Dust Particles: Occupational Considerations

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Glossary

Aerosol Solid or liquid particles suspended in a gas.
Birefringence Difference in refractive indices for a substance.
Organic dusts Particles originating from plant, animal, or microbiologic sources.
Pneumoconiosis Reaction of the lungs to inhalation of dust.
Sign of elongation Elongation of a substance in relation to refractive indices.

OCCUPATIONAL RESPIRATORY DISEASES resulting from the inhalation of dusts generated in working environments have been recognized for centuries. The effects of asbestos, silica, coal, and cotton dusts, for instance, are well documented, although mechanisms for disease initiation and progression are not yet fully understood. At present, despite the availability of improved air sampling techniques and dust control methods, disease persists.

I. Health Effects

Pneumoconiosis is the reaction of the lungs to inspired dust. The pathogenicity of a dust is determined by the effective or retained dose within the lungs and the biological reactivity of the dust with lung tissue. The amount of dust retained in the lungs is the difference between the amount inhaled and deposited in the airways and the quantity cleared from the lung by dissolution, phagocytosis, or the action of the mucociliary escalator (i.e., the movement of airway mucous up the respiratory tree and out of the lungs by the action of airway ciliary cells). Important characteristics of exposure include: the airborne concentration as well as the physical and chemical properties of the dust (aerodynamic diameter, shape, surface area, surface charge, surface reactive groups, contaminants adhered to the surface, etc.). These characteristics determine the acute and chronic reactions of the lungs to dust exposure.

The text that follows discusses "fibrous", "nonfibrous," and "organic" dusts as distinct entities. This distinction is not absolute and was made for ease of presentation. For example, there are obviously fibrous components of many organic dusts. In addition, dusts described in the nonfibrous section may contain particles having a ratio of length to width of ≥ 3 (a morphological distinction made by some groups for defining certain types of fibers).

A. Fibrous Dusts

1. Asbestos

Asbestos refers to a group of naturally occurring fibrous minerals. These silicate minerals can be divided mineralogically into serpentines and amphiboles. Chrysotile is in the serpentine group. It is a sheet silicate mineral rolled into a hollow tube structure. Amphiboles include crocidolite, actinolite,

tremolite, amosite, and anthophyllite. These minerals consist of double chains of linked silicon oxygen tetrahedra with trace metals found between these chains.

Asbestos is resistant to thermal and chemical degradation. Therefore, it has many commercial uses as an insulator or construction material. Occupations exposed to asbestos include: asbestos mining, asbestos milling, auto repair, shipbuilding, construction, and demolition.

Asbestosis is the pneumoconiosis caused by inhalation of asbestos. It is characterized by diffuse interstitial fibrosis and thickening of the visceral pleura (i.e., the external lining of the lungs). Symptoms associated with asbestosis include labored breathing upon exertion and cough. Pulmonary function tests indicate restrictive lung disease with a decrease in vital capacity and gas exchange. X-rays often show small irregular opacities in the lower regions of the lungs and pleural thickening. Gross examination of diseased lungs shows the presence of plaques on the lung surface. These pleural plaques are a cellular, fibrous material composed of collagen arranged in a basket weave pattern. In severe cases, this fibrous material can surround the lungs and restrict their full expansion. Histologically, asbestosis is characterized by fibrosis (i.e., increased collagen in the interstitial spaces). Fibrotic lesions most often occur in the lower lobes of the lungs near the bifurcation of the respiratory bronchioles where asbestos fibers lodge. These fibrous lesions surround asbestos bodies (i.e., asbestos fibers coated with an iron–protein material deposited by alveolar macrophages). In severe disease, this diffuse fibrosis may advance to conglomerate fibrosis where alveolar spaces are obliterated.

In addition to pulmonary fibrosis, inhalation exposure is also associated with mesothelioma and lung cancer. Mesothelioma is a malignant tumor of mesothelial cells lining the thoracic or more rarely the abdominal cavity. It is very rare in individuals who have not been exposed to asbestos. Those exposed to crocidolite or amosite appear to have the greatest incidence of mesothelioma.

Asbestos exposure can also lead to lung cancer. These tumors are bronchial carcinomas. Since tumors are associated with the fibrotic lesions of asbestosis, they are most common in the periphery and lower lobes of the lungs. In asbestos workers, smoking and asbestos are multiplicative risk factors for lung cancer (i.e., the risk of lung cancer in a nonsmoking asbestos worker is ≈5-fold, that of a nonexposed smoker is ≈10-fold, and that of a smoking asbestos worker is ≈60-fold higher than normal).

Stanton and co-workers proposed that the pathogenic properties of asbestos are due to its dimensions with long thin fibers being more toxic. The needle-like shape of asbestos acts to lodge it in airways and prevents phagocytosis by alveolar macrophages. Indeed, it is believed that reactive products secreted from macrophages during "frustrated phagocytosis" cause lung damage and induce collagen secretion by interstitial fibroblasts. The durability and needle-like shape of asbestos are also thought to play a role in the migration of asbestos fibers through lung tissue to the thoracic (pleural) cavity where plaque formation and mesothelioma occur.

2. Man-Made Mineral Fibers

Due to the pathogenicity of asbestos, man-made mineral fibers have been introduced that are noncrystalline and differ chemically from asbestos. These fibers are made from glass, natural rock, or slag and include fibrous glass, rock wool, and ceramic fibers.

These fibers are resistant to high temperature and chemicals and exhibit a high tensile strength. They are, therefore, used as asbestos substitutes for thermal and acoustical insulation and reinforcement in plastics. Workers exposed are those involved in the production, cutting, and packing of these fibers; those in the construction industry involved in installing or removing insulation; and those involved in refitting refractory linings of furnaces in the iron and steel industry.

