Insect or plant spray	☐ Metal fumes or dust	☐ Plastic or resin fumes	☐ Engine exhaust fumes
☐ Grain dust	☐ Wood dust	☐ Toxic or irritating gases	☐ Toluene diisocyanate
☐ Methyl isocyanate	☐ Other isocyanates	☐ Mold, spores, pollen, yeast, or fungi	☐ Lead

Do you have a fear of:

☐ Being in closed places ☐ Wearing a face mask or respirator

Have you ever been told by a physician not to wear a face mask:

☐ Yes ☐ No

Do you have a problem getting a face mask or respirator to fit properly because of:

☐ Facial configuration ☐ Facial hair

How often do you wear a respirator?

☐ 4–8 hours per day ☐ Less than 4 hours per day ☐ As needed ☐ For emergencies only

What are the conditions when you use a respirator?

☐ Normal ☐ Noisy ☐ Heavy physical work

Can you use a respirator comfortably?

☐ Yes ☐ No

Have you been trained in the proper use of a respirator?

☐ Yes ☐ No

Do you have any of the above following symptoms while at work?

☐ Coughing and wheezing ☐ Throat irritation ☐ Nose irritation ☐ Eye irritation

Do you have any of the above symptoms after work?

☐ At night ☐ On weekends

Have you ever been off work for a shift or longer after acute exposure to gases or fumes?

☐ Yes ☐ No

Comments

Appendix L-2

Employment History: Pre-Placement and Biennial Update

Name: _____ Social Security Number: _____ Date: _____

List below all of your employment with a description of each specific kind of work, the approximate duration of each job, and the materials you used. Begin with the most recent employment and go back to your first job. Be sure to include your present job, along with all of your previous ones.

Kind of Business or Industry	Description of Job	Years Worked		Comments on Products and Materials Used
		From	To	

Source: NISA Guide, "Occupational Health Program for Exposure to Crystalline Silica in the Industrial Sand Industry (1997)

Appendix M

Specifications for Chest X-Rays: Public Health Service Specifications for Chest Roentgenograms

§ 37.41 Chest roentgenogram specifications.

(a) Every chest roentgenogram shall be a single posteroanterior projection at full inspiration on a film being no less than 14 by 17 inches and no greater than 16 by 17 inches. The film and cassette shall be capable of being positioned both vertically and horizontally so that the chest roentgenogram will include both apices and costophrenic angles. If a miner is too large to permit the above requirements, then the projection shall include both apices with minimum loss of the costophrenic angle.

(b) Miners shall be disrobed from the waist up at the time the roentgenogram is given. The facility shall provide a dressing area and for those miners who wish to use one, the facility shall provide a clean gown. Facilities shall be heated to a comfortable temperature.

(c) Roentgenograms shall be made only with a diagnostic X-ray machine having a rotating anode tube with a maximum of a 2 mm. source (focal spot).

(d) Except as provided in paragraph (e) of this section, roentgenograms shall be made with units having generators which comply with the following: (1) The generators of existing roentgenographic units acquired by the examining facility prior to July 27, 1973, shall have a minimum rating of 200 mA at 100 kVp.; (2) generators of units acquired subsequent to that date shall have a minimum rating of 300 mA at 125 kVp.

Note: A generator with a rating of 150 kVp. is recommended.

(e) Roentgenograms made with battery-powered mobile or portable equipment shall be made with units having a minimum rating of 100 mA at 110 kVp. at 500 Hz, or of 200 mA at 110 kVp. at 60 Hz.

(f) Capacitor discharge and field emission units may be used if the model of such units is approved by ALOSH for quality, performance, and safety. ALOSH will consider such units for approval when listed by a facility seeking approval under § 37.42 of this subpart.

(g) Roentgenograms shall be given only with equipment having a beamlimiting device which does not cause large unexposed boundaries. The beam limiting device shall provide rectangular collimation and shall be of the type described in part F of the suggested State regulations for the control of radiation or (for beam limiting devices manufactured after August 1, 1974) of the type specified in 21 CFR 1020.31. The use of such a device shall be discernible from an examination of the roentgenogram.

(h) to insure high quality chest roentgenograms:

(1) The maximum exposure time shall not exceed 1/20 of a second except that with single phase units with a rating less than 300 mA at 125 kVp. and subjects with chests over 28 cm. posteroanterior, the exposure may be increased to not more than 1/10 of a second;

(2) The source or focal spot to film distance shall be at least 6 feet;

(3) Medium speed film and medium speed intensifying screens are recommended. However, any film-screen combination, the rated "speed" of which is at least 100 and does not exceed 300, which produces roentgenograms with spatial resolution, contrast, latitude and quantum mottle similar to those of systems designated as "medium speed" may be employed;

(4) Film-screen contact shall be maintained and verified at 6 month or shorter intervals;

(5) Intensifying screens shall be inspected at least once a month and cleaned when necessary by the method recommended by the manufacturer;

Source: NISA "Occupational Health Program for Exposure to Crystalline Silica in the Industrial Minerals Industry" (1997). Originally from 30 CFR Title 42, Part 37, Section 37.41.

(6) All intensifying screens in a cassette shall be of the same type and made by the same manufacturer;

(7) When using over 90 kV., a suitable grid or other means of reducing scattered radiation shall be used;

(8) The geometry of the radiographic system shall insure that the central axis (ray) of the primary beam is perpendicular to the plane of the film surface and impinges on the center of the film;

(9) A formal quality assurance program shall be established at each facility.

(i) Radiographic processing:

(1) Either automatic or manual film processing is acceptable. A constant time-temperature technique shall be meticulously employed for manual processing.

(2) If mineral or other impurities in the processing water introduce difficulty in obtaining a high-quality roentgenogram, a suitable filter or purification system shall be used.

(j) Before the miner is advised that the examination is concluded, the roentgenogram shall be processed and inspected and accepted for quality by the physician, or if the physician is not available, acceptance may be made by the radiologic technologist. In a case of a substandard roentgenogram, another shall be immediately made. All substandard roentgenograms shall be clearly marked as rejected and promptly sent to AL0SH for disposal.

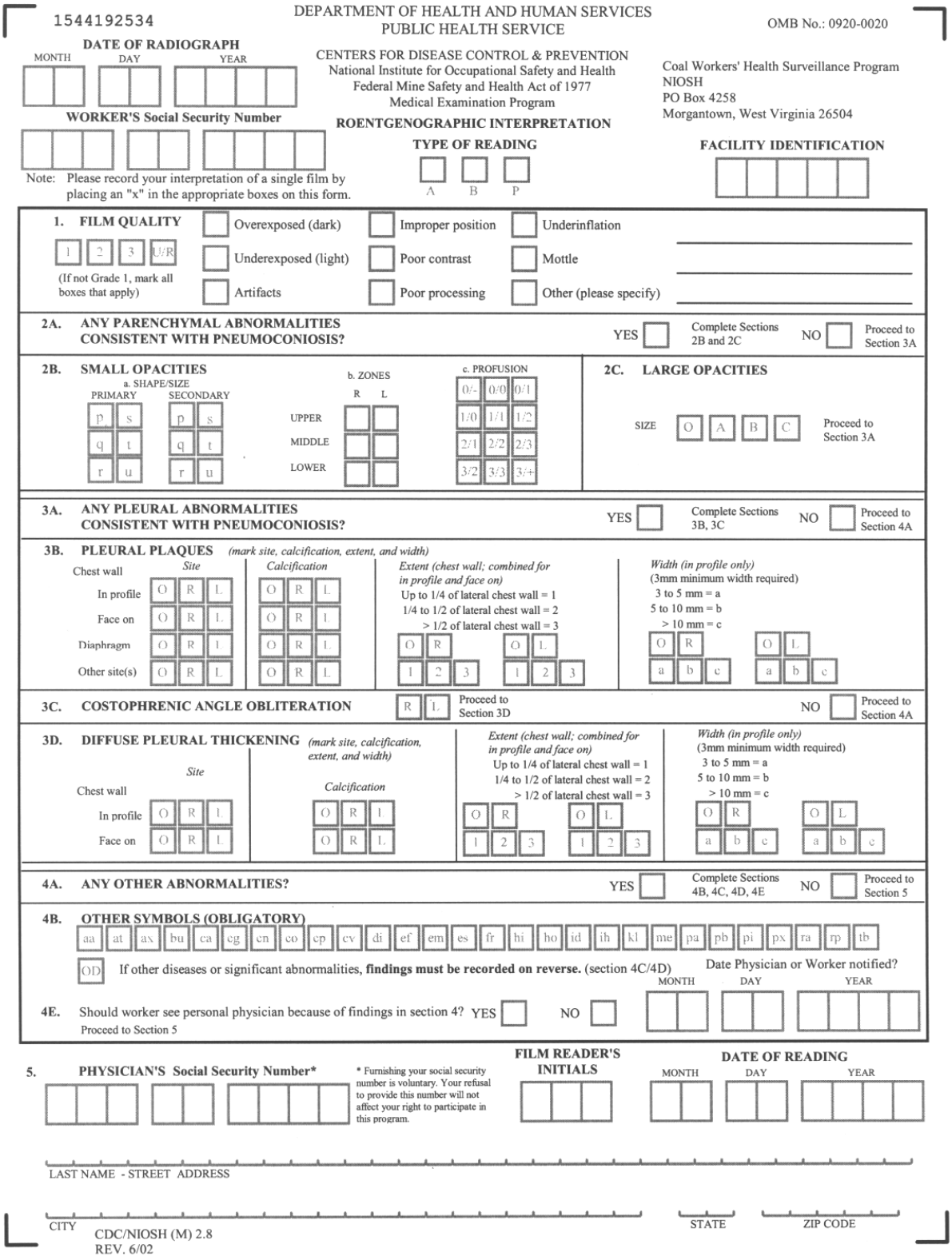
(k) An electric power supply shall be used which complies with the voltage, current, and regulation specified by the manufacturer of the machine.

(l) A densitometric test object may be required on each roentgenogram for an objective evaluation of fill quality at the discretion of ALOSH.

(m) Each roentgenogram made hereunder shall be permanently and legibly marked with the name and address or ALOSH approval number of the facility at which it is made, the social security number of the miner, and the date of the roentgenogram. No other identifying markings shall be recorded on the roentgenogram.

[43 FR 33715, Aug. 1, 1978, as amended at 52 FR 7866, Mar. 13, 1987]

Appendix N



1544192534

DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE

OMB No.: 0920-0020

DATE OF RADIOGRAPH MONTH DAY YEAR

CENTERS FOR DISEASE CONTROL & PREVENTION
National Institute for Occupational Safety and Health
Federal Mine Safety and Health Act of 1977
Medical Examination Program

Coal Workers' Health Surveillance Program
NIOSH
PO Box 4258
Morgantown, West Virginia 26504

WORKER'S Social Security Number

ROENTGENOGRAPHIC INTERPRETATION

TYPE OF READING A B P

FACILITY IDENTIFICATION

Note: Please record your interpretation of a single film by placing an "x" in the appropriate boxes on this form.

1. FILM QUALITY 1 2 3 U/R (If not Grade 1, mark all boxes that apply)

Overexposed (dark) | Improper position | Underinflation
Underexposed (light) | Poor contrast | Mottle
Artifacts | Poor processing | Other (please specify) _____

2A. ANY PARENCHYMAL ABNORMALITIES CONSISTENT WITH PNEUMOCONIOSIS? YES Complete Sections 2B and 2C NO Proceed to Section 3A

2B. SMALL OPACITIES

a. SHAPE/SIZE — PRIMARY: p q r; SECONDARY: s t u

b. ZONES — R L: UPPER, MIDDLE, LOWER

c. PROFUSION: 0/- 0/0 0/1 / 1/0 1/1 1/2 / 2/1 2/2 2/3 / 3/2 3/3 3/+

2C. LARGE OPACITIES SIZE O A B C Proceed to Section 3A

3A. ANY PLEURAL ABNORMALITIES CONSISTENT WITH PNEUMOCONIOSIS? YES Complete Sections 3B, 3C NO Proceed to Section 4A

3B. PLEURAL PLAQUES *(mark site, calcification, extent, and width)*

Chest wall	Site O R L	Calcification O R L	Extent (chest wall; combined for in profile and face on): Up to 1/4 of lateral chest wall = 1; 1/4 to 1/2 of lateral chest wall = 2; > 1/2 of lateral chest wall = 3	Width (in profile only) (3mm minimum width required): 3 to 5 mm = a; 5 to 10 mm = b; > 10 mm = c
In profile	O R L	O R L	O R: 1 2 3 — O L: 1 2 3	O R: a b c — O L: a b c
Face on	O R L	O R L		
Diaphragm	O R L	O R L		
Other site(s)	O R L	O R L		

3C. COSTOPHRENIC ANGLE OBLITERATION R L Proceed to Section 3D NO Proceed to Section 4A

3D. DIFFUSE PLEURAL THICKENING *(mark site, calcification, extent, and width)*

Chest wall	Site O R L	Calcification O R L	Extent (chest wall; combined for in profile and face on): Up to 1/4 of lateral chest wall = 1; 1/4 to 1/2 of lateral chest wall = 2; > 1/2 of lateral chest wall = 3	Width (in profile only) (3mm minimum width required): 3 to 5 mm = a; 5 to 10 mm = b; > 10 mm = c
In profile	O R L	O R L	O R: 1 2 3 — O L: 1 2 3	O R: a b c — O L: a b c
Face on	O R L			

4A. ANY OTHER ABNORMALITIES? YES Complete Sections 4B, 4C, 4D, 4E NO Proceed to Section 5

4B. OTHER SYMBOLS (OBLIGATORY)

aa at ax bu ca cg cn co cp cv di ef em es fr hi ho id ih kl me pa pb pi px ra rp tb

OD If other diseases or significant abnormalities, **findings must be recorded on reverse.** (section 4C/4D)

Date Physician or Worker notified? MONTH DAY YEAR

4E. Should worker see personal physician because of findings in section 4? YES NO
Proceed to Section 5

5. PHYSICIAN'S Social Security Number* * Furnishing your social security number is voluntary. Your refusal to provide this number will not affect your right to participate in this program.

