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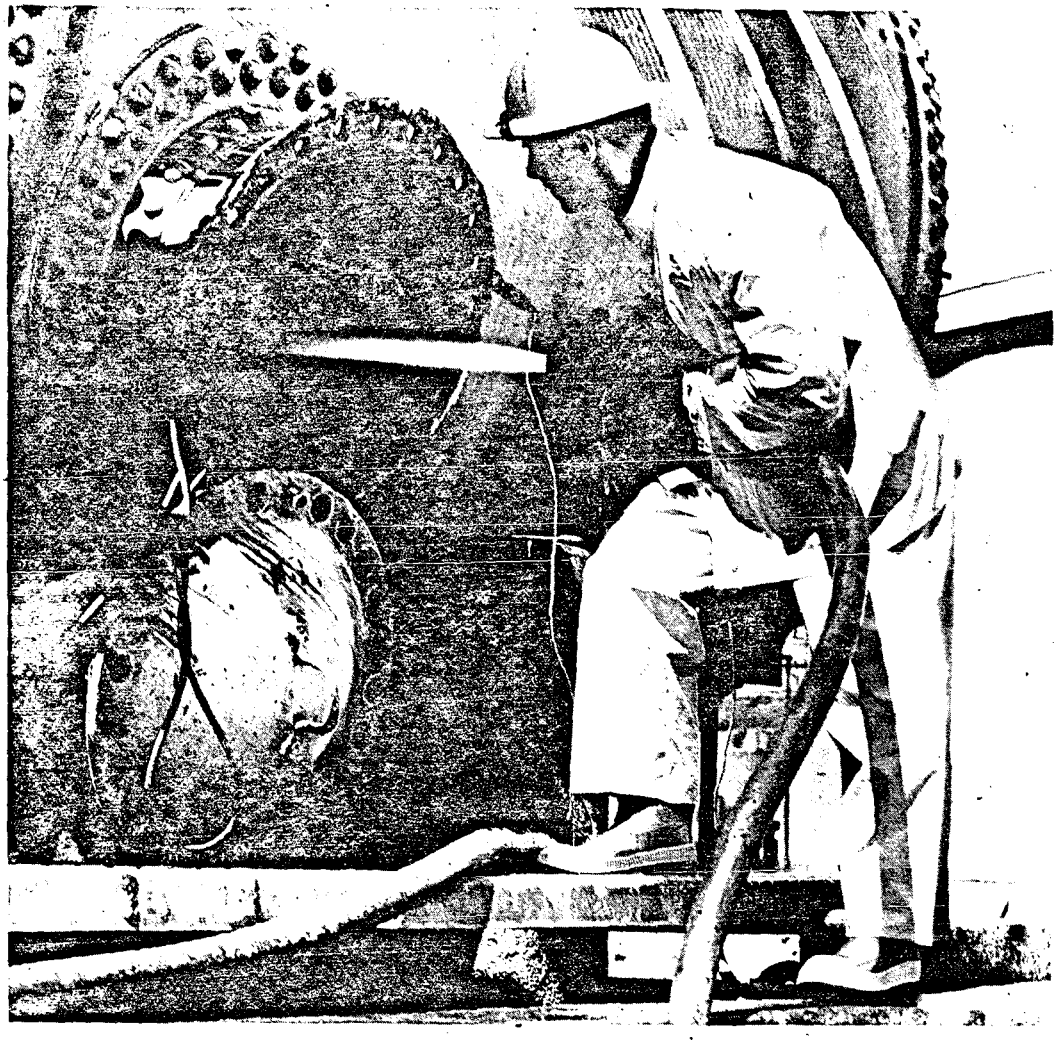

Men's clothes were going to pieces

THAT man is cleaning out a diesel fuel oil tank. To finish the job, he has to squirm into the tank where there's a mixture of oil and water. Trouble was the oil softened his work suit and boots, caused the rubber coating to peel off at the slightest snag.

This was the situation until B.F.Goodrich came up with protective clothing that solved this costly problem. The BFG work suit is made of a special nylon fabric that is four times stronger than the fabric used in ordinary protective clothing. This is then coated with a special oil-resisting rubber compound.

On many industrial jobs, B.F.Goodrich oil-resisting suits have shown they can stand the most punishing wear and tear—outlast ordinary work suits by as much as 2 to 1. In spite of being far stronger, the BFG suit weighs much less than regular waterproof clothing, and it's softer and more comfortable, too.

The B.F.Goodrich Xtratuf boot, shown here, is ideal for use wherever oil and grease are encountered. It has a non-skid molded outsole that gives terrific traction on the slipperiest surfaces. Long-lasting BFG gloves have many features, too, that make them easy to wear as well as protective.

To find out more about B.F.Goodrich protective clothing, boots and gloves, see your supplier or write for free catalogs. *B.F.Goodrich Industrial Products Co., Dept. M-507, Akron 18, O. In Canada: Kitchener, Ont.*

B.F.Goodrich

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A NATIONAL SAFETY COUNCIL
TECHNICAL SERVICE

DATA SHEET 531

DUSTS, FUMES, AND MISTS IN INDUSTRY

Copies of this data sheet will be available for purchase within 30 days. Subscribers to the Council's data sheet maintenance service will receive a copy in the next quarterly mailing.