Since the use of man-made mineral fibers is relatively recent, little data exists concerning the fibrogenicity of these fibers in humans. However, some epidemiological evidence has been obtained linking fibrous glass with a moderate elevation in lung cancer risk.

Cellular and animal studies are more numerous. Cellular studies indicate that man-made mineral fibers can be cytotoxic to lung cells. Injection of these fibers into the abdominal cavity results in tumor formation (mesothelioma). Intratracheal instillation of this material has been associated with fibrosis but not with lung tumors. To date neither fibrosis nor lung cancer has been found in animals exposed to fibrous glass, rock wool, or slag wool by inhalation. However, recent inhalation experiments indicate that ceramic fibers induce fibrosis and mesothelioma in hamsters and fibrosis in rats.

Some man-made mineral fibers would be judged as pathogenic according to the "Stanton Hypothesis" which states that long thin particles are associated with disease. However, fibrous glass may be less durable than asbestos, and the ability of fibrous glass to be bent may lessen its ability to migrate into the pleural space. At present, the question of the toxicity of man-made mineral fibers is an area of extensive research.

B. Nonfibrous Dusts

1. Silica

Mineralogically, silica can exist in either a crystalline or amorphous form. Quartz, cristobalite, and tridymite are silicon dioxide (SiO_2) crystals. Silica is used in glass manufacturing, pottery making, and sandblasting. In addition, workers in foundries, mining, tunneling, quarrying, and road working can be exposed to crystalline silica.

Silicosis is a fibrotic disease produced by inhalation of silica-containing dusts. High exposures to crystalline silica can result in acute silicosis. Acute silicosis develops rapidly (1–3 yr) and is characterized by labored breathing (dyspnea), fatigue, cough, and weight loss. Histologically, acute silicosis is characterized by alveolar proteinosis (i.e., edema, increased number of macrophages in the alveolar walls, and positive PAS staining of protein-like material in the alveolar airspaces). Acute silicosis may also be associated with fibrosis. However, these lesions are diffuse rather than nodular in appearance and are located in the middle and lower lobes of the lung. As the disease progresses, dramatic decreases in pulmonary function, lung volumes, and gas exchange are noted.

Chronic silicosis occurs 20–40 yr after initial exposure to crystalline silica. The disease progresses in degree from simple silicosis to complicated silicosis (progressive massive fibrosis). In simple silicosis, few symptoms are noted and pulmonary function is relatively normal. However, x-rays reveal small rounded opacities in the upper lobes of the lungs. These opacities are indicative of silicotic nodules which are made up of collagen arranged in a whirled or circular pattern. As the disease becomes more severe, it is classified as "complicated silicosis." At this time, shortness of breath upon exercise is common. Pulmonary function tests reveal restrictive lung diseases (decreased vital capacity) and x-rays reveal opacities that are more numerous, larger, and may be associated with contraction of lung tissue in the upper lobes resulting in expanded airspaces (emphysema).

Several theories have been proposed to explain the importance of surface properties to the cytotoxicity of silica. One theory suggests that SiOH groups on the crystal surface form hydrogen bonds with lung tissue resulting in damage. A second theory suggests that SiO^- groups are critical to cytotoxicity. A third proposal states that when silica is cleaved, radicals ($\dot{S}i$ or $Si\dot{O}$) are formed on the surface. These radicals can oxidize and damage cell membranes (lipid peroxidation). In addition to the lung damage caused directly by silica, this dust can cause inflammation (i.e., migration of phagocytes into the airspaces) and activate these cells to release reactive products (superoxide anion, hydrogen peroxide, hydroxyl radical, and lysosomal enzymes) that can further damage lung tissue. Silica also stimulates alveolar macrophages to produce cytokines such as interleukin 1, platelet activating factor, tumor necrosis factor, fibronectin, macrophage-derived growth factor, and platelet-derived growth factor. Some of the mediators are inflammatory while others are fibrogenic (i.e., causing proliferation of fibroblasts and increased collagen production by these cells).

Available animal and epidemiological data suggest that amorphous silica is far less toxic than crystalline silica.

2. Coal

It has long been known that coal miners can be stricken by a chronic lung disease commonly called "black lung disease." Disability is associated with chronic airway obstruction and thus labored exhalation. The more precise term to describe the lungs' reaction to inhalation of coal mine dust is "coal workers' pneumoconiosis."

Coal workers' pneumoconiosis (CWP) is categorized according to disease severity as simple CWP and progressive massive fibrosis. In simple CWP, there may be few symptoms and only small declines in forced expiratory lung volumes. However, x-rays show small rounded opacities in the upper lobes of the lungs. Histologically these opacities are associated with coal macules (i.e., black areas of the lung 1–4 mm in diameter). These macules are located near the respiratory bronchioles and are concentrated in the upper lung lobes. Adjacent to these macules may be areas of focal emphysema and fibrosis containing reticulin but little collagen. In pro-

gressive massive fibrosis, breathing may be labored especially upon expiration. Pulmonary function indicates increased airway resistance and obstructive lung disease characterized by decreased forced expiratory volumes. A decrease in gas exchange may also be present. X-rays demonstrate multiple irregular opacities which are larger and more numerous than with simple CWP. Histologically, those opacities are associated with large coal macules (2 cm in diameter). Lesions of collagen arranged in bundles rather than in a circular pattern are present and emphysema often occurs around these lesions.

CWP is characterized radiologically by the size and number of opacities as category 0, 1, 2, and 3. There is a direct relationship between cumulative coal mine dust exposure (i.e., the product of dust level and exposure duration) and the probability of progressing to category 2 or greater. There is also an increased risk of progressive massive fibrosis in miners with category 2 and 3 disease. In addition, the risk of CWP and progressive massive fibrosis at any given dust level increases with coal rank (i.e., disease risk is greater in anthracite miners than in bituminous miners).