FILM READER'S INITIALS

DATE OF READING MONTH DAY YEAR

LAST NAME - STREET ADDRESS

CITY STATE ZIP CODE

CDC/NIOSH (M) 2.8
REV. 6/02

Source: CDC/NIOSH. Revision 6/02

4961192530

4C. MARK ALL BOXES THAT APPLY: (Use of this list is intended to reduce handwritten comments and is optional)

Abnormalities of the Diaphragm

- ☐ Eventration
- ☐ Hiatal hernia

Airway Disorders

- ☐ Bronchovascular markings, heavy or increased
- ☐ Hyperinflation

Bony Abnormalities

- ☐ Bony chest cage abnormality
- ☐ Fracture, healed (non-rib)
- ☐ Fracture, not healed (non-rib)
- ☐ Scoliosis
- ☐ Vertebral column abnormality

Lung Parenchymal Abnormalities

- ☐ Azygos lobe
- ☐ Density, lung
- ☐ Infiltrate
- ☐ Nodule, nodular lesion

Miscellaneous Abnormalities

- ☐ Foreign body
- ☐ Post-surgical changes/sternal wire
- ☐ Cyst

Vascular Disorders

- ☐ Aorta, anomaly of
- ☐ Vascular abnormality

4D. OTHER COMMENTS

Appendix O-1

Occupational Health Program: Sample of Narrative-Style Chest Radiological Evaluation Report

Name __John Doe_____ Plant ___Niles, Ohio_____
No __22468_____ Reading date __6/10/07_____
Interpretation of: _14 x 17 PA roentgenogram of chest taken on 6-5-07_____

Comments:

This film is of good diagnostic quality. The soft tissues and bones of the thorax show no abnormality. The diaphragms are smooth and rounded and in normal position for full inspiration. The costophrenic angles are clear, and there is no abnormal thickening of the pleura. The cardiac and lung root shadows are normal with respect to contour, size, and position. The bronchovascular markings are within normal limits, distributed evenly throughout both lungs, and show normal attenuation. No unusual densities are seen in either lung. The appearance of this film is entirely within the limits of normal.

Physician __George W. Stevens, M.D. __ Date ___6/10/07_____

Source: NISA Guide: "Occupational Health Program for Exposure to Crystalline Silica in the Industrial Minerals Industry" (1997).

Appendix O-2

Occupational Health Program: Sample Cumulative Radiology Report of Chest X-Rays

Company Unimin Corporation
Name John Doe ID Number 123-45-6789 Date of Birth 5/17/37

June 25, 2001 Chest PA: Marked emphysema left lung with well-defined mass or fibrosis inferior left lower lobe, unknown cause. (I called Unimin on this finding.) Scarred RUL and apex and possibly upper portion left lung. Irregular and small nodular, compatible with probable healed TB or silicotuberculosis with minimal emphysema right lung. CTR: 10/32
07-11-02 10:24 Paul S. Wheeler, MD

July 16, 2002 Chest PA: Moderately large left pneumothorax with partial atelectasis left lung and several bullous blebs are defined by air. Unimin called. Few small calcified granulomata in right lung. No old films but prior report describes right lung disease. CTR: 8/32
09-12-02 11:16 Paul S. Wheeler, MD

CT scan report sent by Mr. Vorpahl at Unimun 10/13/02:

Aug. 23, 2002 Chest CT scan (St. Margaret's Hosp): Gastric hiatus hernia in medial portion left mid and lower lung apparently is the "well-defined mass or fibrosis" which I described on 06-25-01. When a hiatus hernia contains fluid and no air it can look like a mass. They usually are in midline mediastinum and when asymmetrical like this may be paraesophageal which can be complicated by twisting. Suggest getting an upper GI series. CT scan also confirms COPD and some scarring.
10-20-02 11:08 Paul S. Wheeler, MD

Oct. 18, 2003 Chest PA: Moderate left diaphragm evaluation to level of lower left hilum. Moderate fibrosis RUL with tiny calcified granulomata compatible with healed TB. Moderate emphysema with decreased lung markings left lower lung. Probably dilatation hilar portion pulmonary arteries due to COPD rather than adenopathy. This is a complex case and should be read with prior films. CTR: 14/33
12-07-03 18:47 Paul S. Wheeler, MD

Sept. 20, 2004 Chest PA: No old films / Prior report describes this exam.
Approximate CTR: 11.5/31.5
01-16-05 11:08 Paul S. Wheeler, MD

Comparing original PA chest film of 7-16-02 with copies of PA views on 10-18-03 and 9-20-04: All show COPD with probable healed TB RUL and apex with irregular scars and several calcified granulomata. Sparing LUL except for few tiny peripheral scars is against silicosis in this case. Moderate pneumothorax with tiny pleural effusion on first film gone on 2nd exam. Elevation or eventration medial portion left hemidiaphragm increased between first 2 films / It could be disphragmatic rupture but is not a classic hiatus hernia. Underexposure is only change between last two exams.
01-16-05 11:06 Paul S. Wheeler, MD

Feb 10, 2007 Chest PA: Moderate to marked emphysema left lung and healed TB with scars and tiny calcified granulomata right mid and upper lung and few linear scars in right apex and probable blebs in left apex. Moderate left diaphragm eventration to level of lower left hilum or possible healed rupture medial portion diaphragm. Minimal pleural fibrosis blunting left CPA.
CTR: 12. 5/32
02-20-07 13:56 Paul S. Wheeler, MD

Source: NISA Guide: "Occupational Health Program for Exposure to Crystalline Silica in the Industrial Minerals Industry" (1997)

Appendix P

Spirometry

As discussed in Section 4 of the text, spirometry is an optional part of the OHP program. However, if a company chooses to provide spirometry it must be conducted to meet stringent quality control standards. Although expertise in spirometry is outside the traditional experience of member-company safety and health personnel, it is important to have a good working knowledge of the intricacies of spirometry to be able to evaluate the technical service being provided. In addition, the physician or allied health professional who performs spirometry for member companies should be thoroughly familiar with and meet the requirements of this appendix. This appendix therefore covers, in some detail, basic information to assist in gauging the technical expertise of the spirometry provider.

Technique

The training and skill of the individual who performs spirometry often makes the difference between a successful and an unsuccessful program of pulmonary function testing. For this reason, the spirometry technician must devote meticulous effort to subject preparation, testing technique, and assessment of the spirogram for validity. The technician should have successfully completed a NIOSH-approved occupational spirometry course.

Subject preparation consists of explaining the purpose of the test, knowing when to postpone spirometry, and positioning the subject properly for the forced expiratory effort. The procedure should be explained to the patient in simple terms. The brief statement "I want to test how hard and fast you can breathe" may not be physiologically precise but is usually the best explanation.

Because the proper performance of spirometry is an effort-dependent phenomenon, it is prudent to postpone testing if the individual is acutely ill from any cause. This is particularly true in respiratory infections, such as influenza, pneumonia, and bronchitis, where actual involvement of the airways or pulmonary parenchyma (gas exchange region) may further lower spirometric results. A 3-week recovery period is recommended in such circumstances before testing is undertaken. Improvements in the forced vital capacity of up to 1 liter have occurred in individuals 3 weeks after recovering from an episode of nonspecific bronchitis. Postponing spirometry is usually not necessary in uncomplicated upper respiratory tract infections (colds) unaccompanied by profound systemic complaints. Cigarettes or aerosolized bronchodilators may transiently alter airway resistance for 1–2 hours, particularly in smaller bronchi or bronchioles. It may be advisable to postpone spirometry if the patient has used either of these in the past hour. Although unusual in the industrial setting, a recent heavy meal is also regarded as a reason to postpone spirometry for approximately 1 hour.

The subject should be instructed to loosen tight clothing and to remove any dentures, if they are poorly fitted or loose. The subject may sit or stand, whichever is more comfortable or convenient. Most test subjects are comfortable sitting, and under normal circumstances there is little difference in the pulmonary function values obtained in either position. The sole exception is in the case of a grossly obese individual, where seated test results may be lower. The chin should be elevated and the neck slightly extended. Under the revised 1994 ATS criteria, the use of a nose clip is not required when the open-circuit technique is used. Nose clips are required for closed-circuit techniques with carbon dioxide absorption and may be necessary for subjects if they breathe through their nose during testing.

The subject should be instructed to take the deepest possible inspiration from a normal breathing pattern, close his or her mouth firmly around the mouthpiece, and without further hesitation blow into the apparatus as hard, fast, and completely as possible. This particular method of eliciting the forced expiratory maneuver is often

Source: NISA "Occupational Health Program for Exposure to Crystalline Silica in the Industrial Minerals Industry" (1997). Guide from the American Thoracic Society.

referred to as the *open-circuit technique* and is the most common way of performing spirometry in the screening setting. Almost all subjects master this technique with minimal explanation and practice, consistently performing reproducible forced expiratory efforts. An occasional individual may have difficulties, such as failure to maintain an airtight seal around the mouthpiece, pursing of the lips as with a musical instrument, or obstruction of the mouthpiece with the tongue. Some technicians avoid these problems by routinely demonstrating proper mouthpiece positioning to each subject. Spirometry utilizing the open circuit technique is outlined in the Spirometry Procedure Checklist (see page D-25).

Some pulmonary physicians prefer the *closed-circuit technique*. With this method, the subject establishes a constant tidal breathing pattern after insertion of the mouthpiece. The patient is then instructed to slowly exhale. When expiration is maximal, the subject breathes in as deeply as possible. When full inspiration is reached, the patient initiates the forced expiratory maneuver. Some physicians believe that this technique avoids the loss of inspired air that may theoretically occur during positioning of the mouthpiece in the open-circuit method. Because some subjects may attempt to breathe through the nose when the closed-circuit technique is used, the use of a nose clip is required. Regardless of the technique used, vigorous coaching is necessary throughout the entire forced expiratory effort.

A valid spirogram consists of three "acceptable" forced expiratory maneuvers. These three tracings must be free from cough, early termination of expiration, inconsistent effort, and excessive variability. Tracings marred by cough or inconsistent effort are readily apparent, as shown in Figures D-1 and D-2, respectively. Early termination of expiration occurs when the tracing fails to become horizontal or to plateau, as shown in Figure D-3. Mathematically, the plateau or end of test is reached when no volume change occurs for 1 second. The expiratory test must be recorded for at least 6 seconds, and the plateau should be maintained for at least 1 second before the maneuver is terminated. In workers with severe obstructive pulmonary disease, the exhalation maneuver may require 15 seconds before a plateau is reached. To avoid excessive variability, the two largest forced vi-