Introduction

1. Industrial dusts, mists, and fumes, their hazards and their control, are discussed in this data sheet.* The general principles presented can be applied to evaluate most industrial situations involving these air contaminants and to determine the need for controls. This data sheet is intended to guide employers, plant safety engineers, personnel managers, and supervisors.

2. A plant manager who believes that he has a toxic or irritating dust problem should consult a competent industrial hygienist. Such help may be obtained from his own company, insurance carrier, private consultants, or state health or labor agency.

3. To protect the health of employees who work where a dust, fume, or mist created by a manufacturing process is released into the atmosphere, a control program may be required. In such a case, three steps must be taken:

a. The properties of the specific dust, *fume, or mist and its possible* physiological effects on employees must be ascertained.

b. The particular exposure must be evaluated by dust counts or by chemical analyses of air samples, and a step-by-step analysis of the operations must be made to find the areas where employees are exposed to hazardous amounts of the material. The operational analysis also should determine how the dust, fume, or mist is dispersed.

c. Appropriate methods of control must be provided where indicated. The type and extent of controls will depend upon the physical, chemical, and toxic properties of the dust, fume, or mist, the evaluation made of the exposure, and the operation that disperses the contaminant. The extensive controls needed for lead oxide dust, for example, would not be needed for limestone dust, since much greater quantities of limestone dust can be tolerated.

*This data sheet covers toxic and irritating air contaminants encountered in industry. It does *not* include a discussion of the explosive properties of such airborne particulate matter.

This data sheet is one of a series published by the National Safety Council, reflecting experience from many sources. Not every acceptable safety procedure in this field is necessarily included. This data sheet should not be confused with American Safety Standards, federal laws, insurance requirements, state laws, rules, regulations or municipal ordinances.

4. Except for the skin diseases, most occupational diseases are acquired by inhalation of material. Lung tissue is by far the most efficient medium the body possesses for absorbing materials. In addition, the surface area of this lung tissue averages 55 square meters or about 590 square feet.

5. Certain dusts that reach the lungs can pass directly into the blood stream and be absorbed over a long period of time. Others may stay in the lungs and set up local irritant or damaging action.

6. Toxic and irritant dusts can also be ingested in amounts that may cause trouble. If toxic dust swallowed with food or saliva is not soluble in body fluids, it is eliminated directly through the intestinal tract. Toxic materials that are readily soluble in body fluids can be absorbed in the digestive system and picked up by the blood.

7. A third way in which toxic and irritant substances may enter the system is skin absorption. Many organic compounds, such as TNT, cyanides, and most aromatic amines, amides, and phenols, can produce systemic poisoning by direct contact with the skin. Contact of toxic and irritant dusts with the skin also may result in skin irritation.

8. As compared to inhalation,

however, both ingestion and skin contact are of relatively minor importance in industrial poisoning insofar as dusts, fumes, and mists are concerned.

Origin and Properties of Particulate Matter

9. The dust normally present in the atmosphere has a beneficial effect in screening out some of the harmful rays of the sun. Inhalation of this dust may not be harmful because either the dust may be nontoxic or body mechanisms capture, remove and eliminate or isolate the small amounts of dust trapped in the lungs. Air pollution, radioactive fallout, pollens, and similar conditions may have an adverse effect on some individuals. Also, when the air breathed contains excessive amounts of dust, the body has difficulty in handling the load and dust may remain in the lungs.

Sources

10. The term *dust* as used in industry is generally applied to air-borne solid particles that range in size from 0.1 micron to 25 microns (one micron = 1/10,000 centimeter = 1/25,000 inch). Process dusts below 0.5 micron in size are rare. Dusts above 5 microns in size usually will not stay air-borne long enough to present an inhalation problem.

11. Dust may enter the air from various sources. It may be dispersed when a dusty material is handled, such as when lead oxide is dumped into a mixer or a product is dusted with talc. Dust may be formed and dispersed when solid materials are reduced to small sizes in processes such as grinding, crushing, blasting, shaking, and drilling. In these processes, the mechanical action of the grinding or shaking device supplies a source of energy to disperse the dust formed (Figure 1).

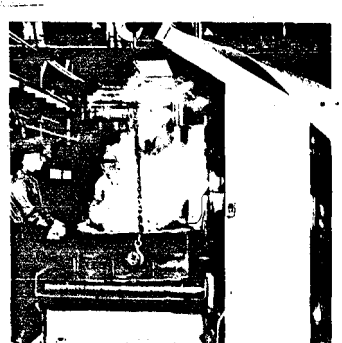


Figure 1. Dust from foundry sand is generated during the shake-out of castings. The mechanical action of the shake-out machine disperses the dust. Path taken by the dust particles as they are drawn into the hood shows the efficiency of the local exhaust system. (Courtesy American Foundrymen's Society)

12. When a solid such as a metal is heated to a temperature high enough to volatilize it, the volatilized matter later condenses in cooler air to form a *fume* (Figure 2). The solid particles that make up a fume are extremely fine, usually less than 0.5 micron in size. In some cases, the hot material reacts with the air to form an oxide. Examples are lead oxide fume from smelting and iron oxide fume from arc welding. Also, a fume can be formed when a material such as magnesium metal is burned or when welding or gas cutting is done on galvanized metal.