There is no association between inhalation of coal mine dust and lung cancer. However, stomach cancer is elevated in coal miners. It has been proposed that coal dust is cleared from the lungs by the mucociliary escalator, swallowed, and nitrosated under the acidic conditions in the stomach. Nitrosated coal dust has been shown to be highly mutagenic and genotoxic.

In animal models, inhalation of coal dust results in activation of alveolar macrophages and increased release of reactive products that may cause lung damage. Such activated macrophages have been obtained from lungs of coal miners with CWP. In addition, these cells secrete fibrogenic cytokines such as fibronectin and alveolar macrophage-derived growth factor. Such results correlate with the presence of macrophages in coal macules characteristic of CWP. Later studies suggest that surface radicals can be generated when coal is crushed. These radicals could result in direct damage to lung tissue.

3. Diesel Particulate

During operation, diesel engines produce particulate material that is contaminated with a variety of organic chemicals adsorbed to the particulate surface. Diesels are extensively used in trucks, buses, and railroad engines. They are now being introduced within mines to power equipment. Workers who service these engines and some miners are exposed to this particulate.

Little information concerning disease in workers is available. However, cellular studies indicate that the organic chemicals adsorbed onto diesel particulate is highly mutagenic. Exposure of animals to diesel particulate has resulted in tumor formation at doses above 4 mg/m^3. Diesel particulate has been shown to decrease the phagocytotic potential of alveolar macrophages, to decrease particle clearance by the lungs, and to decrease the ability of the lungs to prevent the spread of pulmonary viral infection. Epidemiology studies on workers exposed to diesel particulate are less conclusive. However, some studies show increased risk of lung cancer while others report a mild elevation in reports of respiratory infections.

4. Other Silicates

Silicate minerals such as kaolin, beryl, kyanite, mica, talc, and vermiculite are generally considered to possess relatively low toxicity and are classified as nuisance dusts by OSHA. However, toxicity may occur when these dusts are contaminated with silica or asbestos or when pulmonary deposition of dust is high enough to compromise particulate clearance.

C. Organic Dusts

1. Cotton Dust

Exposure to cotton, flax, and hemp dust is associated with a set of respiratory symptoms referred to as byssinosis. These symptoms are characterized by chest tightness and respiratory tract irritation on the first day of the work week following a break of two or more days. This is often referred to as the "Monday response." Symptoms begin 2–3 hr after exposure and increase in severity throughout the workday. Therefore, the time course is distinct from asthma which would occur immediately upon exposure. Workers in the cotton or linen textile industry are exposed to cotton or flax dust. Disease is more common in the early stages of the textile process where the cotton fiber is less pure and contaminated with other plant parts such as the bract, leaf, and stem. Occupational exposure to hemp dust is associated with byssinosis in workers involved in producing rope from these plant fibers.

Schilling introduced a system for categorizing the severity of byssinotic symptoms. With grade 0 byssinosis, there are no symptoms. Grade 1/2 dis-

plays occasional chest tightness and respiratory tract irritation on Monday, while in grade 1 byssinosis these symptoms occur regularly on Monday. In grade 2 byssinosis symptoms occur on other work days as well as Mondays.

In acute byssinosis, chest tightness and a fall in forced expiratory volumes occurs over the working shift on Mondays. With chronic byssinosis, obstructive lung disease (i.e., decreased forced expiratory volumes) becomes apparent even on nonworkdays.

Byssinosis is associated with increased rates of chronic cough, phlegm, and chronic bronchitis (defined as production of phlegm on most days for at least three months over a year). In late stages of the disease, dyspnea may occur upon exercise.

Both the occurrence of byssinosis and workshift decreases in forced expiratory volumes are related to the dust levels in the workplace. Although decreases in forced expiratory volume correlate with byssinotic symptoms, they do not seem to be the cause of perceived chest tightness.

No x-ray changes are associated with byssinosis and no fibrosis has been identified histologically. The occurrence of bronchitis in byssinotics is associated with hyperplasia (increased number) and hypertrophy (increased size) of mucous glands in the bronchi.

Several mechanisms have been proposed to explain the onset of byssinosis. Some evidence suggests that cotton dust stimulates histamine release from airway mast cells. This histamine would induce constriction of airway smooth muscle and result in the observed decrease in forced expiratory volume. Evidence also indicates that cotton dust causes an inflammatory response dominated by the influx of leukocytes into the airways. These activated leukocytes could produce mediators (leukotriene D_4) which cause airway smooth muscle contraction. Still other evidence suggests that cotton dust directly causes airway constriction.

The etiologic agent of byssinosis is still undefined. Tannin, gossypol, and other plant chemicals in the cotton bract, leaves, and stems are biologically active and have been proposed as causitive agents. In addition, cotton dust contains significant microbial contamination, and bacterial products such as endotoxin can cause biological effects similar to cotton dust itself. Such effects include infiltration of leukocytes and acceleration of breathing rate. It may be that the syndrome of byssinosis results from the combined effects of several agents in cotton dust.

2. Other Agricultural Dust

Vegetable dusts generated by handling or cutting rice, corn, oats, wheat, hay, straw, wood, and compost can cause adverse lung reactions. Similar reactions occur upon exposure to dusts in swine or dairy confinement buildings and to dusts associated with poultry housing and processing. Therefore, farmers, foresters, woodworkers, grain handlers, food processors, and gardeners can be exposed.

The response to agricultural dust exposure is complex and not fully understood. It depends on factors such as exposure level and sensitization. Organic dust toxic syndrome (ODTS) refers to an adverse reaction to relatively high dust levels. No prior exposure sensitization is required for this reaction to occur. Symptoms appear 4–6 hr after exposure and include pulmonary inflammation, fever, chills, fatigue, headache, and chest tightness. Chest x-rays are usually normal and bronchoalveolar lavage samples are characterized by an increase in polymorphonuclear leukocytes. Serum antibodies to the dust in question need not be present.