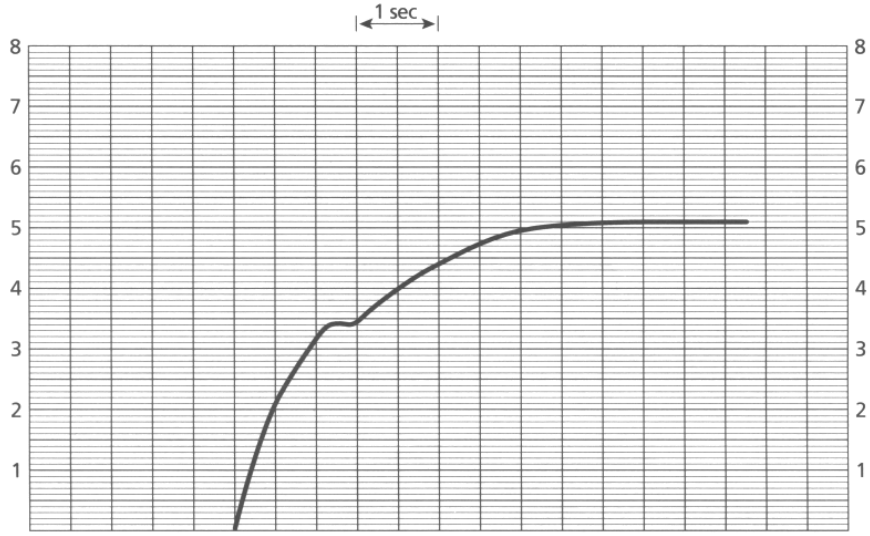


Figure D-1—Unacceptable Tracing: Cough

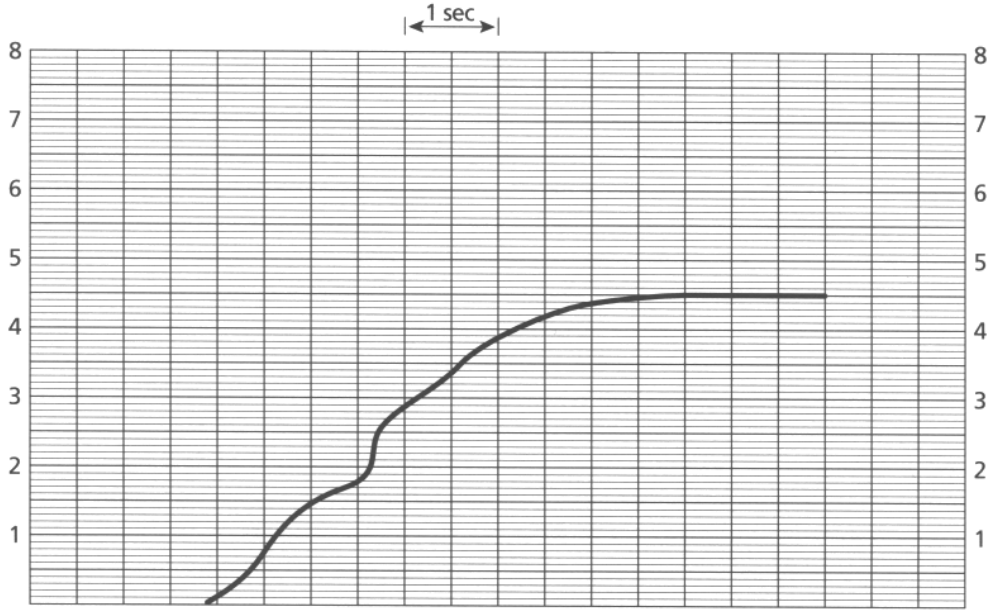


Figure D-2—Unacceptable Tracing: Inconsistent Effort

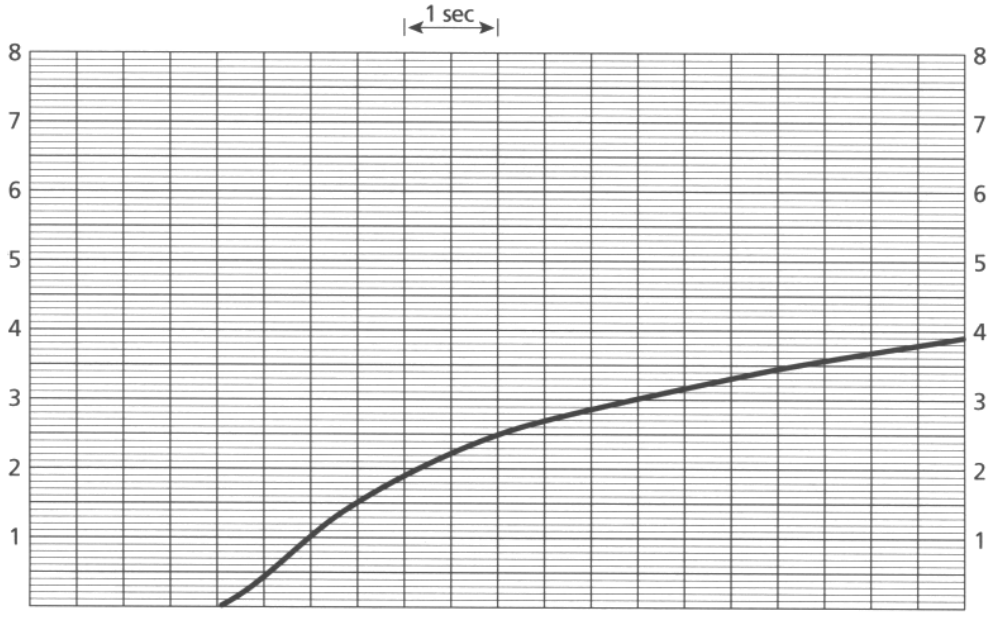


Figure D-3—Unacceptable Tracing: Early Termination of Expiration—Failure to "Plateau"

tal capacities and forced expiratory volume in 1 second of the three acceptable tracings should not vary by more than 200 milliliters (see Figure D-4). When subjects are properly instructed and actively coached, almost all can produce a valid spirogram with 3–5 forced expiratory efforts. The criteria for a valid spirogram are summarized in Table D-1.

Calculations

Several spirometric indices can be calculated from the time–volume tracing. Of importance in this appendix are forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), and forced expiratory volume in 1 second as a percentage of total forced vital capacity (FEV_1/FVC%). Other spirometry measurements, such as mean forced expiratory flow ($FEF_{25\%–75\%}$), may be reported, but FVC, FEV_1, and FEV_1/FVC% are the most important and are covered below.

Forced Vital Capacity (FVC)

Vital capacity (VC) is defined as the maximal volume of air exhaled from the point of maximal inspiration. FVC is the volume of air that can be exhaled forcefully after full inspiration. The determination of FVC is illustrated in Figure D-5.

In most individuals, the values obtained for VC and FVC are nearly identical. In patients with severe obstructive pulmonary disease, however, FVC is often smaller than VC because of expiratory slowing, air trapping, and hyperinflation. In the absence of airway obstruction, reduction of FVC is usually described as a *restrictive ventilatory defect.* This term encompasses conditions in which there is an actual reduction in the volume of air that can be inspired. Extrapulmonary factors such as neuromuscular disorders or chest-wall abnormalities can interfere with full expansion of the chest. Replacement or removal of functional lung tissue by

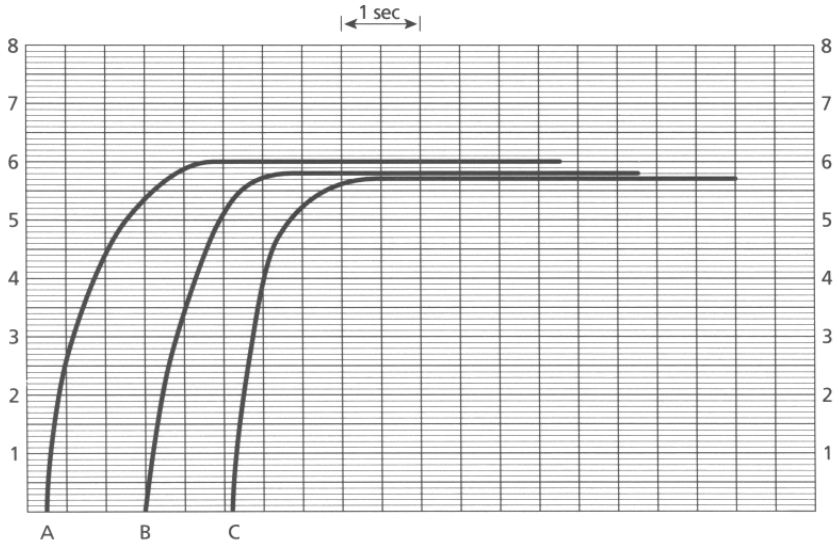


Figure D-4—Valid Spirogram: Two Best Curves Within 5%

Table D-1—Criteria for a Valid Spirogram

Three acceptable forced expiratory maneuvers free from the following:

1. Cough
2. Early termination of expiration—End of test occurs when plateau is noted in tracing or mathematical definition; no change in volume for 1 second (30 milliliters or less).
3. Inconsistent effort—Active coaching is a must throughout the entire effort.
4. Excessive variability—The two best FVCs and FEV,s should not vary by more than 200 milliliters.

tumor, fluid, or surgery directly diminishes lung volume. Interstitial fibrosis, such as occurs in silicosis, stiffens the lungs, lowering pulmonary compliance. This interferes with the ability to achieve full inspiration and thereby decreases FVC.

Forced Expiratory Volume in 1 Second (FEV_1)

Forced expiratory volume in 1 second (FEV_1) is the volume of air exhaled during the first second of the forced expiratory effort. Determination of FEV_1 is influenced by the point selected as the start of the test, the *zero time point*. A uniform method of selecting this point is required to maintain consistency of results. In a published statement on the standardization of spirometry, ATS identified the *back extrapolation method* as the most consistent and accepted technique for determining the zero time point and recommended its use "until other methods are demonstrated to give equivalent results." Determination of the zero time point and FEV_1 by the back extrapolation method is illustrated in Figure D-6. Exceptionally hesitant expiratory starts may prevent accurate back extrapolation and determination of the zero time point. Any tracing with an extrapolated volume greater than 5% of the total FVC or 150 milliliters, whichever is greater, should be repeated. In actual practice, such trac-

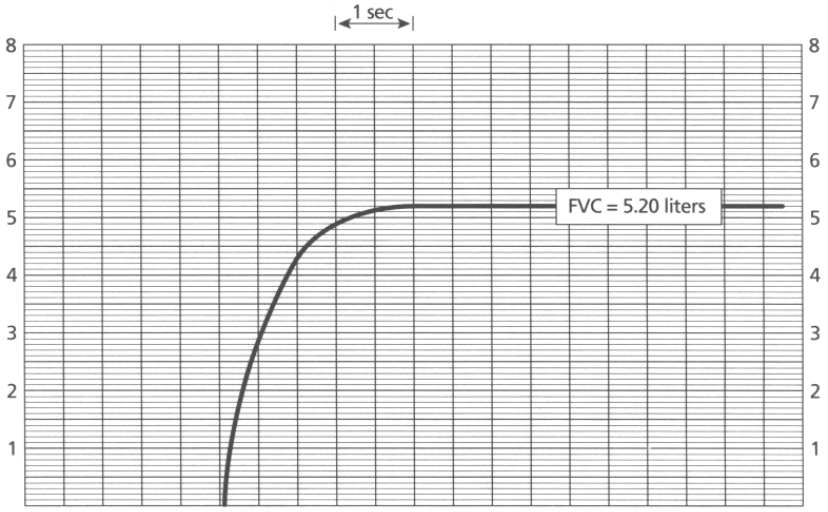


Figure D-5—Forced Vital Capacity (FVC)

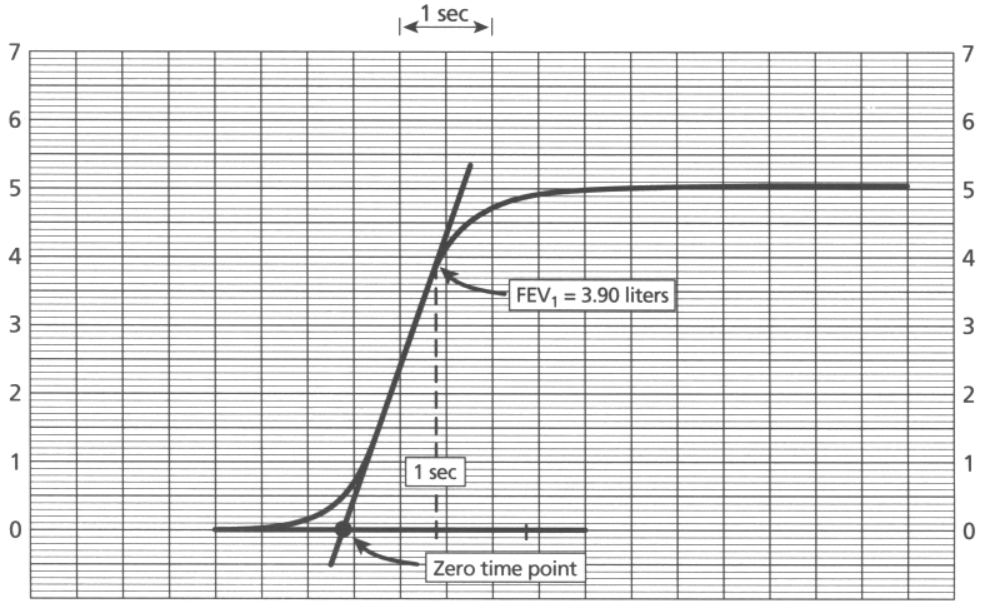


Figure D-6—Determination of Zero Time Point and FEV_1

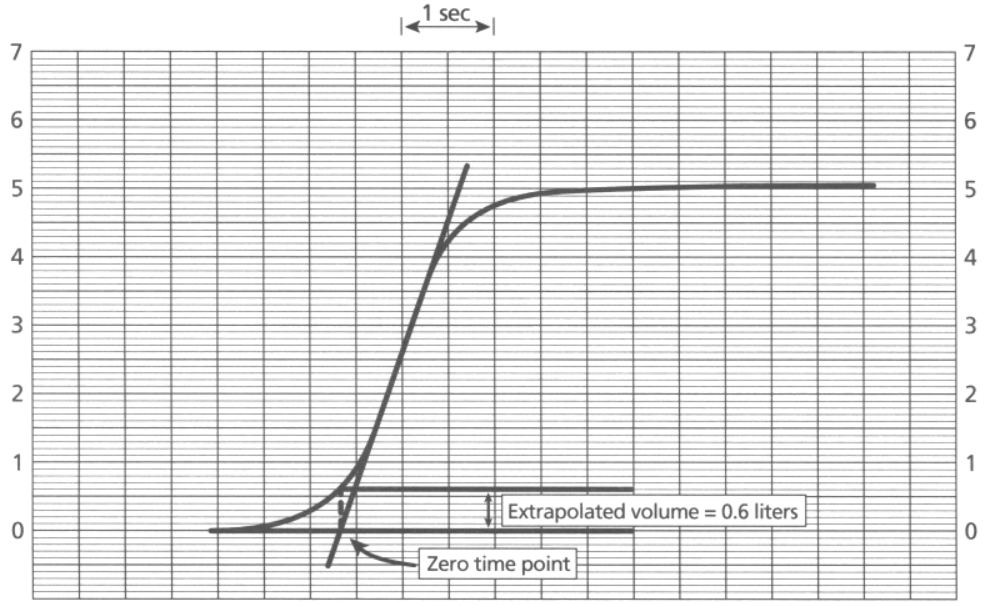


Figure D-7—Determination of Extrapolated Volume

ings are rare. Determination of extrapolated volume is illustrated in Figure D-7.