13. A *mist* is formed when a finely divided liquid is suspended in air. An example is the oil mist produced during cutting and grinding operations.

14. *Smoke* may be formed by the incomplete combustion of organic materials. Smoke generally contains droplets as well as dry particles. Tobacco, for instance, produces a wet smoke composed of minute tarry droplets. The size of the particles contained in tobacco smoke is about 0.25 micron.

15. Radioactive dust may be dispersed in the same ways as other industrial dusts. Radium, thorium, and other radioactive elements are present in extremely minute amounts in the atmosphere.

Magnitude of particles

16. When a solid is broken into finely divided particles, its surface area is increased many times. For example, 1 cubic centimeter (0.061 cubic inch) of quartz in the form of a cube when crushed into 1-micron cubes will give 10^{12} (1,000,000,000,000 or one trillion) particles with a total surface area of 6 square meters (9,300 square inches), as compared with 6 square centimeters (0.930 square inch) for the original cube.

17. When a solid is broken into finely divided particles, the volume occupied by the mass is also increased because of the voids between the particles. A dust concentration of 50 million particles per cubic foot of air (mppcf), resulting from 1 cubic centimeter of material reduced to particles 1 cubic micron in size, will occupy an air space of 20,000 cubic feet.

18. Even smaller amounts of toxic dusts, fumes, and mists, will make a workroom atmosphere hazardous. For example, the threshold limit value for lead, as adopted by the American Conference of Governmental Industrial Hygienists, is 0.2 milligram per cubic meter of air (mg cu m), which is 0.0000002 ounce per cubic foot. Therefore, the dispersion of only 0.002 ounce of lead will be enough to give the threshold limit value of 0.2 mg cu m of dust or fume in an air space of 10,000 cubic feet (280 cubic meters). The concentrations that may be present in the workroom without harm to health are different for different substances.

19. A person with normal eyesight can detect dust particles as small as 50 microns in diameter. Smaller air-borne particles can be detected individually by the naked eye only when strong light is reflected from them. Dust of respirable size (below 10 microns) cannot be seen without the aid of a microscope.

20. Most industrial dusts consist of particles that vary widely in size, with the small particles greatly outnumbering the large ones. Consequently, with few exceptions, when dust is noticeable in the air around an operation, probably more invisible dust particles than visible ones are present.

Separation in air-borne dust

21. Dust in the air may or may not have the same composition as its parent material. The determining factors are the particle size and density of each component in the original mixture, and the hardness of the materials (hard materials will resist the pulverizing action of a mechanical device.)

22. For example, foundry molding sand contains a large percentage of free silica (quartz) with a lower percentage of clays. Most of the clays consist of fine particles that can be air-borne, but most of the quartz particles are too large to be air-borne. The air-borne dust, therefore, as compared with the original mixture, may contain a much higher percentage of clays and a much

lower percentage of free silica.

23. Dust particles are, of course, attracted by gravity. Their settling rate through still air will vary with their size, density, and shape. Microscopically small particles settle out more slowly than larger particles because of their relatively minor density and because of their being influenced by Brownian movement. Mineral particles larger than 10 microns will settle out relatively fast. The estimated settling rates for silica dusts in still air are given in Table I.

TABLE I. SETTLING RATES FOR SILICA DUSTS

Size in Microns	Time to Fall 1 Foot (minutes)
0.25	590.0
0.50	187.0
1.00	54.0
2.00	14.5
5.00	2.5

24. Most of the particles in airborne industrial dusts are small. Because of air currents, the fine particles in dust clouds at an operation will remain suspended in the workroom air for relatively long periods of time. The smaller dust particles, moreover, will travel farther away from their point of origin than will the larger particles so that the farther dust is from its source, the greater the percentage of small particles it contains.

Inhalation of Dusts, Fumes, and Mists

25. With the exception of such fibrous materials as asbestos, dust particles must usually be smaller than 5 microns in order to enter the alveoli or inner recesses of the lungs. Although a few particles up to 10 microns in size may enter the lungs occasionally, nearly all the larger particles are trapped in the nasal passages, throat, larynx, trachea, and bronchi, from which they are expectorated or swallowed into the digestive tract.

26. When larger particles of certain toxic dusts are trapped in the upper respiratory passages, they can be absorbed by the body fluids in the nasal passages and in the digestive tract before they are eliminated. Hence the final toxic effects of larger dust particles may be delayed. The larger particles of irritant dusts can cause immediate effects in the upper respiratory system.

27. Ragweed pollen, which varies from 18 to 25 microns in diameter, can cause hay fever from its action in the upper respiratory system. This type of dust and other allergenic types, as well as bacterial and irritant dusts, can cause difficulty even in the larger air-borne sizes.