Hypersensitivity pneumonitis (i.e., allergic alveolitis) comprises a group of allergic lung diseases resulting from sensitization and recurrent exposure to organic dusts. It includes such diseases as farmers' lung, mushroom workers' disease, pigeon breeders' disease, and bark strippers' disease. Symptoms include inflammation of the alveoli characterized by monocytes and lymphocytes with few polymorphonuclear leukocytes. The acute response includes fever, chills, shortness of breath, malaise, decreases in pulmonary function showing both restrictive and obstructive changes, a decrease in diffusion capacity, and a decrease in arterial oxygen levels. X-rays show lung infiltration characteristic of alveolitis and serum antibodies to the inhaled antigen are always present. Acute symptoms appear 4–10 hr after exposure and subside in 18–24 hr. Upon repeated exposure, the disease may progress to a chronic state where granulomatous lesions and diffuse fibrosis can be identified by x-ray. In chronic disease, pulmonary function is compromised even between exposures. Symptoms include those of restrictive lung disease with decreased gas exchange and lower arterial oxygen levels.

The etiologic agents in ODTS and hypersensitivity pneumonitis most likely originate from the microbial contaminants found in organic dusts. ODTS may be in part a reaction to endotoxin which is known to cause fever and leukocytosis. Hypersensi-

tivity pneumonitis is most like an allergic reaction to bacteria or fungi.

II. Sampling and Analysis

A. Fibrous Dust

Sampling and analysis of fibrous dust including asbestos can be done using several techniques that can be grouped into the two general categories of bulk and air analysis.

Bulk sampling and analysis involve the identification of components present in some bulk material, typically a building product. Usually the concern is whether or not asbestos is present. Polarized light microscopy is the most common method used although x-ray diffraction, infrared spectroscopy, and electron microscopy are also useful.

Bulk samples are usually collected with some type of coring device since many samples are multilayered. At the laboratory, samples are typically examined first with a stereomicroscope so that observation of particle morphology, color, and homogeneity can be made. Next, subsamples are transferred into a drop of refractive index liquid and examined under the polarized light microscope. Identifying particles microscopically requires the determination of a variety of optical properties including morphology, refractive index, birefringence, color, extinction characteristics, and sign of elongation. Figure 1 shows how some fibrous materials appear under the polarized light microscope.

For air sampling of fibrous dust, the most common method used is the collection of samples on some type of filter followed by fiber counting using microscopy. For light microscopy, samples are collected on cellulose ester filters that are cleared with acetone. Fiber counts are made using phase contrast illumination. Fibers collected from air samples are typically too small to identify with light microscopy so this technique is not qualitative beyond simple morphological considerations. When fiber identification is required, electron microscopy analysis of the filter samples is required. Fibers are identified by examination of morphological features, electron diffraction patterns, and x-ray analysis data. There is also a direct reading meter available that responds preferentially to elongated particles by exploiting the tendency for elongated particles to align themselves within a magnetic field.

B. Nonfibrous Dust

Particle size is a critical factor in estimating health risk since it is predominately particle size (and specifically aerodynamic size of a particle) that governs where deposition will occur in the respiratory system. In dealing with the problem of dust sampling, scientists have sought to design samplers that simulate the human respiratory system in terms of size selectivity. For instance, certain dusts cause pneumoconiosis that is related mainly to the fraction of dust that deposits in the alveolar region of the lung. Silica and coal dust are prime examples. For these dusts "respirable" samplers are used. These are samplers that preferentially sample that fraction of the dust that enters the alveolar region of the lung. In this country the most common means for making this measurement is to use a small battery-operated pump to first draw air through a miniature cyclone to remove the nonrespirable particles and then through a filter to capture the respirable portion. Samples are either collected on the workers themselves (personal sampling) or are collected from the workers' environment (area sampling). For most other dusts, "total" dust sampling is done. This is done by first drawing air through some arbitrary inlet and then through a filter. It is important to note that all inlets will exhibit size-selective characteristics especially for large particles where inertial forces of the particles tend to resist the drag forces of the fluid as the air enters the inlets. The inlets that are used for "total" dust sampling are not, however, linked to human lung deposition. Recent research has been directed at refining this concept of total dust. New definitions for particle-size-selective sampling have been proposed that include, in addition to respirable dust, thoracic and inhalable dust. For each of these criteria there is defined a distinct penetration curve that was selected by review of the best available experimental data. Thoracic dust includes that dust which would penetrate past the larynx. Since this includes both large and small airway penetration, it would be reasonable to apply this criterion to dusts which cause bronchitis. Inhalable particulate is dust that would penetrate anywhere in the respiratory tract from the head to the alveoli. This would logically be applied to dusts that can cause effects throughout the entire respiratory system. Certain agricultural dusts would seem to fit this category. Since these proposals were made, samplers have been developed for both thoracic and inhalable dust.