Forced Expiratory Volume in 1 Second As a Percentage of FVC (FEV_1/FVC%)

FEV_1 can also be expressed as a percentage of total observed FVC:

$$\frac{\text{Observed } FEV_1}{\text{Observed FVC}} \times 100 = \frac{FEV_1}{FVC\%}$$

Calculation of FEV_1/FVC% is particularly useful in severe restrictive pulmonary disease, where a reduction in FEV_1 may falsely suggest airway obstruction. A normal individual should be able to expire 75%–90% of FVC in 1 second, depending on age and sex. A patient with pulmonary fibrosis may have a significantly reduced FVC of only 2 liters, but in the absence of airway obstruction, he or she should be able to expire greater than 75% of FVC in 1 second. However, this FEV_1 of 1.6 liters would be only 50 percent of the predicted normal FEV_1 of 3.2 liters. Therefore, one could erroneously assume that the patient had obstructive disease when in fact only a restrictive ventilatory impairment is present. In this case, the calculated FEV_1/FVC% ($1.6/2.0 \times 100$) is a normal 80%.

In determining FEV_1, FVC, and FEV_1/FVC%, the largest FEV_1 and FVC should be used, regardless of the curve or curves on which they occur. For example, in calculating FEV_1/FVC%, FEV_1 and FVC need not come from the same curve. This admittedly arbitrary decision has been adopted by ATS as the recommended uniform methodology.

Conversion to BTPS

Before the results of spirometric tests can be incorporated in the patient's permanent record, they must be corrected to conditions at body temperature and ambient pressure, saturated with water vapor (BTPS). This is necessary because the patient exhales a volume of gas at body temperature (37°C). When this volume is collected in the spirometer, it rapidly cools to approach the lower ambient temperature (ATPS) and contracts. The reduced volume recorded by the spirometer must then be multiplied by the appropriate BTPS conversion factor (see Table D-2) to correct it to what it should be at normal body temperature. This usually increases the volume recorded by the spirometer by approximately 8%, although it may vary from 5% to 10% percent depending on ambient temperature. This correction is particularly important in field studies, where ambient temperature may vary considerably.

Some spirometer manufacturers incorporate an automatic correction factor, either in the apparatus itself or on the recording paper. Flow-measuring instruments (electronic spirometers) automatically convert to BTPS. The graph paper from some spirometers may record results corrected to a predetermined ambient temperature such as 20°C. This latter approach is less desirable

Table D-2—Factors for Converting Gas Volumes From Ambient Temperature to BTPS

Gas Temperature (°F)	Gas Temperature (°C)	Conversion Factor
64	18	1.114
66	19	1.111
68	20	1.102
70	21	1.096
72	22	1.091
73	23	1.085
75	24	1.080
77	25	1.075
79	26	1.068
81	27	1.063
82	28	1.057
84	29	1.051
86	30	1.045
88	31	1.039
90	32	1.032
91	33	1.026
93	34	1.020
95	35	1.014
97	36	1.007
99	37	1.000

Note: °C = [5(°F – 32)]/9.

than a calculated BTPS conversion, particularly in industrial medical units, where ambient temperatures may vary from 18°C to 30°C.

Some physicians prefer to use BTPS conversion factors that correct from both ambient pressure and temperature. Although fluctuations in ambient pressure usually produce changes of less than 1% in test results, consideration should be given to using such conversion factors in research studies and in geographic areas (for example, mountainous regions) where pressure varies considerably from that at sea level.

Determination of Percentage of Predicted Normal Values

The decision about whether spirometric tests are "normal" is usually made by comparing the results with a set of published predicted normal values. The NISA OHP recommends that spirometry results be compared with the 95th-percentile lower limit of normal (LLN) values obtained from Knudson's reference equations to identify participants with abnormal patterns of obstruction and restriction. The predicted values from Knudson's equations are listed in Table D-3. In part because Knudson's testing and analysis procedures most closely matched the ATS recommendation, his predicted LLN values were adopted by OSHA for its cotton dust standard. The only potential problem with Knudson's method was his use of the average of the best two of five values—the ATS standard recommends the use of the largest value. Knudson subsequently performed a comparison of both methods and found no difference in the mean FEV_1 and FVC.

In all studies of predicted normal values, several factors, including age, height, sex, and race, have been found to affect lung capacity and flow rates. Even in the absence of a superimposed disease process, pulmonary function declines predictably with advancing age. Taller individuals tend to have larger lung volumes, so when height is measured, the subject should be in stocking feet to preclude the influence of heels of varying heights. Men generally have larger lung volumes than do women of the same age and height.

The subject's FVC or FEV_1 can be expressed as a percentage of their predicted normal values:

$$\%\ \text{predicted FVC} = \frac{\text{Observed FVC}}{\text{Predicted FVC}} \times 100$$

$$\%\ \text{predicted } FEV_1 = \frac{\text{Observed } FEV_1}{\text{Predicted } FEV_1} \times 100$$

It is now well known that the FEV_1 and FVC of non-Caucasians are approximately 15% less than that of whites of the same age, height, and sex. This difference has been noted both for blacks and for Asians. The reason for this phenomenon is not clear, although speculation has centered around differences in thoracic configuration and diaphragmatic position. Allowance must be made for these ethnic differences to prevent serious errors in interpretation. OSHA's cotton dust standard requires the predicted FEV_1 and FVC for blacks to be multiplied by 0.85 to compensate for this difference. This procedure facilitates proper interpretation of spirometry without inadvertently fostering discrimination in employment practices. It should be used until race-specific tables and nomograms become accepted. No ethnic correction factor should be applied to FEV_1/FVC% because it is a ratio.

Regardless of race, the actual calculation of percentage of predicted normal is relatively simple: The observed lung volume or flow rate converted to BTPS is divided by the predicted value and multiplied by 100 to obtain the percentage (see Spirometry Calculation Outline on page D-26). In the absence of airway obstruction, a restrictive ventilatory impairment may be present when the FVC is less than 80% of predicted. An obstructive ventilatory impairment is defined as an FEV_1 of less than 80% of predicted or an FEV_1/FVC% of less than 75%. It should be emphasized, however, that these figures do not discriminate between health and disease with complete certainty. Occasional individuals may be slightly below the normal value (for example, 78% of predicted) and not have a respiratory disorder. Conversely, a patient may exhibit radiographic manifestations of disease and still

(text continued on page P-21)

Table D-3A—LLN for FVC for Males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
157	2.89	3.01	3.13	3.25	3.02	2.97	2.92	2.87	2.82	2.77	2.73	2.68	2.38	2.33	2.29	2.25	2.20	2.16	2.12	2.07	2.03	1.98	1.94	1.90	1.85
158	2.94	3.06	3.18	3.29	3.08	3.04	2.99	2.94	2.89	2.84	2.79	2.75	2.44	2.40	2.35	2.31	2.27	2.22	2.18	2.13	2.09	2.05	2.00	1.96	1.92
159	2.99	3.11	3.22	3.34	3.15	3.10	3.06	3.01	2.96	2.91	2.86	2.81	2.50	2.46	2.41	2.37	2.33	2.28	2.24	2.20	2.15	2.11	2.06	2.02	1.98
160	3.04	3.15	3.27	3.39	3.22	3.17	3.12	3.08	3.03	2.98	2.93	2.88	2.56	2.52	2.48	2.43	2.39	2.35	2.30	2.26	2.21	2.17	2.13	2.08	2.04
161	3.08	3.20	3.32	3.44	3.29	3.24	3.19	3.14	3.10	3.05	3.00	2.95	2.63	2.58	2.54	2.50	2.45	2.41	2.36	2.32	2.28	2.23	2.19	2.15	2.10
162	3.13	3.25	3.37	3.48	3.36	3.31	3.26	3.21	3.16	3.12	3.07	3.02	2.69	2.64	2.60	2.56	2.51	2.47	2.43	2.38	2.34	2.29	2.25	2.21	2.16
163	3.18	3.29	3.41	3.53	3.43	3.38	3.33	3.28	3.23	3.18	3.14	3.09	2.75	2.71	2.66	2.62	2.58	2.53	2.49	2.44	2.40	2.36	2.31	2.27	2.23
164	3.22	3.34	3.46	3.58	3.49	3.45	3.40	3.35	3.30	3.25	3.20	3.16	2.81	2.77	2.72	2.68	2.64	2.59	2.55	2.51	2.46	2.42	2.37	2.33	2.29
165	3.27	3.39	3.51	3.62	3.56	3.51	3.47	3.42	3.37	3.32	3.27	3.22	2.87	2.83	2.79	2.74	2.70	2.66	2.61	2.57	2.52	2.48	2.44	2.39	2.35
166	3.32	3.44	3.55	3.67	3.63	3.58	3.53	3.49	3.44	3.39	3.34	3.29	2.94	2.89	2.85	2.80	2.76	2.72	2.67	2.63	2.59	2.54	2.50	2.45	2.41
167	3.36	3.48	3.60	3.72	3.70	3.65	3.60	3.55	3.51	3.46	3.41	3.36	3.00	2.95	2.91	2.87	2.82	2.78	2.74	2.69	2.65	2.60	2.56	2.52	2.47
168	3.41	3.53	3.65	3.77	3.77	3.72	3.67	3.62	3.57	3.53	3.48	3.43	3.06	3.02	2.97	2.93	2.88	2.84	2.80	2.75	2.71	2.67	2.62	2.58	2.53
169	3.46	3.58	3.69	3.81	3.84	3.79	3.74	3.69	3.64	3.59	3.55	3.50	3.12	3.08	3.03	2.99	2.95	2.90	2.86	2.82	2.77	2.73	2.68	2.64	2.60
170	3.51	3.62	3.74	3.86	3.90	3.86	3.81	3.76	3.71	3.66	3.61	3.57	3.18	3.14	3.10	3.05	3.01	2.97	2.92	2.88	2.83	2.79	2.75	2.70	2.66
171	3.55	3.67	3.79	3.91	3.97	3.93	3.88	3.83	3.78	3.73	3.68	3.64	3.25	3.20	3.16	3.11	3.07	3.03	2.98	2.94	2.90	2.85	2.81	2.76	2.72
172	3.60	3.72	3.84	3.95	4.04	3.99	3.95	3.90	3.85	3.80	3.75	3.70	3.31	3.26	3.22	3.18	3.13	3.09	3.05	3.00	2.96	2.91	2.87	2.83	2.78
173	3.65	3.77	3.88	4.00	4.11	4.06	4.01	3.97	3.92	3.87	3.82	3.77	3.37	3.33	3.28	3.24	3.19	3.15	3.11	3.06	3.02	2.98	2.93	2.89	2.84
174	3.69	3.81	3.93	4.05	4.18	4.13	4.08	4.03	3.99	3.94	3.89	3.84	3.43	3.39	3.34	3.30	3.26	3.21	3.17	3.13	3.08	3.04	2.99	2.95	2.91
175	3.74	3.86	3.98	4.10	4.25	4.20	4.15	4.10	4.05	4.01	3.96	3.91	3.49	3.45	3.41	3.36	3.32	3.27	3.23	3.19	3.14	3.10	3.06	3.01	2.97
176	3.79	3.91	4.02	4.14	4.32	4.27	4.22	4.17	4.12	4.07	4.03	3.98	3.56	3.51	3.47	3.42	3.38	3.34	3.29	3.25	3.21	3.16	3.12	3.07	3.03
177	3.84	3.95	4.07	4.19	4.38	4.34	4.29	4.24	4.19	4.14	4.09	4.05	3.62	3.57	3.53	3.49	3.44	3.40	3.35	3.31	3.27	3.22	3.18	3.14	3.09

Table D-3A (Continued)—LLN for FVC for Males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
178	3.88	4.00	4.12	4.24	4.45	4.40	4.36	4.31	4.26	4.21	4.16	4.11	3.68	3.64	3.59	3.55	3.50	3.46	3.42	3.37	3.33	3.29	3.24	3.20	3.15
179	3.93	4.05	4.17	4.28	4.52	4.47	4.42	4.38	4.33	4.28	4.23	4.18	3.74	3.70	3.65	3.61	3.57	3.52	3.48	3.44	3.39	3.35	3.30	3.26	3.22
180	3.98	4.09	4.21	4.33	4.59	4.54	4.49	4.44	4.40	4.35	4.30	4.25	3.80	3.76	3.72	3.67	3.63	3.58	3.54	3.50	3.45	3.41	3.37	3.32	3.28
181	4.02	4.14	4.26	4.38	4.66	4.61	4.56	4.51	4.46	4.42	4.37	4.32	3.87	3.82	3.78	3.73	3.69	3.65	3.60	3.56	3.52	3.47	3.43	3.38	3.34
182	4.07	4.19	4.31	4.42	4.73	4.68	4.63	4.58	4.53	4.48	4.44	4.39	3.93	3.88	3.84	3.80	3.75	3.71	3.66	3.62	3.58	3.53	3.49	3.45	3.40
183	4.12	4.24	4.35	4.47	4.79	4.75	4.70	4.65	4.60	4.55	4.50	4.46	3.99	3.95	3.90	3.86	3.81	3.77	3.73	3.68	3.64	3.60	3.55	3.51	3.46
184	4.17	4.28	4.40	4.52	4.86	4.81	4.77	4.72	4.67	4.62	4.57	4.52	4.05	4.01	3.96	3.92	3.88	3.83	3.79	3.74	3.70	3.66	3.61	3.57	3.53
185	4.21	4.33	4.45	4.57	4.93	4.88	4.84	4.79	4.74	4.69	4.64	4.59	4.11	4.07	4.03	3.98	3.94	3.89	3.85	3.81	3.76	3.72	3.68	3.63	3.59
186	4.26	4.38	4.50	4.61	5.00	4.95	4.90	4.86	4.81	4.76	4.71	4.66	4.17	4.13	4.09	4.04	4.00	3.96	3.91	3.87	3.83	3.78	3.74	3.69	3.65
187	4.31	4.42	4.54	4.66	5.07	5.02	4.97	4.92	4.88	4.83	4.78	4.73	4.24	4.19	4.15	4.11	4.06	4.02	3.97	3.93	3.89	3.84	3.80	3.76	3.71
188	4.35	4.47	4.59	4.71	5.14	5.09	5.04	4.99	4.94	4.90	4.85	4.80	4.30	4.26	4.21	4.17	4.12	4.08	4.04	3.99	3.95	3.91	3.86	3.82	3.77
189	4.40	4.52	4.64	4.75	5.21	5.16	5.11	5.06	5.01	4.96	4.92	4.87	4.36	4.32	4.27	4.23	4.19	4.14	4.10	4.05	4.01	3.97	3.92	3.88	3.84
190	4.45	4.57	4.68	4.80	5.27	5.23	5.18	5.13	5.08	5.03	4.98	4.94	4.42	4.38	4.34	4.29	4.25	4.20	4.16	4.12	4.07	4.03	3.99	3.94	3.90
191	4.49	4.61	4.73	4.85	5.34	5.29	5.25	5.20	5.15	5.10	5.05	5.00	4.48	4.44	4.40	4.35	4.31	4.27	4.22	4.18	4.13	4.09	4.05	4.00	3.96
192	4.54	4.66	4.78	4.90	5.41	5.36	5.31	5.27	5.22	5.17	5.12	5.07	4.55	4.50	4.46	4.42	4.37	4.33	4.28	4.24	4.20	4.15	4.11	4.07	4.02
193	4.59	4.71	4.82	4.94	5.48	5.43	5.38	5.33	5.29	5.24	5.19	5.14	4.61	4.56	4.52	4.48	4.43	4.39	4.35	4.30	4.26	4.21	4.17	4.13	4.08