28. When dust-laden air is inhaled, some of the larger particles are trapped by the hairs in the nose. Other dust particles are removed from the air as it passes over the moist mucous membranes of the nose, throat, and other portions of the upper respiratory system.

29. The bronchi and other respiratory passages are covered with a large number of tiny, hairlike *cilia* or microscopic whiplashes, which aid in the removal of dust trapped on these moist surfaces. The cilia, all bending in one direction, make a fast stroke toward the mouth and a slower return stroke. This action tends to push mucous and deposited dust upward to the mouth so that the particles can be expectorated or swallowed.

Retention of dust

30. Many studies have been made in an effort to determine the amount of dust that is retained in the lungs, but there is no simple answer to this question. It has been shown that the size of the dust particles, the rate of respiration, the density of the dust in the air, the efficiency of the dust-catching mechanism, and probably many other factors are involved.

Sizes of particles inhaled

31. Although an occasional dust particle of larger size will enter the lungs, particles less than 3 microns in diameter are the most likely to do so and thus have the greatest opportunity to cause a physiological reaction. In silicotic lungs, for example, dust particles under 3 microns greatly outnumber larger ones, and many particles are less than 1 micron.

32. In the case of very fine fibrous asbestos dust, an exception occurs in the size of particles inhaled. Many fibers up to 100 microns long have been found in the lungs of asbestos workers at autopsy. A typical fibrosis caused by asbestos is produced by fibers ranging from 20 to 50 microns in length, but only a few microns wide.

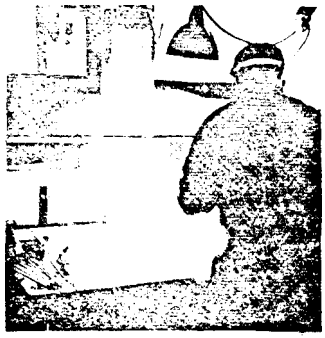


Figure 2. Metal vaporized by the heat of welding later condenses to form a fume. On this bench-welding installation, fumes are removed at their point of origin by a properly located local exhaust installation. (Courtesy American Foundrymen's Society)

Physiological effects

33. The physiological reactions caused by the inhalation of airborne particulate matter will vary with different types of dusts, fumes, and mists. The reactions include:

a. The cardiopulmonary reaction which consists of the pneumoconioses, such as *silicosis* and *asbestosis*. In certain cases, specific types of lung pathology result, and the heart may be affected (cor pulmonale) when the fibrosis is advanced. In other cases, there is mainly just an accumulation of a relatively inert dust in the lungs.

b. The systemic reactions which are caused by toxic dusts of such elements as lead, manganese, cadmium, and mercury, by their compounds, and by certain organic compounds.

c. Metal fume fever which results from the inhalation of finely divided and freshly generated fume of zinc or possibly of magnesium or of their oxides. This is a transient condition.

d. Allergic and sensitization reactions which may be caused by inhalation of, or skin contact with, such materials as organic dusts from flour, grains, and some woods and dusts of a few organic and inorganic chemicals.

e. Bacterial and fungus infections which occur from inhalation of dusts containing active organisms, such as wool or fur dust contain-

TABLE II. SELECTED INDUSTRIAL MINERAL DUSTS

Substance	Description and Uses	Threshold Limit in Million Particles per Cubic Foot of Air*
	CRYSTALLINE FREE SILICA (SiO_2, including microcrystalline forms)	
Chalcedony	A heat-resistant, chemically inert form of microcrystalline quartz. A decorative material. Rare in industry.	Calculate from formula:** 250 / % SiO_2 + 5
Chert	A microcrystalline form of silica. An impure form of flint used in abrasives.	
Cristobalite	A crystalline form of free silica, extremely hard and inert chemically; very resistant to heat. Quartz in refractory bricks and amorphous silica in diatomaceous earth are altered to cristobalite when exposed to high temperatures (calcined). Cristobalite is extensively used in precision casting by the hot wax process, dental laboratory work, and certain specialty ceramics.	
Flint	A microcrystalline form of native quartz, more opaque and granular than chalcedony. Used as an abrasive and in ceramics.	
Jasper	A microcrystalline impure form of silica similar to chert. Used for decorative purposes. Rare in industry.	
Quartz	Vitreous, hard chemically resistant free silica, the most common form in nature. The main constituent in sandstone, igneous rocks, and common sands.	
Tridymite	Vitreous, colorless form of free silica. Formed when quartz is heated to 870 C (1,598 F).	
Tripoli (Rottenstone)	A porous, siliceous rock, resulting from the decomposition of chert or siliceous limestone. Used as a base in soap and scouring powders, in metal polishing, as a filtering agent, and in wood and paint fillers. A cryptocrystalline form of free silica.	
	AMORPHOUS FREE SILICA (Noncrystalline)	
Diatomaceous earth	A soft, gritty amorphous silica composed of minute siliceous skeletons of small aquatic plants. Used in filtration and decolorization of liquids, insulation, filler in dynamite, wax, textiles, plastics, paint, and rubber. Calcined and flux-calcined diatomaceous earth contains appreciable amounts of cristobalite, and dust levels should be the same as for cristobalite.	Amorphous — 20 mppcf Calcined — use formula: 250 / % SiO_2 + 5
Silica gel	A regenerative absorbent consisting of the amorphous silica manufactured by the action of HCl on sodium silicate. Hard, glossy, quartz-like in appearance. Used in dehydrating and in drying and as a catalyst carrier.	20 mppcf
	SILICATES (Compounds made up of silicon, oxygen, and one or more metals with or without hydrogen. These dusts cause nonspecific dust reactions, but generally do not interfere with pulmonary function or result in disability.)	
Asbestos	A hydrated magnesium silicate in fibrous form. The fibers are believed to be the more hazardous component of asbestos dust.	5 mppcf†
Clays	A great variety of aluminum—silicate bearing rocks, plastic when wet, hard when dry. Used in pottery, stoneware, tile, bricks, cements, fillers, and abrasives. Kaolin is one type of clay. Some clay deposits may include appreciable quartz. Commercial grades of clays may contain up to 20 per cent quartz.	50 mppcf‡
Feldspar	Most abundant group of materials, composed of silicates of aluminum with sodium, potassium, calcium, and rarely barium. Most economically important mineral. Used for ceramics, glass, abrasive wheels, cements, insulation, and fertilizer.	50 mppcf††