An alternative solution to the problem of size-

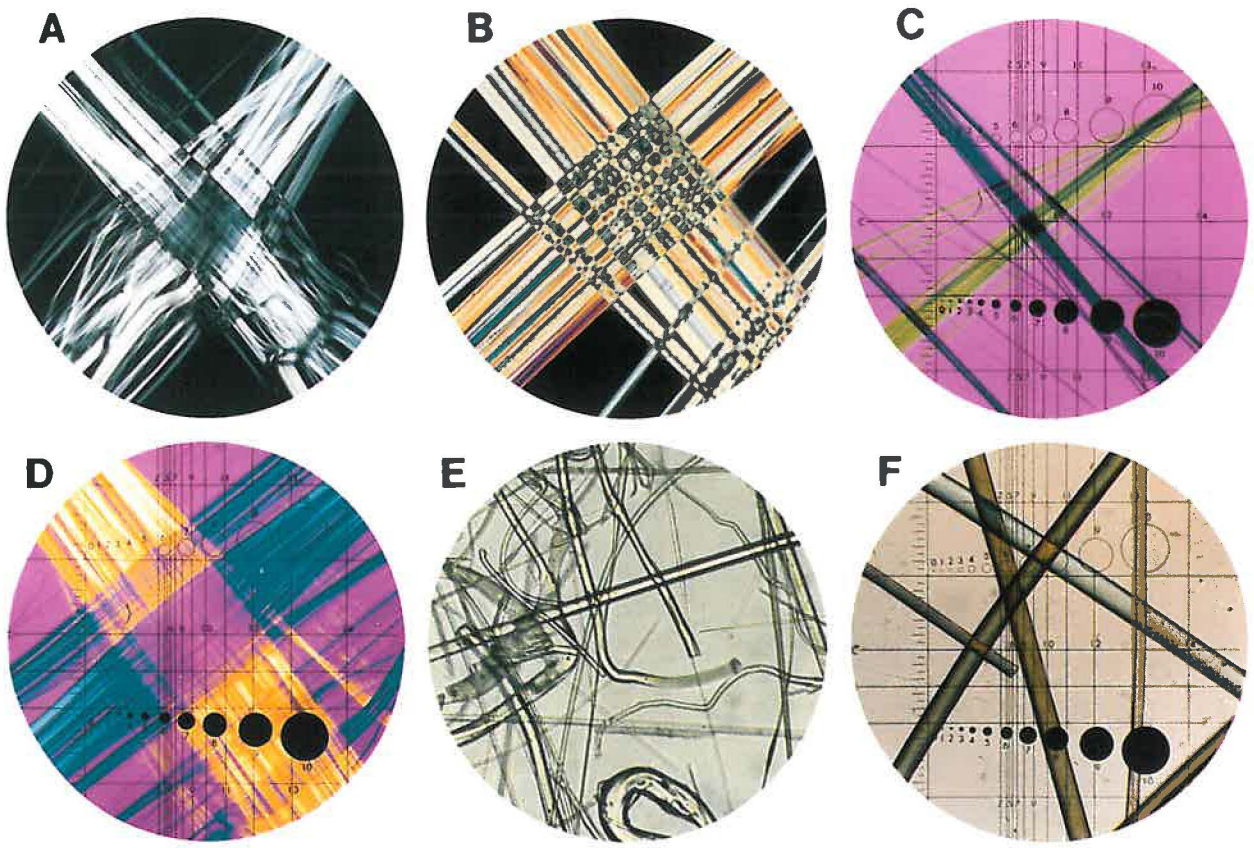

Figure 1 Photomicrographs of "fibrous" materials under various conditions of illumination. (A) Chrysotile asbestos (crossed polars); fiber bundles are ~250 μm in diameter. (B) Amosite asbestos (crossed polars); fiber bundles are ~250 μm in diameter. (C) Crocidolite asbestos (crossed polars/compensator); circle 10 = 80 μm. (D) Chrysotile asbestos (crossed polars/compensator); circle 10 = 80 μm. (E) Glass wool (brightfield); large fibers are ~10 μm in diameter. (F) Human hair (slightly uncrossed polars); circle 10 = 200 μm.

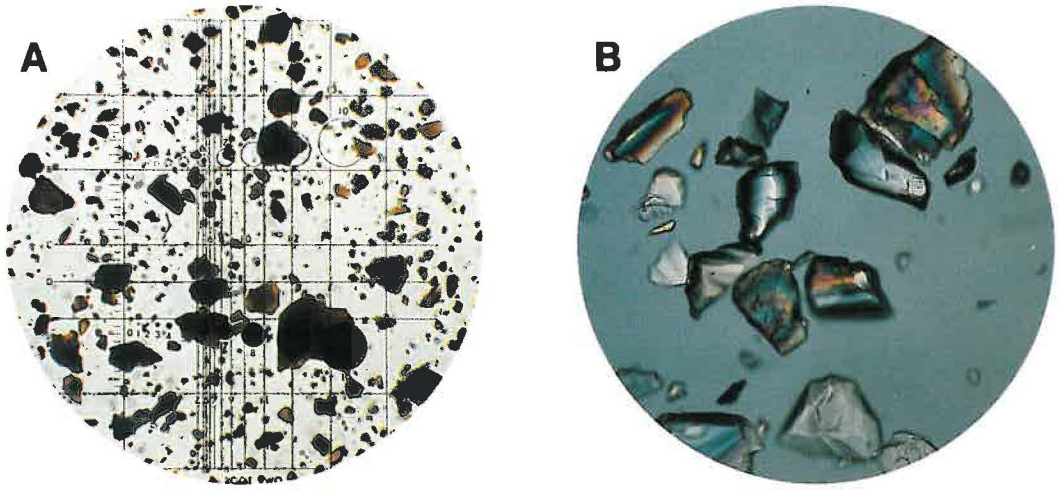

Figure 2 Photomicrographs of "nonfibrous" particles under various conditions of illumination. (A) Coal dust (brightfield); circle 10 = 20 μm. (B) Silica (slightly uncrossed polars); large particles are 100–200 μm. (C) Corundum (slightly uncrossed polars); circle 10 = 80 μm. (D) Calcite (crossed polars); particles are ~200 μm. *(Figure continues.)*