Table D-3B—LLN for FEV_1 for Males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
157	2.52	2.62	2.73	2.83	2.52	2.48	2.43	2.38	2.34	2.29	2.25	2.20	2.10	2.06	2.01	1.97	1.92	1.88	1.83	1.79	1.74	1.70	1.65	1.61	1.56
158	2.56	2.67	2.77	2.87	2.58	2.53	2.48	2.44	2.39	2.34	2.30	2.25	2.15	2.11	2.06	2.02	1.97	1.93	1.88	1.84	1.79	1.75	1.70	1.66	1.61
159	2.61	2.71	2.81	2.92	2.63	2.58	2.54	2.49	2.44	2.40	2.35	2.30	2.20	2.16	2.11	2.07	2.02	1.98	1.93	1.89	1.84	1.80	1.75	1.71	1.66
160	2.65	2.75	2.85	2.96	2.68	2.63	2.59	2.54	2.50	2.45	2.40	2.36	2.26	2.21	2.17	2.12	2.08	2.03	1.98	1.94	1.89	1.85	1.80	1.76	1.71
161	2.69	2.79	2.90	3.00	2.73	2.69	2.64	2.59	2.55	2.50	2.46	2.41	2.31	2.26	2.22	2.17	2.13	2.08	2.04	1.99	1.95	1.90	1.86	1.81	1.77
162	2.73	2.84	2.94	3.04	2.79	2.74	2.69	2.65	2.60	2.55	2.51	2.46	2.36	2.31	2.27	2.22	2.18	2.13	2.09	2.04	2.00	1.95	1.91	1.86	1.82
163	2.77	2.88	2.98	3.08	2.84	2.79	2.75	2.70	2.65	2.61	2.56	2.52	2.41	2.36	2.32	2.27	2.23	2.18	2.14	2.09	2.05	2.00	1.96	1.91	1.87
164	2.82	2.92	3.02	3.13	2.89	2.84	2.80	2.75	2.71	2.66	2.61	2.57	2.46	2.42	2.37	2.33	2.28	2.24	2.19	2.15	2.10	2.06	2.01	1.96	1.92
165	2.86	2.96	3.07	3.17	2.94	2.90	2.85	2.81	2.76	2.71	2.67	2.62	2.51	2.47	2.42	2.38	2.33	2.29	2.24	2.20	2.15	2.11	2.06	2.02	1.97
166	2.90	3.00	3.11	3.21	3.00	2.95	2.90	2.86	2.81	2.77	2.72	2.67	2.56	2.52	2.47	2.43	2.38	2.34	2.29	2.25	2.20	2.16	2.11	2.07	2.02
167	2.94	3.05	3.15	3.25	3.05	3.00	2.96	2.91	2.86	2.82	2.77	2.73	2.61	2.57	2.52	2.48	2.43	2.39	2.34	2.30	2.25	2.21	2.16	2.12	2.07
168	2.99	3.09	3.19	3.29	3.10	3.06	3.01	2.96	2.92	2.87	2.82	2.78	2.67	2.62	2.58	2.53	2.49	2.44	2.40	2.35	2.31	2.26	2.22	2.17	2.13
169	3.03	3.13	3.23	3.34	3.15	3.11	3.06	3.02	2.97	2.92	2.88	2.83	2.72	2.67	2.63	2.58	2.54	2.49	2.45	2.40	2.36	2.31	2.27	2.22	2.18
170	3.07	3.17	3.28	3.38	3.21	3.16	3.11	3.07	3.02	2.98	2.93	2.88	2.77	2.72	2.68	2.63	2.59	2.54	2.50	2.45	2.41	2.36	2.32	2.27	2.23
171	3.11	3.21	3.32	3.42	3.26	3.21	3.17	3.12	3.07	3.03	2.98	2.94	2.82	2.78	2.73	2.68	2.64	2.59	2.55	2.50	2.46	2.41	2.37	2.32	2.28
172	3.15	3.26	3.36	3.46	3.31	3.27	3.22	3.17	3.13	3.08	3.03	2.99	2.87	2.83	2.78	2.74	2.69	2.65	2.60	2.56	2.51	2.47	2.42	2.38	2.33
173	3.20	3.30	3.40	3.51	3.36	3.32	3.27	3.23	3.18	3.13	3.09	3.04	2.92	2.88	2.83	2.79	2.74	2.70	2.65	2.61	2.56	2.52	2.47	2.43	2.38
174	3.24	3.34	3.44	3.55	3.42	3.37	3.32	3.28	3.23	3.19	3.14	3.09	2.97	2.93	2.88	2.84	2.79	2.75	2.70	2.66	2.61	2.57	2.52	2.48	2.43
175	3.28	3.38	3.49	3.59	3.47	3.42	3.38	3.33	3.28	3.24	3.19	3.15	3.03	2.98	2.94	2.89	2.85	2.80	2.76	2.71	2.66	2.62	2.57	2.53	2.48
176	3.32	3.43	3.53	3.63	3.52	3.48	3.43	3.38	3.34	3.29	3.25	3.20	3.08	3.03	2.99	2.94	2.90	2.85	2.81	2.76	2.72	2.67	2.63	2.58	2.54
177	3.36	3.47	3.57	3.67	3.57	3.53	3.48	3.44	3.39	3.34	3.30	3.25	3.13	3.08	3.04	2.99	2.95	2.90	2.86	2.81	2.77	2.72	2.68	2.63	2.59

Table D-3B (Continued)—LLN for FEV_1 for Males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
178	3.41	3.51	3.61	3.72	3.63	3.58	3.54	3.49	3.44	3.40	3.35	3.30	3.18	3.13	3.09	3.04	3.00	2.95	2.91	2.86	2.82	2.77	2.73	2.68	2.64
179	3.45	3.55	3.66	3.76	3.68	3.63	3.59	3.54	3.50	3.45	3.40	3.36	3.23	3.19	3.14	3.10	3.05	3.01	2.96	2.92	2.87	2.83	2.78	2.73	2.69
180	3.49	3.59	3.70	3.80	3.73	3.69	3.64	3.59	3.55	3.50	3.46	3.41	3.28	3.24	3.19	3.15	3.10	3.06	3.01	2.97	2.92	2.88	2.83	2.79	2.74
181	3.53	3.64	3.74	3.84	3.79	3.74	3.69	3.65	3.60	3.55	3.51	3.46	3.33	3.29	3.24	3.20	3.15	3.11	3.06	3.02	2.97	2.93	2.88	2.84	2.79
182	3.58	3.68	3.78	3.88	3.84	3.79	3.75	3.70	3.65	3.61	3.56	3.51	3.38	3.34	3.29	3.25	3.20	3.16	3.11	3.07	3.02	2.98	2.93	2.89	2.84
183	3.62	3.72	3.82	3.93	3.89	3.84	3.80	3.75	3.71	3.66	3.61	3.57	3.44	3.39	3.35	3.30	3.26	3.21	3.17	3.12	3.08	3.03	2.99	2.94	2.90
184	3.66	3.76	3.87	3.97	3.94	3.90	3.85	3.80	3.76	3.71	3.67	3.62	3.49	3.44	3.40	3.35	3.31	3.26	3.22	3.17	3.13	3.08	3.04	2.99	2.95
185	3.70	3.80	3.91	4.01	4.00	3.95	3.90	3.86	3.81	3.76	3.72	3.67	3.54	3.49	3.45	3.40	3.36	3.31	3.27	3.22	3.18	3.13	3.09	3.04	3.00
186	3.74	3.85	3.95	4.05	4.05	4.00	3.96	3.91	3.86	3.82	3.77	3.72	3.59	3.55	3.50	3.46	3.41	3.36	3.32	3.27	3.23	3.18	3.14	3.09	3.05
187	3.79	3.89	3.99	4.10	4.10	4.05	4.01	3.96	3.92	3.87	3.82	3.78	3.64	3.60	3.55	3.51	3.46	3.42	3.37	3.33	3.28	3.24	3.19	3.15	3.10
188	3.83	3.93	4.03	4.14	4.15	4.11	4.06	4.01	3.97	3.92	3.88	3.83	3.69	3.65	3.60	3.56	3.51	3.47	3.42	3.38	3.33	3.29	3.24	3.20	3.15
189	3.87	3.97	4.08	4.18	4.21	4.16	4.11	4.07	4.02	3.98	3.93	3.88	3.74	3.70	3.65	3.61	3.56	3.52	3.47	3.43	3.38	3.34	3.29	3.25	3.20
190	3.91	4.02	4.12	4.22	4.26	4.21	4.17	4.12	4.07	4.03	3.98	3.94	3.80	3.75	3.71	3.66	3.62	3.57	3.53	3.48	3.43	3.39	3.34	3.30	3.25
191	3.95	4.06	4.16	4.26	4.31	4.27	4.22	4.17	4.13	4.08	4.03	3.99	3.85	3.80	3.76	3.71	3.67	3.62	3.58	3.53	3.49	3.44	3.40	3.35	3.31
192	4.00	4.10	4.20	4.31	4.36	4.32	4.27	4.23	4.18	4.13	4.09	4.04	3.90	3.85	3.81	3.76	3.72	3.67	3.63	3.58	3.54	3.49	3.45	3.40	3.36
193	4.04	4.14	4.25	4.35	4.42	4.37	4.32	4.38	4.23	4.19	4.14	4.09	3.95	3.90	3.86	3.81	3.77	3.72	3.68	3.63	3.59	3.54	3.50	3.45	3.41

Table D-3C—LLN for $FEV_1/FVC\%$ for Males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
157	74.5	74.5	74.5	74.5	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
158	74.4	74.4	74.4	74.4	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
159	74.3	74.3	74.3	74.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
160	74.3	74.3	74.3	74.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
161	74.2	74.2	74.2	74.2	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
162	74.1	74.1	74.1	74.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
163	74.1	74.1	74.1	74.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
164	74.0	74.0	74.0	74.0	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
165	73.9	73.9	73.9	73.9	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
166	73.9	73.9	73.9	73.9	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
167	73.8	73.8	73.8	73.8	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
168	73.7	73.7	73.7	73.7	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
169	73.6	73.6	73.6	73.6	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
170	73.6	73.6	73.6	73.6	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
171	73.5	73.5	73.5	73.5	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
172	73.4	73.4	73.4	73.4	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
173	73.4	73.4	73.4	73.4	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
174	73.3	73.3	73.3	73.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
175	73.2	73.2	73.2	73.2	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
176	73.2	73.2	73.2	73.2	73.0	72.8	72.6	72.5	72.3	72.1,71.9		71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
177	73.1	73.1	73.1	73.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3

Table D-3C (Continued)—LLN for $FEV_1/FVC\%$ for Males

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
178	73.0	73.0	73.0	73.0	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
179	73.0	73.0	73.0	73.0	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
180	72.9	72.9	72.9	72.9	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
181	72.8	72.8	72.8	72.8	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
182	72.7	72.7	72.7	72.7	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
183	72.7	72.7	72.7	72.7	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
184	72.6	72.6	72.6	72.6	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
185	72.5	72.5	72.5	72.5	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
186	72.5	72.5	72.5	72.5	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
187	72.4	72.4	72.4	72.4	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
188	72.3	72.3	72.3	72.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
189	72.3	72.3	72.3	72.3	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
190	72.2	72.2	72.2	72.2	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
191	72.1	72.1	72.1	72.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
192	72.1	72.1	72.1	72.1	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3
193	72.0	72.0	72.0	72.0	73.0	72.8	72.6	72.5	72.3	72.1	71.9	71.7	71.5	71.4	71.2	71.0	70.8	70.6	70.4	70.3	70.1	69.9	69.7	69.5	69.3