[illegible] Conference of Governmental Industrial Hygienists [illegible] substances in "Crystalline Free Silica" group [illegible] "Silicates" [illegible] for compounds containing less than [illegible] crystalline silica. For compounds containing [illegible] % SiO_2 +

TABLE II. SELECTED INDUSTRIAL MINERAL DUSTS (Continued)

	SILICATES	
	(Compounds made up of silicon, oxygen, and one or more metals with or without hydrogen. These dusts cause nonspecific dust reactions, but generally do not interfere with pulmonary function or result in disability.)	
Fuller's earth	A hydrated silica—alumina compound, associated with ferric oxide. Used as a filter medium and as a catalyst and catalyst carrier and in cosmetics and insecticides.	50 mppcft
Kaolin	A type of clay composed of mixed silicates and used for refractories, ceramics, tile, and stoneware.	50 mppcft
Mica	A large group of silicates of varying composition, but similar in physical properties. All have excellent cleavage and can be split into very thin sheets. Used in electrical insulation.	20 mppcft
Portland cement	Fine powder containing compounds of lime, alumina, silica, and iron oxide. Used as construction material.	50 mppcft
Silicon carbide (Carborundum)	Bluish-black, very hard crystals. Used as abrasive and refractory material.	50 mppcft
Talc	A hydrous magnesium silicate used in ceramics, cosmetics, paint, and pharmaceuticals, and as a filler in soap, putty, and plaster.	20 mppcft
Vermiculite	An expanded mica (hydrated magnesium-aluminum-iron silicate). Used in lightweight aggregates, insulation, fertilizer, and soil conditioners, as a filler in rubber and paints, and as a catalyst carrier.	50 mppcft

[1]Threshold limits given for substances in "Silicates" group are for compounds containing *less* than 1 per cent crystalline silica. For compounds containing more than 1 per cent silica, calculate threshold limit from formula: $\frac{250}{\%\ SiO_2 + 5}$

ing anthrax spores or wood bark or grain dust containing parasitic fungi.

f. Irritation of the nose and throat, which is caused by acid, alkali, or other irritating dusts or mists. Some dusts such as soluble chromate dusts may cause ulceration of the nasal passages or even lung cancer.

g. Damage to internal tissues, which may result from inhaled radioactive materials such as radium and its daughter products and from other radioisotopes that emit highly ionizing radiation.

Pneumoconioses

34. *Pneumoconiosis* comes from three Greek words that mean "lung," "dust," and "abnormal condition." The present generally accepted meaning of the word is merely "dusty lung." The kind of dust inhaled determines the type of condition or injury. A number of organic dusts are capable of producting lung diseases, but not all these diseases are classified as pneumoconioses because they are not all a "dusty condition" of the lung.

35. In very rare cases, enough dust had been inhaled to cause mechanical blockage of the air spaces. Flour dust has been known to cause this condition. Some of

may be essentially inert and remain in the lungs indefinitely with no recognizable irritation, and a few like limestone dust may be gradually dissolved and eliminated without harm.

Silicosis

36. The most important lung disease caused by the inhalation of mineral dust is *silicosis*—well-known in industries where crystalline free silica dust is present, such as foundries, glass manufacturing, granite cutting, mining, and tunneling in quartz rock. It is found throughout the world, and in the past it has had many names, such miner's asthma, grinder's consumption, miner's phthisis, potter's rot, and stonemason's disease. The same occupational disease, however, is meant by all these names, and it is caused by dust from crystalline free silica, usually quartz (see Table II).

37. Although considerable progress has been made in dust control in industry, men still develop silicosis in plants and on jobs where dust control is not adequate. Engineering control is still the basic means of preventing this disease, and dust control equipment and procedures must be carefully maintained.