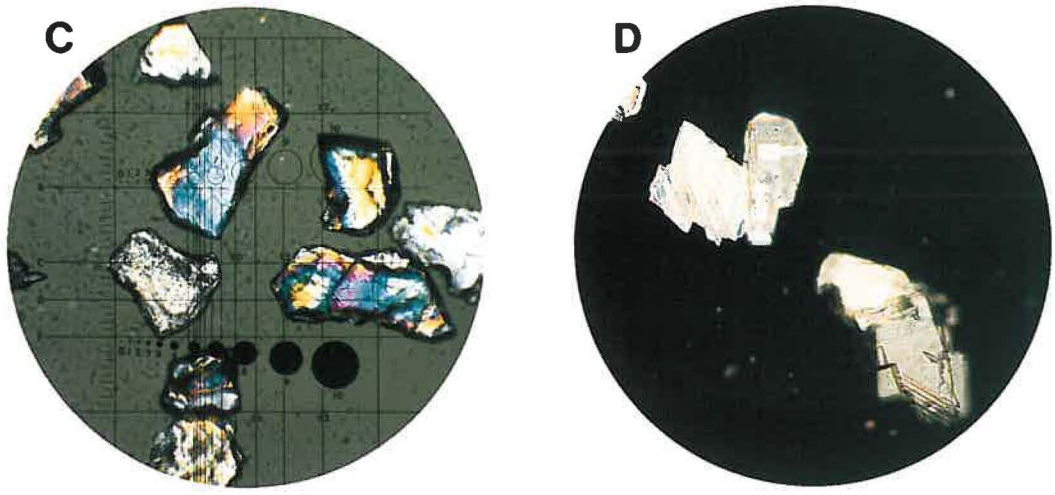

Figure 2 *(Continued)*

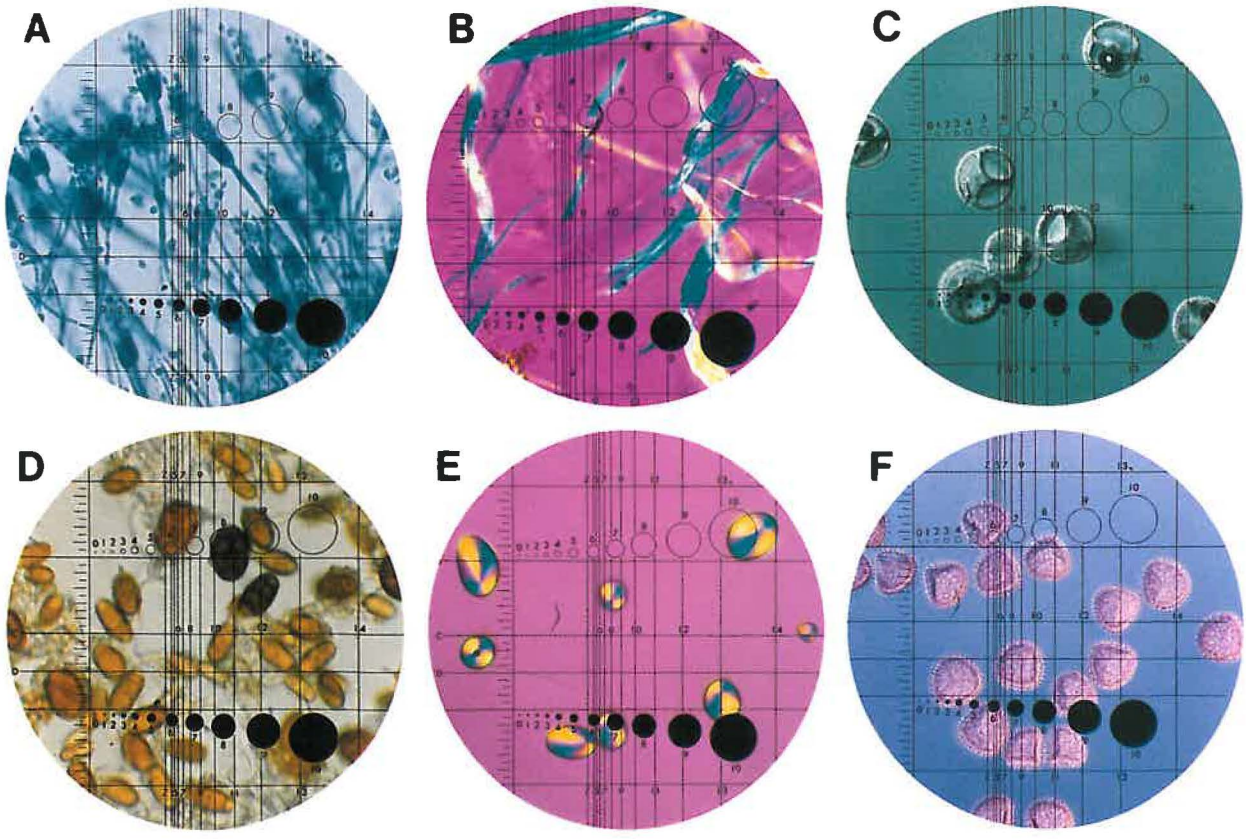

Figure 3 Photomicrographs of organic dusts under various conditions of illumination. (A) Fungal colony, stained (brightfield); circle 10 = 20 μm. (B) Cotton dust (crossed polars/compensator); circle 10 = 40 μm. (C) Ragweed pollen (differential interference contrast); circle 10 = 20 μm. (D) Fungal spores (brightfield); circle 10 = 20 μm. (E) Starch particles (crossed polars/compensator); circle 10 = 20 μm. (F) Lycopodium spores (Rheinburg illumination); circle 10 = 30 μm.

selective sampling is to measure the complete size distribution of the aerosol. Once one knows this, estimates of exposure based on any criteria can be made. A common sampler for making such measurements is the impactor. In this device, dust-laden air emerges from an orifice and is directed to a surface referred to as an "impactor plate." The air is forced to make an abrupt change in direction as it moves around the plate and those particles that have gained sufficient momentum will cross the airstream lines and hit or "impact" the plate while others will follow the airstream around the plate. Impactors are commonly operated in multistage configurations and both series and parallel versions have been described. Particles are sized aerodynamically so that data from these units can be used to predict human lung deposition.

Several techniques are available for the analysis of dust samples. Gravimetric analysis is considered routine for general hazard evaluation. In many cases, though, gravimetric assay must be complemented by other methods to determine dust composition.