Table D-3D—LLN for FVC for Females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	5l	53	55	57	59	61	63	65
148	2.17	2.27	2.32	2.29	2.27	2.24	2.21	2.19	2.16	2.14	2.11	2.08	2.01	1.99	1.96	1.94	1.91	1.89	1.86	1.84	1.81	1.78	1.76	1.73	1.71
149	2.20	2.30	2.35	2.33	2.30	2.27	2.25	2.22	2.20	2.17	2.14	2.12	2.05	2.02	2.00	1.97	1.94	1.92	1.89	1.87	1.84	1.82	1.79	1.77	1.74
150	2.23	2.33	2.39	2.36	2.33	2.31	2.28	2.26	2.23	2.20	2.18	2.15	2.08	2.05	2.03	2.00	1.98	1.95	1.93	1.90	1.88	1.85	1.83	1.80	1.77
151	2.26	2.36	2.42	2.40	2.37	2.34	2.32	2.29	2.27	2.24	2.21	2.19	2.11	2.09	2.06	2.04	2.01	1.99	1.96	1.94	1.91	1.88	1.86	1.83	1.81
152	2.29	2.40	2.46	2.43	2.40	2.38	2.35	2.33	2.30	2.27	2.25	2.22	2.15	2.12	2.10	2.07	2.04	2.02	1.99	1.97	1.94	1.92	1.89	1.87	1.84
153	2.32	2.43	2.49	2.46	2.44	2.41	2.39	2.36	2.33	2.31	2.28	2.26	2.18	2.15	2.13	2.10	2.08	2.05	2.03	2.00	1.98	1.95	1.93	1.90	1.88
154	2.35	2.46	2.52	2.50	2.47	2.45	2.42	2.39	2.37	2.34	2.32	2.29	2.21	2.19	2.16	2.14	2.11	2.09	2.06	2.04	2.01	1.98	1.96	1.93	1.91
155	2.38	2.49	2.56	2.53	2.51	2.48	2.45	2.43	2.40	2.38	2.35	2.32	2.25	2.22	2.20	2.17	2.15	2.12	2.09	2.07	2.04	2.02	1.99	1.97	1.94
156	2.41	2.52	2.59	2.57	2.54	2.51	2.49	2.46	2.44	2.41	2.38	2.36	2.28	2.25	2.23	2.20	2.18	2.15	2.13	2.10	2.08	2.05	2.03	2.00	1.98
157	2.45	2.55	2.63	2.60	2.57	2.55	2.52	2.50	2.47	2.44	2.42	2.39	2.31	2.29	2.26	2.24	2.21	2.19	2.16	2.14	2.11	2.08	2.06	2.03	2.01
158	2.48	2.58	2.66	2.63	2.61	2.58	2.56	2.53	2.50	2.48	2.45	2.43	2.35	2.32	2.30	2.27	2.25	2.22	2.19	2.17	2.14	2.12	2.09	2.07	2.04
159	2.51	2.61	2.69	2.67	2.64	2.62	2.59	2.56	2.54	2.51	2.49	2.46	2.38	2.35	2.33	2.30	2.28	2.25	2.23	2.20	2.18	2.15	2.13	2.10	2.08
160	2.54	2.64	2.73	2.70	2.68	2.65	2.62	2.60	2.57	2.55	2.52	2.49	2.41	2.39	2.36	2.34	2.31	2.29	2.26	2.24	2.21	2.18	2.16	2.13	2.11
161	2.57	2.68	2.76	2.74	2.71	2.68	2.66	2.63	2.61	2.58	2.55	2.53	2.45	2.42	2.40	2.37	2.35	2.32	2.29	2.27	2.24	2.22	2.19	2.17	2.14
162	2.60	2.71	2.80	2.77	2.74	2.72	2.69	2.67	2.64	2.61	2.59	2.56	2.48	2.46	2.43	2.40	2.38	2.35	2.33	2.30	2.28	2.25	2.23	2.20	2.18
163	2.63	2.74	2.83	2.80	2.78	2.75	2.73	2.70	2.67	2.65	2.62	2.60	2.51	2.49	2.46	2.44	2.41	2.39	2.36	2.34	2.31	2.29	2.26	2.23	2.21
164	2.66	2.77	2.86	2.84	2.81	2.79	2.76	2.73	2.71	2.68	2.66	2.63	2.55	2.52	2.50	2.47	2.45	2.42	2.39	2.37	2.34	2.32	2.29	2.27	2.24
165	2.70	2.80	2.90	2.87	2.85	2.82	2.80	2.77	2.74	2.72	2.69	2.67	2.58	2.56	2.53	2.50	2.48	2.45	2.43	2.40	2.38	2.35	2.33	2.30	2.28
166	2.73	2.83	2.93	2.91	2.88	2.86	2.83	2.80	2.78	2.75	2.73	2.70	2.61	2.59	2.56	2.54	2.51	2.49	2.46	2.44	2.41	2.39	2.36	2.33	2.31
167	2.76	2.86	2.97	2.94	2.92	2.89	2.86	2.84	2.81	2.79	2.76	2.73	2.65	2.62	2.60	2.57	2.55	2.52	2.49	2.47	2.44	2.42	2.39	2.37	2.34
168	2.79	2.89	3.00	2.98	2.95	2.92	2.90	2.87	2.85	2.82	2.79	2.77	2.68	2.66	2.63	2.60	2.58	2.55	2.53	2.50	2.48	2.45	2.43	2.40	2.38

Table D-3D (Continued)—LLN for FVC for Females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
169	2.82	2.92	3.04	3.01	2.98	2.96	2.93	2.91	2.88	2.85	2.83	2.80	2.71	2.69	2.66	2.64	2.61	2.59	2.56	2.54	2.51	2.49	2.46	2.43	2.41
170	2.85	2.96	3.07	3.04	3.02	2.99	2.97	2.94	2.91	2.89	2.86	2.84	2.75	2.72	2.70	2.67	2.65	2.62	2.60	2.56	2.54	2.52	2.49	2.47	2.44
171	2.88	2.99	3.10	3.08	3.05	3.03	3.00	2.97	2.95	2.92	2.90	2.87	2.78	2.76	2.73	2.70	2.68	2.65	2.63	2.60	2.58	2.55	2.53	2.50	2.48
172	2.91	3.02	3.14	3.11	3.09	3.06	3.03	3.01	2.98	2.96	2.93	2.90	2.81	2.79	2.76	2.74	2.71	2.69	2.66	2.64	2.61	2.59	2.56	2.53	2.51
173	2.94	3.05	3.17	3.15	3.12	3.09	3.07	3.04	3.02	2.99	2.96	2.94	2.85	2.82	2.80	2.77	2.75	2.72	2.70	2.67	2.64	2.62	2.59	2.57	2.54
174	2.98	3.08	3.21	3.18	3.15	3.13	3.10	3.08	3.05	3.02	3.00	2.97	2.88	2.86	2.83	2.80	2.78	2.75	2.73	2.70	2.68	2.65	2.63	2.60	2.58
175	3.01	3.11	3.24	3.21	3.19	3.16	3.14	3.11	3.08	3.06	3.03	3.01	2.91	2.89	2.86	2.84	2.81	2.79	2.76	2.74	2.71	2.69	2.66	2.63	2.61
176	3.04	3.14	3.27	3.25	3.22	3.20	3.17	3.14	3.12	3.09	3.07	3.04	2.95	2.92	2.90	2.87	2.85	2.82	2.80	2.77	2.74	2.72	2.69	2.67	2.64
177	3.07	3.17	3.31	3.28	3.26	3.23	3.20	3.18	3.15	3.13	3.10	3.07	2.98	2.96	2.93	2.91	2.88	2.85	2.83	2.80	2.78	2.75	2.73	2.70	2.68
178	3.10	3.21	3.34	3.32	3.29	3.26	3.24	3.21	3.19	3.16	3.13	3.11	3.01	2.99	2.96	2.94	2.91	2.89	2.86	2.84	2.81	2.79	2.76	2.74	2.71
179	3.13	3.24	3.38	3.35	3.33	3.30	3.27	3.25	3.22	3.20	3.17	3.14	3.05	3.02	3.00	2.97	2.95	2.92	2.90	2.87	2.84	2.82	2.79	2.77	2.74
180	3.16	3.27	3.41	3.39	3.36	3.33	3.31	3.28	3.26	3.23	3.20	3.18	3.08	3.06	3.03	3.01	2.98	2.95	2.93	2.90	2.88	2.85	2.83	2.80	2.78
181	3.19	3.30	3.45	3.42	3.39	3.37	3.34	3.32	3.29	3.26	3.24	3.21	3.11	3.09	3.06	3.04	3.01	2.99	2.96	2.94	2.91	2.89	2.86	2.84	2.81
182	3.23	3.33	3.48	3.45	3.43	3.40	3.38	3.35	3.32	3.30	3.27	3.25	3.15	3.12	3.10	3.07	3.05	3.02	3.00	2.97	2.94	2.92	2.89	2.87	2.84
183	3.26	3.36	3.51	3.49	3.46	3.44	3.41	3.38	3.36	3.33	3.31	3.28	3.18	3.16	3.13	3.11	3.08	3.05	3.03	3.00	2.98	2.95	2.93	2.90	2.88
184	3.29	3.39	3.55	3.52	3.50	3.47	3.44	3.42	3.39	3.37	3.34	3.31	3.22	3.19	3.16	3.14	3.11	3.09	3.06	3.04	3.01	2.99	2.96	2.94	2.91

Table D-3E—LLN for FEV_1 for Females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
148	2.13	2.25	2.09	2.06	2.03	2.00	1.97	1.95	1.92	1.89	1.86	1.83	1.80	1.77	1.74	1.71	1.68	1.65	1.62	1.59	1.56	1.53	1.50	1.47	1.44
149	2.16	2.27	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70	1.68	1.65	1.62	1.59	1.56	1.53	1.50	1.47
150	2.19	2.30	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70	1.67	1.64	1.61	1.58	1.55	1.52	1.49
151	2.22	2.33	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.85	1.82	1.79	1.76	1.73	1.70	1.67	1.64	1.61	1.58	1.55	1.52
152	2.25	2.36	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.81	1.78	1.75	1.72	1.69	1.66	1.63	1.60	1.58	1.55
153	2.28	2.39	2.22	2.19	2.16	2.13	2.10	2.07	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.81	1.78	1.75	1.72	1.69	1.66	1.63	1.60	1.57
154	2.30	2.42	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.98	1.95	1.92	1.89	1.86	1.83	1.80	1.77	1.75	1.72	1.69	1.66	1.63	1.60
155	2.33	2.45	2.27	2.24	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.98	1.95	1.92	1.89	1.86	1.83	1.80	1.77	1.74	1.71	1.68	1.65	1.62
156	2.36	2.48	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.92	1.89	1.86	1.83	1.80	1.77	1.74	1.71	1.68	1.65
157	2.39	2.50	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70	1.67
158	2.42	2.53	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88	1.85	1.82	1.79	1.76	1.73	1.70
159	2.45	2.56	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.82	1.79	1.76	1.73
160	2.48	2.59	2.40	2.37	2.34	2.31	2.29	2.26	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.81	1.78	1.75
161	2.51	2.62	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.02	1.99	1.96	1.93	1.90	1.87	1.84	1.81	1.78
162	2.53	2.65	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.98	1.95	1.92	1.89	1.86	1.83	1.80
163	2.56	2.68	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24	2.21	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.98	1.95	1.92	1.89	1.86	1.83
164	2.59	2.70	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.92	1.89	1.86
165	2.62	2.73	2.53	2.50	2.47	2.44	2.41	2.38	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.03	2.00	1.97	1.94	1.91	1.88
166	2.65	2.76	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.11	2.09	2.06	2.03	2.00	1.97	1.94	1.91
167	2.68	2.79	2.58	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.93
168	2.71	2.82	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.26	2.23	2.20	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96

Table D-3E (Continued)—LLN for FEV_1 for Females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
169	2.73	2.85	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01	1.99
170	2.76	2.88	2.66	2.63	2.60	2.57	2.54	2.51	2.48	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.10	2.07	2.04	2.01
171	2.79	2.91	2.69	2.66	2.63	2.60	2.57	2.54	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24	2.21	3.18	2.16	2.13	2.10	2.07	2.04
172	2.82	2.93	2.71	2.68	2.65	2.63	2.60	2.57	2.54	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06
173	2.85	2.96	2.74	2.71	2.68	2.65	2.62	2.59	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09
174	2.88	2.99	2.77	2.74	2.71	2.68	2.65	2.62	2.59	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14	2.11
175	2.91	3.02	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.55	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32	2.29	2.26	2.23	2.20	2.17	2.14
176	2.94	3.05	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.26	2.23	2.20	2.17
177	2.96	3.08	2.84	2.81	2.78	2.75	2.72	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22	2.19
178	2.99	3.11	2.87	2.84	2.81	2.78	2.75	2.72	2.69	2.66	2.63	2.60	2.57	2.54	2.51	2.48	2.45	2.43	2.40	2.37	2.34	2.31	2.28	2.25	2.22
179	3.02	3.14	2.90	2.87	2.84	2.81	2.78	2.75	2.72	2.69	2.66	2.63	2.60	2.57	2.54	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27	2.24
180	3.05	3.16	2.92	2.89	2.86	2.83	2.80	2.77	2.74	2.71	2.68	2.65	2.62	2.60	2.57	2.54	2.51	2.48	2.45	2.42	2.39	2.36	2.33	2.30	2.27
181	3.08	3.19	2.95	2.92	2.89	2.86	2.83	2.80	2.77	2.74	2.71	2.68	2.65	2.62	2.59	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.33	2.30
182	3.11	3.22	2.97	2.94	2.91	2.88	2.85	2.82	2.80	2.77	2.74	2.71	2.68	2.65	2.62	2.59	2.56	2.53	2.50	2.47	2.44	2.41	2.38	2.35	2.32
183	3.14	3.25	3.00	2.97	2.94	2.91	2.88	2.85	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.50	2.47	2.44	2.41	2.38	2.35
184	3.17	3.28	3.02	2.99	2.97	2.94	2.91	2.88	2.85	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.61	2.58	2.55	2.52	2.49	2.46	2.43	2.40	2.37