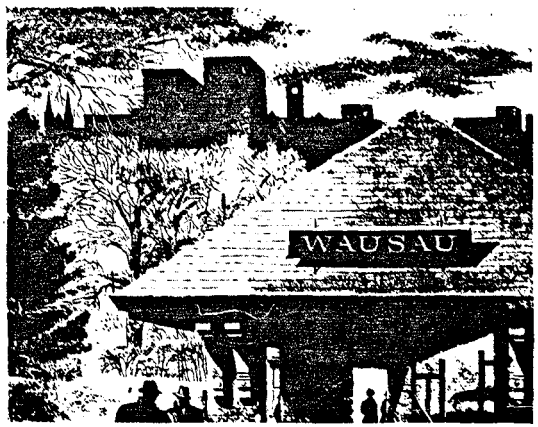
38. *Definition.* Silicosis has been defined as "a disease due to breathing air containing silica (SiO_2) characterized *anatomically* by generalized fibrotic changes and the development of miliary nodulation in both lungs, and *clinically* by shortness of breath, decreased chest expansion, lessened capacity for work, absence of fever, increased susceptibility to tuberculosis (some or all of which symptoms may be present), and by characteristic X-ray findings."*

39. *Factors of influence.* Silicosis has been known to manifest itself after widely differing periods of exposure to silica dust. Apparently, development of the disease depends upon:

a. The amount and kind of dust inhaled.
b. The percentage of free silica contained in the dust.
c. The form of the silica.
d. The size of the particles inhaled.
e. The duration of the exposure.

—*Continued on page 95*

*"Report (Joint) of the Committee on Pneumoconiosis and the Committee on Standard Practices in Compensation of Occupational Diseases." *Year Book*, 1933, American Public Health Association, 1790 Broadway, New York 19, p 100.



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f. The powers of resistance of the individual concerned.

g. The presence or absence of a complicating process such as infection.

40. Many theories have been advanced over the years to explain why crystalline free silica acts as it does in the lungs. Theories have been based on the hardness of the material and the effect of sharp edges, solubility phenomena, electrochemical action of the crystals, and immunological reactions.

41. It is believed now that the fibrosis produced is caused not by the hardness or sharpness of the particles, but by a combination of slight solubility with a physiochemical effect and an immunological effect—but no one is certain of the exact mechanism of the disease. Experimental work on the reasons for the development of silicosis is still going on in various parts of the world. If the precise mechanism of silicosis could be determined, better medical preventive measures might be developed and possibly a cure could be found.

42. *Three stages.* Silicosis is generally classified in three separate stages by medical authorities. More sophisticated classifications are sometimes used for the various X-ray stages and complications of the disease, but for a basic understanding the three stages give a good breakdown.

43. The first stage of the disease produces no disability. The affected man can carry on his work as well as ever. Frequently, the individual is not aware that anything is wrong, and the disease is revealed only by opaque nodular shadows on a chest X-ray coupled with a known exposure to crystalline free silica.

44. In the second stage, respiration may be affected in some persons but not in all by any means. Labored breathing on heavy exertion usually is noted first, and a dry cough also may be present.

45. The third stage can develop after the second stage even though the individual has been removed from exposure to silica dust. However, the progress of the disease will be slower without continued dust-exposure. Breathing may become severely labored. The worker is far below normal physically and is susceptible to respiratory diseases. Chest X-rays may show an enlarged heart as a result of the body's attempts to overcome the resistance of restricted blood vessels in the lungs. Pulmonary tuberculosis is a frequent complication and occasionally results in death.

46. *Detection and development.* Silicosis may be detected by chest X-rays in each of the three stages. However, X-rays alone are not sufficient for a positive diagnosis, for the shadows may be due to a variety of other conditions, including infection or another type of pneumoconiosis. The individual must have had a definite exposure to free silica, because only it can cause silicosis. The complete occupational and medical history of the employee must therefore be evaluated before a conclusion can be reached. The correlation of chest X-ray findings and physical disability may be poor in many cases.

47. From most industrial experience, silicosis seldom develops in less than five years and in many cases may take 20 years or longer to become disabling.

48. The development of silicosis in its earliest stage is not perceived by the individual. The disease cannot be cured by any means yet known. Tuberculosis is more prevalent in persons with silicosis, but the incidence is decreasing, as it is in the general population.

49. Men with early signs of silicosis are able to perform their duties and are not a menace to other employees, for it is not a contagious disease. A perceptible X-ray change is not grounds for assuming disability because most people show chest changes with advance in age even without exposure to dust. Where there is a known exposure to silica dust, however, men with early signs of silicosis should be seen periodically by a physician.

50. *Action of silica on the lungs.* At the points in the lung where silica dust is deposited and accumulated, a fibrous tissue develops and grows around the particles. This fibrous tissue is tough like scar tissue. It is not as elastic as normal lung tissue, does not permit the ready passage of oxygen and carbon dioxide, and as it proliferates, cuts down the amount of normal lung tissue. As a result, the available functional volume of the lung is reduced.