For crystalline materials, x-ray diffraction is useful since crystalline compounds produce unique x-ray diffraction patterns that can be matched with patterns from known standards. Infrared spectroscopy is also applied to the analysis of some dust samples. These two techniques are commonly used for analysis of crystalline silica. Light microscopy, and especially polarized light microscopy, is very useful for identifying small particles. Figure 2 shows a number of different dusts as they appear under the polarized light microscope. Electron microscopy offers a variety of analytical techniques that are also useful for particle identification.

Direct reading meters are available also for measuring airborne dust levels and a number of them are portable. In one type, particles are deposited on a grease-coated film. The mass concentration of dust is measured by determining attenuation of beta radiation through the dust deposit. In another design, dust levels are measured by the change in vibration of a piezoelectric quartz crystal as particles are collected onto its surface. Several instruments are available that measure aerosols by light scattering. Size distribution measurements may also be made with direct reading instruments. In one type of sampler, aerodynamic size is recorded by measuring the velocity of particles in an accelerating airstream.

C. Organic Dust

Sampling organic dusts offers additional challenges for environmental scientists due to the typical complex nature of these aerosols and the added problem of maintaining viability of microorganisms. The area is further complicated by the lack of dose–response data on individual components that are found in these samples.

For measuring levels of bacteria and fungi, two samplers have historically been considered more or less as "standard" samplers. These are the Andersen viable sampler and the AGI-30 all-glass impinger although consideration of these samplers as "standard" is probably as much due to tradition as it is to aerodynamic considerations or some notion of absolute accuracy.

In the Andersen sampler, dust is impacted directly into culture plates. The plates are brought back to the laboratory and kept under controlled conditions. After a period of time, the colony-forming units are counted. A variety of collection media (some general, some specific) have been reported for both bacteria and fungi. One version of the sampler has six stages arranged in series, each with progressively lower cut-off diameters. The result is that the dust particles are partitioned throughout the sampler as a function of aerodynamic size thus enabling one to estimate human lung deposition. There is also a two-stage version that provides less size resolution but is more convenient since there are fewer culture plates to prepare and count. There is also a single-stage version that has been shown to be useful in indoor air quality surveys where concentrations of microorganisms are relatively low. Another version of this type of sampler is the slit-to-agar sampler. In this device, a rectangular jet stream is directed to the surface of a culture plate that slowly rotates. These samplers provide data on the relationship between concentration of microorganisms and time.

An advantage of these types of samplers is that the microbes are collected directly in the media and no further handling is required. They also tend to have reasonable collection efficiencies for smaller microorganisms. A disadvantage is that they are prone to overloading (especially the one- and two-stage versions) in areas of high concentration such as agricultural environments.

In the AGI-30 sampler, particles are impacted onto or into a liquid. At the laboratory, the solution is diluted, plated out, and after a period of time, colony-forming units are counted. These samplers

are especially useful in highly contaminated environments since they afford infinite dilution potential. A disadvantage is that the collection efficiency drops off for smaller (submicrometer) organisms.

A third method of viable sampling is to collect samples on filters. The filters are then plated directly or the dust is washed off, diluted, and plated. A distinct advantage of filter sampling is that most filters are highly efficient for small particles. A problem is that viability may not be maintained as well as with impinger samples or samples collected directly onto media. This is probably less of a problem with fungal spores and endospore-producing bacteria.

There is another class of samplers available for estimating concentrations of bacteria, fungi, and pollen. These samplers collect particles in a form that enables one to do counts under the microscope. There is a trend these days for doing microscopic counts rather than viable sampling in occupational environments. The idea is that the nonviable organisms can also cause health effects and these microbes are not considered with viable techniques. Also missed are those organisms that will not grow with a particular medium or set of environmental conditions. With the microscope, one can count them all. The size of fungal spores and pollen is such that they are easily recognized using light microscopy. Bacteria are more difficult to resolve even with various contrast enhancements (phase contrast, interference contrast, darkfield, etc.); thus they usually require some staining technique. Acridine orange stain followed by epifluorescence microscopy is one alternative. A problem with microscopic counting is that, although an analyst can learn fairly quickly to resolve between a bacteria, a fungal spore, or a pollen grain, it takes much more skill to identify organisms even to the genus level. In some cases, electron microscopy reveals more detail that aids in identification. However, confident identifications can often only be made by observing colony characteristics. In an attempt to combine approaches, methods have been proposed where one takes a single filter sample and from that does (1) acridine orange counts, (2) electron microscope examination, and (3) culturing for identification.

In addition to bacteria, fungi, and pollen, there are also methods for sampling and analysis of viruses and protozoa, as well as for some of the toxic products of microorganisms (endotoxin and mycotoxins).

Many organic dusts (especially agricultural dusts) also contain a variety of other materials such as mineral components, insect parts, starch particles, and various other botanical components. With such complex exposures, gravimetric analysis is of limited value. It is more appropriate to try to identify and quantify the individual components of the sample. Polarized light microscopy again can be quite useful here since many of the materials can be readily identified. Figure 3 shows some organic dusts as seen under the polarized light microscope.

III. Control Methods

A. Air Standards

In the United States there are three groups that deal with exposure limits for airborne particles in the general occupational environment. The American Conference of Governmental Industrial Hygienists (ACGIH) was organized in 1938 with a mission to promote standards and techniques in occupational health. Each year ACGIH publishes an updated version of threshold limit values (TLVs) for chemical and physical agents. Documentation for the TLV list is also available, and this provides the background information on how individual limits are selected.

The National Institute for Occupational Safety and Health (NIOSH), which promotes education and conducts research in the area of occupational safety and health, also makes recommendations for safe exposure limits for various contaminants. Many of these recommendations are contained within criteria documents. These are reports that also include information on sampling and analysis, surveillance, control methods, labeling procedures, and so forth.