Table D-3F—LLN for FEV_1/FVC% for Females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
148	74.8	75.9	77.5	77.2	76.9	76.5	76.2	75.9	75.6	75.2	74.9	74.6	74.2	73.9	73.6	73.3	72.9	72.6	72.3	72.0	71.6	71.3	71.0	70.7	70.3
149	74.7	75.8	77.3	77.0	76.7	76.4	76.0	75.7	75.4	75.1	74.7	74.4	74.1	73.8	73.4	73.1	72.8	72.5	72.1	71.8	71.5	71.2	70.8	70.5	70.2
150	74.5	75.6	77.2	76.9	76.5	76.2	75.9	75.6	75.2	74.9	74.6	74.3	73.9	73.6	73.3	73.0	72.6	72.3	72.0	71.7	71.3	71.0	70.7	70.3	70.0
151	74.4	75.5	77.0	76.7	76.4	76.1	75.7	75.4	75.1	74.7	74.4	74.1	73.8	73.4	73.1	72.8	72.5	72.1	71.8	71.5	71.2	70.8	70.5	70.2	69.9
152	74.2	75.3	76.9	76.5	76.2	75.9	75.6	75.2	74.9	74.6	74.3	73.9	73.6	73.3	73.0	72.6	72.3	72.0	71.7	71.3	71.0	70.7	70.4	70.0	69.7
153	74.1	75.1	76.7	76.4	76.1	75.7	75.4	75.1	74.8	74.4	74.1	73.8	73.5	73.1	72.8	72.5	72.2	71.8	71.5	71.2	70.8	70.5	70.2	69.9	69.5
154	73.9	75.0	76.6	76.2	75.9	75.6	75.2	74.9	74.6	74.3	73.9	73.6	73.3	73.0	72.6	72.3	72.0	71.7	71.3	71.0	70.7	70.4	70.0	69.7	69.4
155	73.8	74.8	76.4	76.1	75.7	75.4	75.1	74.8	74.4	74.1	73.8	73.5	73.1	72.8	72.5	72.2	71.8	71.5	71.2	70.9	70.5	70.2	69.9	69.6	69.2
156	73.6	74.7	76.2	75.9	75.6	75.3	74.9	74.6	74.3	74.0	73.6	73.3	73.0	72.7	72.3	72.0	71.7	71.3	71.0	70.7	70.4	70.0	69.7	69.4	69.1
157	73.5	74.5	76.1	75.7	75.4	75.1	74.8	74.4	74.1	73.8	73.5	73.1	72.8	72.5	72.2	71.8	71.5	71.2	70.9	70.5	70.2	69.9	69.6	69.2	68.9
158	73.3	74.4	75.9	75.6	75.3	74.9	74.6	74.3	74.0	73.6	73.3	73.0	72.7	72.3	72.0	71.7	71.4	71.0	70.7	70.4	70.1	69.7	69.4	69.1	68.7
159	73.2	74.2	75.8	75.4	75.1	74.8	74.5	74.1	73.8	73.5	73.2	72.8	72.5	72.2	71.8	71.5	71.2	70.9	70.5	70.2	69.9	69.6	69.2	68.9	68.6
160	73.0	74.1	75.6	75.3	74.9	74.6	74.3	74.0	73.6	73.3	73.0	72.7	72.3	72.0	71.7	71.4	71.0	70.7	70.4	70.1	69.7	69.4	69.1	68.8	68.4
161	72.8	73.9	75.4	75.1	74.8	74.5	74.1	73.8	73.5	73.2	72.8	72.5	72.2	71.9	71.5	71.2	70.9	70.6	70.2	69.9	69.6	69.2	68.9	68.6	68.3
162	72.7	73.8	75.3	75.0	74.6	74.3	74.0	73.7	73.3	73.0	72.7	72.3	72.0	71.7	71.4	71.0	70.7	70.4	70.1	69.7	69.4	69.1	68.8	68.4	68.1
163	72.5	73.6	75.1	74.8	74.5	74.1	73.8	73.5	73.2	72.8	72.5	72.2	71.9	71.5	71.2	70.9	70.6	70.2	69.9	69.6	69.3	68.9	68.6	68.3	68.0
164	72.4	73.5	75.0	74.6	74.3	74.0	73.7	73.3	73.0	72.7	72.4	72.0	71.7	71.4	71.1	70.7	70.4	70.1	69.7	69.4	69.1	68.8	68.4	68.1	67.8
165	72.2	73.3	74.8	74.5	74.2	73.8	73.5	73.2	72.8	72.5	72.2	71.9	71.5	71.2	70.9	70.6	70.2	69.9	69.6	69.3	68.9	68.6	68.3	68.0	67.6
166	72.1	73.1	74.6	74.3	74.0	73.7	73.3	73.0	72.7	72.4	72.0	71.7	71.4	71.1	70.7	70.4	70.1	69.8	69.4	69.1	68.8	68.5	68.1	67.8	67.5
167	71.9	73.0	74.5	74.2	73.8	73.5	73.2	72.9	72.5	72.2	71.9	71.6	71.2	70.9	70.6	70.2	69.9	69.6	69.3	68.9	68.6	68.3	68.0	67.6	67.3
168	71.8	72.8	74.3	74.0	73.7	73.3	73.0	72.7	72.4	72.0	71.7	71.4	71.1	70.7	70.4	70.1	69.8	69.4	69.1	68.8	68.5	68.1	67.8	67.5	67.2

Table D-3F (Continued)—LLN for $FEV_1/FVC\%$ for Females

Height (cm)	Age																								
	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65
169	71.6	72.7	74.2	73.8	73.5	73.2	72.9	72.5	72.2	71.9	71.6	71.2	70.9	70.6	70.3	69.9	69.6	69.3	69.0	68.6	68.3	68.0	67.7	67.3	67.0
170	71.5	72.5	74.0	73.7	73.4	73.0	72.7	72.4	72.1	71.7	71.4	71.1	70.7	70.4	70.1	69.8	69.4	69.1	68.8	68.5	68.1	67.8	67.5	67.2	66.8
171	71.3	72.4	73.8	73.5	73.2	72.9	72.5	72.2	71.9	71.6	71.2	70.9	70.6	70.3	69.9	69.6	69.3	69.0	68.6	68.3	68.0	67.7	67.3	67.0	66.7
172	71.2	72.2	73.7	73.4	73.0	72.7	72.4	72.1	71.7	71.4	71.1	70.8	70.4	70.1	69.8	69.5	69.1	68.8	68.5	68.2	67.8	67.5	67.2	66.8	66.5
173	71.0	72.1	73.5	73.2	72.9	72.6	72.2	71.9	71.6	71.2	70.9	70.6	70.3	69.9	69.6	69.3	69.0	68.6	68.3	68.0	67.7	67.3	67.0	66.7	66.4
174	70.8	71.9	73.4	73.0	72.7	72.4	72.1	71.7	71.4	71.1	70.8	70.4	70.1	69.8	69.5	69.1	68.8	68.5	68.2	67.8	67.5	67.2	66.9	66.5	66.2
175	70.7	71.8	73.2	72.9	72.6	72.2	71.9	71.6	71.3	70.9	70.6	70.3	70.0	69.6	69.3	69.0	68.7	68.3	68.0	67.7	67.3	67.0	66.7	66.4	66.0
176	70.5	71.6	73.1	72.7	72.4	72.1	71.7	71.4	71.1	70.8	70.4	70.1	69.8	69.5	69.1	68.8	68.5	68.2	67.8	67.5	67.2	66.9	66.5	66.2	65.9
177	70.4	71.5	72.9	72.6	72.2	71.9	71.6	71.3	70.9	70.6	70.3	70.0	69.6	69.3	69.0	68.7	68.3	68.0	67.7	67.4	67.0	66.7	66.4	66.1	65.7
178	70.2	71.3	72.7	72.4	72.1	71.8	71.4	71.1	70.8	70.5	70.1	69.8	69.5	69.2	68.8	68.5	68.2	67.8	67.5	67.2	66.9	66.5	66.2	65.9	65.6
179	70.1	71.2	72.6	72.2	71.9	71.6	71.3	70.9	70.6	70.3	70.0	69.6	69.3	69.0	68.7	68.3	68.0	67.7	67.4	67.0	66.7	66.4	66.1	65.7	65.4
180	69.9	71.0	72.4	72.1	71.8	71.4	71.1	70.8	70.5	70.1	69.8	69.5	69.2	68.8	68.5	68.2	67.9	67.5	67.2	66.9	66.6	66.2	65.9	65.6	65.2
181	69.8	70.8	72.3	71.9	71.6	71.3	71.0	70.6	70.3	70.0	69.7	69.3	69.0	68.7	68.3	68.0	67.7	67.4	67.0	66.7	66.4	66.1	65.7	65.4	65.1
182	69.6	70.7	72.1	71.8	71.4	71.1	70.8	70.5	70.1	69.8	69.5	69.2	68.8	68.5	68.2	67.9	67.5	67.2	66.9	66.6	66.2	65.9	65.6	65.3	64.9
183	69.5	70.5	71.9	71.6	71.3	71.0	70.6	70.3	70.0	69.7	69.3	69.0	68.7	68.4	68.0	67.7	67.4	67.1	66.7	66.4	66.1	65.7	65.4	65.1	64.8
184	69.3	70.4	71.8	71.5	71.1	70.8	70.5	70.2	69.8	69.5	69.2	68.8	68.5	68.2	67.9	67.5	67.2	66.9	66.6	66.2	65.9	65.6	65.3	64.9	64.6

have spirometric values technically within the normal range. In such instances, more sophisticated tests (for example, diffusion capacity, exercise studies) may be necessary to characterize the nature and degree of pulmonary impairment. Spirometric guidelines for the assessment of the degree of ventilatory impairment are provided in Table D-4.

Calculation of Changes in Follow-Up Spirograms

When no previous spirograms are available, the usual interpretive method is to compare an individual's test results with a set of predicted normals. However, an even more desirable approach is the longitudinal testing of the same worker over a period of time, as occurs in medical surveillance programs. Here the worker serves as his or her own control, and follow-up values can be compared with changes in pulmonary function that are normally expected with aging. In males, a 30-milliliter annual decline in FEV_1 and a 25-milliliter decline in FVC can be attributed to normal aging. In females, the value is 25 milliliters for both FEV_1 and FVC. It must be pointed out, however, that these values represent group averages and that considerable variation may occur among individuals.

When a current spirometric value is compared with a previous one, the difference can be expressed as either an absolute change, in liters, or a percentage change. For example, in an annual surveillance program for asbestos workers, a 24-year-old woman is found to have an FVC of 3.59 liters. Her previous year's FVC was 4.17 liters:

$$\begin{aligned}\text{Absolute change} &= \text{Previous FVC} - \text{Current FVC}\\ &= 4.17 - 3.59\\ &= 0.58 \text{ liter}\end{aligned}$$

$$\begin{aligned}\text{Percent change} &= \frac{\text{Previous FVC} - \text{Current FVC}}{\text{Previous FVC}}\\ &= \frac{4.17 - 3.59}{4.17} \times 100\\ &= 13.9\%\end{aligned}$$

Current results can be compared with last year's values or with the previously recorded best value for each test, regardless of when it occurred. In any event, the expected normal decline in pulmonary function over the period of time in question must be considered in the final interpretation.

In any respiratory surveillance program, the responsible physician must be aware of other variables besides the effects of age and disease. Cigarette smoking may alter the results of certain pulmonary function tests, particularly forced expiratory flow rates. Recent use of aerosolized bronchodilators can produce misleading results. Instrument-dependent factors also introduce variability. Some spirometers inherently give inconsistent results, and any instrument may lose calibration during repeated use or when subjected to trauma. Comparing follow-up values obtained using different instruments can be an additional source of error. However, inconsistent spirometric technique, including fluctuating patient effort, remains the single most important source of variability. Widespread adoption of the minimum instrument specifications and methodological principles recommended by ATS in its 1994 update will ameliorate such problems.

All of the aforementioned variables aside, what criteria should be used to decide whether a given change is due to disease? More extensive experience in respiratory medical surveillance is neces-

Table D-4—ATS Guidelines for Assessing Degree of Ventilatory Impairment

Indicator	Normal	Mild	Moderate	Severe
Percent predicted FVC	≥80%	60%–79%	51%–59%	≤50%
Percent predicted FEV	≥80%	60%–79%	41%–59%	≤40%
FEV/FVC%	≥75%	60%–74%	41%–59%	≤40%

sary before certain changes in spirometric tests can be regarded as clinically significant. In the interim, individual physicians will need to exercise considerable judgment in assessing year-to-year changes in pulmonary function tests. When not specifically superseded by existing regulations or policies, NIOSH suggests the following guidelines as potentially useful in the assessment of changes in annual spirometry:

1. A decline in FEV_1 or FVC greater than 12%.
2. A decline in FEV_1/FVC% greater than 5%.

If these changes are not clearly attributable to non-disease-related variables, they should be regarded as potentially abnormal. It is further suggested that any abnormal results in either baseline or follow-up spirometry be verified by means of repeat testing.