51. In some advanced cases, the fibrous tissue will slow down or even prevent the diffusion of oxygen from the lung to the blood in the capillaries, and the blood in the area will not be completely oxygenated. The fibrous tissue can also affect the blood vessels by obliterating them or cutting down the flow of blood. All these effects tend to limit the rate at which oxygen is supplied to the body tissues. *Emphysema* is the most obvious symptom.

52. As the inhalation of silica continues over the years, the amount of fibrous tissue will, of course, increase, with the ultimate result that the lungs will not readily oxygenate sufficient blood for the body's needs. Then when the oxygen demand of the body is increased by exertion, the individual will feel distress with shortness of breath.

53. *Amorphous free silica* differs from crystalline free silica in physical structure and in physiological effects. In the amorphous state, molecules of silica exist in random orientation, which may be caused by natural forces to form opal and diatomaceous earth (kieselguhr). Amorphous silica may be converted by artificial processes into such forms as silica gel, silica fume, and fused silica or quartz.

54. If amorphous silica is heated to a high temperature, as in calcining, forms of crystalline free silica called cristobalite and tridymite result. These intermediate forms of amorphous silica are known as cryptocrystalline (ultra-microcrystalline.) Inhalation of these crystalline forms can readily cause diatomite pneumoconiosis.

55. When diatomaceous earth is calcined, particularly in the presence of a trace of alkaline flux, appreciable quantities are converted to cristobalite. As a result of studies made by the U. S. Public Health Service, it has been recommended that the threshold limit value for crude or amorphous diatomite be placed at 20 mppcf (see Table II), but that the atmospheric concentration for dust containing cristobalite be kept under 5 mppcf.

56. Various commercial products containing particles of silica under 1 micron in size are available. The

physiological effects of these products have not been well defined. Until more experience with human beings is available, it is believed these products should be handled with care.

57. *Free silica and silicates.* Free silica is uncombined silicon dioxide (SiO_2). Silicates contain silicon and oxygen combined with other elements in a more complex molecule. Analyses of minerals, particularly in geological reports, are sometimes reported as percentages of oxides, which may include SiO_2, Al_2O_3, K_2O, Fe_2O_3. The SiO_2 reported in such chemical analyses is the total of the silicon dioxide present, both the free silica (if present), and the silica combined in the mineral. Such analyses are not reliable indications of the silicosis potential of the material.

58. It is uncombined or free silica that is most important in industrial dust exposure. So that an exposure can be properly evaluated, the percentage of uncombined silica must be determined by petrographic analysis using a polarizing microscope or, preferably, by X-ray diffraction analyses and special analytical chemical procedures.

59. There has been some experimental evidence that some dusts may tend to inhibit the action of silica on the body, but this inhibiting action is so slight and uncertain that it must be discounted in practice. In fact, there also is evidence that the nonsiliceous components of a dust mixture containing free silica may provoke a disabling condition more severe than that caused by the silica acting alone.

60. With the exception of asbestos and some tales, the silicate dusts do not ordinarily cause a serious disabling lung condition such as is produced by free silica. Much higher levels of silicate dusts than of free silica dust can be tolerated.

61. In many industries, men have worked with silicate dusts that contained no free silica without development of disability or of nodulation in the lungs. The X-ray may show shadows indicating dust deposits in the lungs, but the pneumoconiosis is essentially harmless. However, partially disabling pneumoconioses have been reported where men have worked for long periods of time in very high concentrations of certain silicate dusts.

62. Disabling pneumoconioses from exposure to abnormally high concentrations of mica, tremolite tale, and kaolin dusts have been described in the literature. The clinical signs are not the same for these silicate dusts as for free silica, but the symptoms can be marked.

63. The body does not have adequate defense against indiscriminate amounts of dust of any kind. Therefore, although specific symptoms have not been described for many mineral dusts, the general experience would indicate that dust levels should be kept within threshold limit values or below (Table II).

Asbestosis

64. Asbestos is a general term applied to several minerals having a fibrous character. These asbestos minerals are hydrated silicates of magnesium with variable amounts of iron, calcium, sodium, potassium, and aluminum present as impurities.

65. Asbestos when inhaled produces fibrous tissue in the lungs of both men and animals. It has been shown that fibers of asbestos must be present for the production of *asbestosis*. Other silicate minerals of the same chemical composition but nonfibrous in form produce no reaction or a relatively mild reaction, but not the severe reaction of fibrous asbestos dust.

66. These facts lead to the conclusion that asbestosis is mainly the result of physical irritation of the lung tisssue and not of a chemical action, which is thought to be one of the causes of silicosis. It is suspected that lung cancer may be induced by asbestos. However, there is no impressive amount of evidence to support this assumption.

67. The fine air-borne fibers of asbestos can pass through the upper respiratory tract to the lower parts of the lungs to cause irritation and to form "asbestos bodies" where the fibers are encapsulated. This diffuse fibrosis probably begins as a "collar" about the terminal bronchioles. There is evidence that other minerals having a fibrous character can produce a reaction similar to that of asbestos. Fiber glass, however, does not produce such a reaction.