The Occupational Safety and Health Administration (OSHA) is the agency that enforces health and safety regulations in the general workplace. Part of these regulations are the permissible exposure limits (PELs) which were initially adopted from the TLV list. For many contaminants the NIOSH recommendation, TLV, and permissible exposure limits are identical. Table I lists the exposure limits for selected dusts. For some agents such as asbestos, OSHA has in addition to the exposure limit, regulations that cover other aspects of exposure including surveillance, personal protective equipment, recordkeeping, training, and monitoring schedules.

The Mine Safety and Health Administration (MSHA) is the agency that enforces health and safety regulations specifically in mining environments. The MSHA air quality standards have also traditionally been linked to TLV lists.

Table I TLVs, OSHA Standards, and NIOSH Recommendations for Selected Dusts

Dust	TLV	OSHA	NIOSH	Sampler
Silica (crystalline quartz)	0.1 mg/m^3	0.1 mg/m^3	0.05 mg/m^3	Respirable
Asbestos	Varies for individual forms	0.2 fibers/cc	0.1 fibers/cc	Total
Coal dust	2.0 mg/m^3	2.0 mg/m^3		Respirable
Cotton dust	0.2 mg/m^3	1.0 mg/m^3	0.2 mg/m^3	Verticle elutriator
Nuisance particulates	10.0 mg/m^3	15.0 mg/m^3 5.0 mg/m^3		Total Respirable
Cellulose	10.0 mg/m^3	15.0 mg/m^3 5.0 mg/m^3		Total Respirable
Fiberglass	10.0 mg/m^3		5.0 mg/m^3 3 fibers/cc	Total Total

B. Engineering Controls

There are a variety of control methods available that can be used to reduce dust exposures in occupational environments. These include ventilation, isolation, substitution, and dust suppression by wetting.

Ventilation systems can be divided into general categories: local exhaust ventilation and general ventilation. In local ventilation systems, the contaminant is captured near the point of generation. In general ventilation systems, the entire room is supplied with intake and exhaust air to dilute concentrations within the area. Local exhaust has the advantage of lower air flow requirements and the contaminant is captured before it enters the general workroom air. General ventilation is usually restricted to the removal of low levels of relatively nontoxic contaminants from decentralized sources.

Substitution of hazardous materials with less harmful ones is also a means for controlling occupational exposures. There are materials for instance which may be substituted for silica in several applications. There are also insulation products that can be used in place of asbestos. Process changes and isolation of hazardous areas can also be effective control measures.

Dust suppression can often be accomplished by the application of water or other suitable liquid. This technique is used extensively in mines to reduce the concentration of coal and other dusts. Also, water that is forced through drill bits in rock drilling operations can be effective in dust reduction.

C. Personal Protective Equipment

Personal protective equipment, and in the case of dust exposure, specifically respiratory protection, should only be considered for operations where it is not possible to control exposure by other means. They should never be considered as an alternative to engineering controls.

There are two general categories of respirators: air purifying and atmosphere-supplying. The latter can be further divided into self-contained breathing apparatus (SCBA) and supplied air respirators.

Air purifying devices for use against dust exposures consist of a facepiece along with some type of mechanical filter. Facepieces come in three types. Quarter-masks cover the mouth and nose, half-masks fit over the chin, and full-facepieces cover from above the eyes to below the chin. There are some types of single-use respirators where the facepiece itself serves as the filter. Dust filters usually are made of a fibrous material and collection mechanisms include impaction, sedimentation, interception, diffusion, and electrostatic attraction. There are a variety of filter types designed to provide protection against different classes of airborne particles. There is usually some trade-off between collection efficiency, resistance to breathing, and clogging time. A special class of air purifying respirator is the powered air-purifying respirator (PAPR). With this device a blower is used to pass contaminated air through a filter to provide purified air to a facepiece, helmet, or hood. An advantage is that it provides an airstream that can have a cooling effect in warm

temperatures. Some are also designed with loose fitting hoods or helmets that enable them to be worn by some individuals with beards or facial scars as long as the beard or scar does not lie along any sealing surface of the hood/helmet (many helmets have cheek and/or temple seals).

When a high level of protection is required or when there is low oxygen, atmosphere-supplying respirators are appropriate. One type, the airline respirator, uses compressed air from a stationary source to supply air through a hose to a facepiece. In the SCBA design, the wearer carries the breathing gas source, thus eliminating the need for connection to some stationary source. These units are either open circuit (where exhaled air is exhausted to the atmosphere) or closed circuit (where exhaled gas is recirculated).

NIOSH has a program of certification and evaluation for respirators. The certifications are done in collaboration with the Mine Safety and Health Administration. OSHA has requirements for respirator programs that contain provisions for training, fit testing, cleaning, inspection, selection, and storage.

IV. Summary

Despite well-documented effects of dust exposure in occupational environments, health problems persist. Exposure standards exist, however, for many dusts and a variety of engineering controls has been described. When controls are not possible, personal protective equipment is available. Sampling and analysis systems have been developed for many dusts with sampler designs motivated mainly by the size-selective characteristics of the human respiratory system. Although lung deposition is principally a function of particle size, the type and extent of biological response are also affected by other chemical and physical features of the particles as well as the concentration and duration of exposure. Organic dust exposures are especially complex in terms of both exposure and response. However, it is just this complexity that makes the study of such exposures essential to improving control, diagnosis, and treatment. Although precise dose–response data are difficult to achieve even for well-studied dusts, occupational settings often provide the best data available for estimating risks to community populations where environmental dose is much more difficult to estimate.

Related Articles: DIESEL EXHAUST, EFFECTS ON THE RESPIRATORY SYSTEM; INORGANIC MINERAL PARTICULATES IN THE LUNG; SILICA AND LUNG INFLAMMATION.

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