The necessity of maintaining complete and permanent medical records must also be underscored. Spirometric results should be inscribed on an appropriate form in the patient's record (see Pulmonary Function Studies Record, Appendix B, pages B-9 and B-10). FEV_1 and FVC should be expressed in liters rounded to two decimal places (for example, 5.61 liters). FEV_1/FVC% and all percentage predicted normals should be rounded to one decimal place (for example, 85.4%). Changes in spirometric values over time can be expressed in liters or milliliters or as a percentage change. A "+" prefix is customarily used to indicate an increase in pulmonary function, whereas a "–" prefix is used to indicate a decline. The technician should always record an assessment of subject cooperation. The spirogram itself should be retained either in a separate folder or in the medical record.

Interpretation of Spirometry

Spirometry results must be interpreted by a physician, preferably one trained in pulmonary medicine. A diagnosis of pulmonary disease can seldom be made based on spirometry alone; however, spirometry is an important part of the total clinical presentation. Most pulmonary abnormalities measured by spirometry are not due to work-related disorders but are related to smoking, nonoccupational pulmonary disease, and other respiratory conditions. Certain patterns of disordered lung function can be recognized, and although the patterns are seldom characteristic of a specific disease, they can be used to identify the various types of clinical illnesses related to the type of abnormal lung function.

Chronic obstructive pulmonary disease (COPD), which includes emphysema and chronic bronchitis, is characterized by a pattern of airway obstruction and reduced airflow. Most individuals with these diseases have a long history of heavy cigarette smoking. Chronic bronchitis is diagnosed when an individual has excessive airway mucus secretion (sputum), leading to a persistent productive cough. The production of excessive mucus can lead to a narrowing of the large and small airways, making it more difficult to move air in and out of the lungs. Emphysema is characterized by a permanent destruction of the *alveoli,* the lungs' tiny elastic air sacs, where exchange of carbon dioxide and oxygen takes place. The destruction of the alveoli causes small air passages, called *bronchioles,* to narrow or collapse, which in turn limits airflow out of the lung.

When airways narrow as a result of chronic bronchitis or collapse as a result of emphysema, the affected individual has difficulty exhaling air from the lungs. Airway obstruction is determined by using spirometry to measure FEV_1 and FEV_1 expressed as a percentage of FVC, namely, FEV_1/FVC%. In obstructive airway disease, these measurements are reduced.

Restrictive lung diseases caused by pulmonary fibrosis, such as silicosis, lead to a stiffening of the lungs as a result of the presence of fibrotic tissue. Rather than obstructing or collapsing the airways, as with chronic bronchitis and emphysema, fibrosis increases the stiffness of the lungs, restricting the lungs' ability to expand fully on inhalation. Spirometry showing a restrictive response pattern is characterized by a reduction in lung volumes and ventilatory capacity, measured by a reduction in FVC, with normal FEV_1/FVC%.

A mixed pattern of obstructive and restrictive impairment may be present in a worker with complicated silicosis or when more than one disease process (for example, silicosis and emphysema) is present. In complicated silicosis, large masses of fibrosis reduce the ability of the lungs to expand and reduce FVC. Obstruction may also be present, presumably because of increased airway resistance and alveolar abnormalities.

Instrument Specifications

The ATS's efforts to standardize spirometric equipment began in June 1976 with the development of a draft of proposed standards. In January 1977, ATS sponsored a workshop on standardization of spirometry at Snowbird, Utah. At the two-day workshop the draft was revised, and the workshop's recommendations were later published in the *ATS News* (Summer 1977). After comments were received, a final statement, "Standardization of Spirometry," was approved by the ATS Council in May 1978. This report has since been published in the *American Review of Respiratory Diseases* and was updated in 1987 and again in 1994.

Calibration

The simplest and most accurate method of calibrating a spirometer is with a large calibrating syringe. The instrument manufacturer should provide a calibration method that uses a syringe of at least 3 liters. A calibrating syringe can also be used to determine whether a spirometer meets the minimum ATS requirements. The syringe must be emptied into the spirometer at various flow rates, and the corresponding volumes compared with the syringe volume. For spirometers that measure volume directly, care should be taken to ensure that the air inside the syringe is at the same temperature and relative humidity as the air inside the spirometer.

Types of Spirometers

There are two general types of spirometers—devices that measure volume directly, and devices that measure flow and derive volume by some method such as integration of the flow signal. If the primary measurements of interest are FEV_1 and FVC, which are volume measures, then an instrument that measures volume directly will, in general, be superior to an instrument that measures flow and derives volume. The main advantage of flow-measuring devices is their smaller size and portability. However, flow-measuring devices are usually less accurate and more difficult to calibrate and maintain. For the NISA OHP, volume spirometers are preferred over flow spirometers.

Volume Spirometers

The three most common types of direct-volume-measuring spirometers are the water-seal, dry-rolling-seal, and bellows types. The water-seal spirometer is simple to operate, accurate, and requires little maintenance other than occasional checks for leaks.

The bellows spirometer is also simple to operate and is perhaps one of the most popular types of screening instruments. Some bellows spirometers are quite accurate and meet or exceed all the ATS requirements. However, a few bellows spirometers have difficulty meeting the minimum requirements for several specifications.

First, the mechanical linkages on some bellows spirometers are bulky and introduce excessive inertia. Second, some bellows spirometers do not record the FVC maneuver for a full 15 seconds or longer; they may therefore underestimate the FVC of patients with obstructive lung disease. Other bellows spirometers do not start their chart recorder until the exhalation has begun. Use of such spirometers is not recommended, because an accurate record of the start of the FVC test is needed to achieve a reliable result by back extrapolation and to determine the quality of the start of the FVC test.

The preferred spirometer for the NISA OHP is the dry-rolling-seal type. A dry-rolling-seal spirometer consists of a cylinder and piston that are sealed by means of a rolling plastic seal. The rolling seal offers very little friction, and most rolling-seal spirometers meet or exceed the minimum ATS re-

quirements. Most rolling-seal spirometers provide electrical output signals, which enables a separate recording device to be used. However, at least one manufacturer provides a direct-recording rolling-seal spirometer.

Flow Spirometers

The three most common types of flow spirometers are pneumocotachographs, hot-wire anemometers, and rotating vanes. In general, devices that measure flow and derive volume are more difficult to calibrate and maintain and are less accurate in determining volume. Since flow is usually integrated to obtain volume, a small flow error or a small flow offset can become significant when integrated over 5–10 seconds. For this reason, some flow-measuring devices terminate the measurement of volume prematurely to reduce the time over which small errors in flow are integrated. Premature termination of the FVC maneuver, especially in patients with obstructive lung disease, often results in a falsely low FVC and a more normal FEV_1/FVC%.

Another potential problem with flow-measuring devices is that volume accuracy may depend on the flow profile presented to the sensor. A flow spirometer may give very accurate volumes with moderate flow rates, yet underestimate volumes with high flow rates or overestimate volumes with low flow rates. This means that some flow spirometers may give accurate volumes for normal subjects and incorrect volumes for subjects with reduced ventilatory capacities. However, several well-engineered flow spirometers do meet the ATS minimum requirements and are acceptable if they are checked on a regular basis.

Evaluating Spirometry Testing Services

To assist member companies in evaluating the services provided by physicians and/or technicians conducting spirometry, a checklist can be found in Appendix E (Checklist for Evaluating Spirometry Testing Services). NISA suggests that member companies specify that spirometry service providers meet the criteria of the ATS "Standardization of Spirometry—1994 Update." Consult the *NISA Silicosis Prevention Program—Directory of Volunteers* for a list of members that can provide additional information on selection and evaluation of spirometry providers.

Occupational Health Program
Spirometry Procedure Checklist

1. Briefly explain the purpose of spirometry: "I want to test how hard, how fast, and how long you can breathe."
2. Ask appropriate questions to determine if spirometry should be postponed:
   a. "How are you feeling today?"
   b. "Have you smoked a cigarette, used an aerosolized bronchodilator, or had a heavy meal in the past hour?"
   c. "Have you had pneumonia, bronchitis, influenza, or a severe cold in the past three weeks?"
3. Position the subject comfortably, requesting that he or she either stand or sit.
4. Instruct the subject to loosen tight clothing, remove loose or poorly fitting dentures, and extend the chin slightly.
5. Securely apply a nose clip.
6. Instruct the subject in proper performance of the forced expiratory maneuver: "Whenever you're ready, take the deepest possible breath, place your mouth firmly around the mouthpiece and without further hesitation, blow into the spirometer as hard, fast, and completely as possible."
7. Place the recorder pen in the appropriate position on the chart paper.
8. Start the chart paper moving at least 1 second before the subject blows into the mouthpiece.
9. Coach actively throughout the entire forced expiratory effort until a plateau occurs in the tracing for at least 1 second (30 milliliters or less).
10. Examine the tracing and reinstruct if necessary.
11. Continue testing until three acceptable tracings have been obtained. The two largest forced vital capacities (FVCs) and forced expiratory volume in 1 second (FEV_1) should not vary by more than 200 milliliters.

Occupational Health Program
Spirometry Calculation Outline

1. Measure FVC in each tracing, from baseline to plateau.
2. Select the largest FVC from the three acceptable tracings.
3. Measure FEV_1 in each curve. If necessary, use back extrapolation to determine the zero time point.
4. Select the largest FEV_1 (usually found on the same curve as the largest FVC) from the three tracings.
5. Obtain the BTPS conversion factor from Table D-2, using the ambient temperature.
6. Perform the following calculations:

$$FEV_{1\,(ATPS)} \times \text{BTPS conversion factor} = FEV_{1\,OBS\,(BTPS)}$$

$$FVC_{(ATPS)} \times \text{BTPS conversion factor} = FVC_{OBS\,(BTPS)}$$

7. Determine the predicted FEV_1 and the predicted FVC from Tables D-3A–D-3F, using sex, height, and age. For non-Caucasians, multiply the predicted FEV_1 and the predicted FVC by the ethnic correction factor of 0.85.
8. Perform the following calculations:

$$FEV_{BTPS} \div FEV_{1\,predicted \times 100} = FEV_1 \text{ predicted normal}$$

$$FVC_{BTPS} \div FVC_{predicted \times 100} = \text{FVC\% predicted normal}$$

9. For FEV_1/FVC%, perform the following calculation:

$$FEV_{1\,OBS} \div FVC_{OBS} = FEV_1/\text{FVC\%}$$

Note: Use the largest FEV_1 and FVC in the calculation above, even if they do not come from the same curve.

The calculations can be summarized as follows:

$$FEV_{1\,(ATPS)} \times \text{BTPS conversion factor} = FEV_{1\,OBS\,(BTPS)}$$

$$FVC_{ATPS} \times \text{BTPS conversion factor} = FVC_{OBS\,(BTPS)}$$

$$FEV_{1\,OBS} \div FVC_{OBS} = FEV_1/FVC_{\%}$$

$$FEV_{1\,OBS} \div FEV_{1\,predicted \times 100} = FEV_1 \text{ predicted}$$

$$FVC_{OBS} \div FVC_{predicted \times 100} = \text{FVC\% predicted}$$

Appendix Q

Occupational Health Program: Checklist for Evaluating Spirometry Testing Services

Though not a comprehensive listing, this checklist can assist in evaluating the proficiency of a spirometry testing provider.

Standardization

- Does the spirometry testing provided meet the requirements of the ATS "Standardization of Spirometry – 1994 updates"?
- Are the criteria of the ATS "Standardization of Spirometry – 1994 Update" specified in any agreement for services or cited by the contractor in a discussion of services to be provided?

Technicians

- Have spirometry technicians successfully completed a NIOSH-approved course in spirometry? Many providers advertise that their technicians are NIOSH-approved or certified, but NIOSH approves only the course, not individuals.
- Does the technician elicit vigorous subject effort in performing the forced expiratory maneuver?
- Does the technician observe the subject and instruments to detect faulty technique during testing?
- Does the technician obtain a minimum of three acceptable forced expiratory volume maneuvers on each subject?

Spirometer

- Does the provider use a dry-rolling-seal spirometer?
- Has the instrument been independently tested at the LDS Hospital, Salt Lake City, Utah, in the laboratory of Drs. Gardner and Crapo?
- Does the provider have a copy of the results of the tests by Drs. Gardner and Crapo on the instrument being used?
- Does the provider calibrate the spirometer daily, using a 3-liter syringe according to ATS recommendations?

Source: NISA "Occupational Health Program for Exposure to Crystalline Silica in the Industrial Minerals Industry" (1997).

Measurements

- Does the provider measure FVC and FEV, and express their ratio (FEV_1/FVC%)?

Note: Some providers report mean forced expiratory flow at the middle portion of the FVC ($FEF_{25\%-75\%}$). $FEF_{25\%-75\%}$ has much larger intrasubject variability, has a wider normal range, and is less sensitive than FEV_1/FVC%. For these and other reasons, $FEF_{25\%-75\%}$ is not generally recommended for occupational surveillance programs.

- Are the spirometry results corrected to BTPS)?

- Are predicted FVC and FEV corrected for non-Caucasians by multiplying results by 0.85?

Are the observed values compared with predicted values from Knudson's equations in accordance with ATS standards?

Reports

- In addition to comparison with predicted normals, does the provider compare serial results (repeat testing) from an individual and report significant changes?

- Are the spirometry results reported to the company in an understandable manner?

- Does the provider or company notify individual workers of results and answer questions satisfactorily?