68. Following a study by the U. S. Public Health Service of the asbestos textile industry,* it was recommended that the dust concentration be kept at less than 5 mppcf to prevent asbestosis. Evaluation of an exposure to abestos dust is based on the *total* amount of dust because it has proved out in practice that if the fine dust is kept below the suggested threshold limit, the concentration of injurious fibers will also be kept within safe limits.

Talcosis

69. As used in industry, "tale" is a very general term. To the geologist, tale is a hydrous magnesium silicate, which may be a relatively pure mineral or may be mixed with tremolite or with dolomite depending upon where it is mined. The term "tale" is applied commercially to carbonate mixtures that have the same general feel and physical properties; it also is applied to pyrophyllite, a hydrous aluminum silicate, which frequently is mixed with a high percentage of quartz. The free silica generally found with pyrophyllite can cause silicosis. It is therefore essential to know which tale is being used in order to evaluate a specific dust exposure.

70. *Talcosis* is usually associated with tremolite tale. This disease produces changes in the lungs and symptoms similar to those of asbestosis.

Anthracosilicosis

71. *Anthracosilicosis*, a complex form of pneumoconiosis, is a chronic disease caused by breathing air containing dust that has free silica as one of its components and that is generated in the various processes involved in mining and preparing anthracite (hard coal)** and, to a lesser degree, bituminous coal.

72. The disease is characterized anatomically by generalized fibrotic changes throughout both lungs and by the presence of excessive amounts

* Dreesen, W. C., Dalla Valle, J. M., Edwards, T. I., Miller, J. W., and Sayers, R. R., *A Study of Asbestosis in the Asbestos Textile Industry*, U. S. Public Health Bulletin No. 241, U. S. Public Health Service, Washington 25, D. C., 1938.

** *Anthracosilicosis among Hard-Coal Miners*, U. S. Public Health Bulletin No. 224, U. S. Public Health Service, Washington 25, D. C., 1938.

of carbonaceous and siliceous material. Such lungs on autopsy are coal black.

73. Symptoms found in early stages of the disease are shortness of breath, cough with a coal-black sputum, pain in the chest, and in some cases physical weakness. In the advanced stages, there are loss of weight and decreased capacity for work, partly caused by pulmonary infection (frequently bronchitis), and in some cases there may be heart failure.

74. Experiments with animals showed that mixtures of coal and quartz produced more fibrosis than did quartz alone. The harmful effects of coal dust do not come only from the silica in the dust. Coal dust alone in very heavy concentrations over a period of many years can cause breathlessness and ventilatory impairment.

Miscellaneous pneumoconioses

75. Even though a dust is classified as harmless, excessive amounts of it can lead to trouble by causing a pneumoconiosis or simply by mechanically irritating the walls of the respiratory system. Moreover, even though there is no chemical or physical irritation, mechanical plugging of the lungs and interference with their ordinary processes can result. Mica dust and kaolin dust are two good examples of dusts that ordinarily are considered benign but in excessive amounts can cause a troublesome pneumoconiosis.

76. Mica pneumoconiosis has been observed in grinding operations where mica dust, but no free silica was present. There were marked changes in the X-ray pictures of the lungs and some disability. The cases occurred where the dust exposures were massive over many years.

77. *Kaolinosis* has been described as a condition induced by inhalation of dust released in the grinding and handling of kaolin (china clay). Where the cases occurred, dust levels of several hundred million particles per cubic foot of air were common.

78. Aluminum dust is not considered to be harmful except where exposures are massive. Without adverse effects, aluminum dust inhalation has been used as part of an endeavor to prevent silicosis. Also without adverse effects, extensive exposures to aluminum dust have occurred in the grinding of aluminum parts and castings. It can therefore be concluded that reasonably good control will prevent harm from aluminum dust.

79. Bauxite pneumoconiosis (Shaver's disease) has been found only in workers exposed to fumes containing aluminum oxide and minute or ultramicroscopic silica particles arising from smelting bauxite in the manufacture of corundum, an impure form of aluminum oxide. It is essentially a diffuse interstitial fibrosis and marked associated emphysema, with a complete absence of any nodular fibrosis. It definitely does not occur from the use of corundum grinding wheels or from other forms of aluminum oxide.

80. Some pneumoconioses may show marked shadows on an X-ray film; these shadows, without the necessary information on the exposure of the individual, may be alarming in a general X-ray screening program. On clinical examination of individuals showing the X-ray markings, however, often no disability or symptom can be found.

81. These shadows are frequently encountered when the dusts contain atoms of relatively high molecular weight because the heavier atoms are fairly opaque to X-rays. Insoluble barium dusts and tin oxide dusts, for example, can show very marked shadows on X-ray films without producing signs of significant pathology (barium dust that is soluble in the body fluids can give a toxic reaction).

82. Iron oxide, particularly excessive fume from welding operations, may produce *siderosis* with a pigmentation of the lungs (black in welders and red in iron ore miners) without disability. The X-ray shadows produced by the iron oxide in the lungs are somewhat similar to the shadows from silicosis. Because of this similarity, differential diagnosis is often difficult, and heavy exposures to iron oxide dust and fume may lead to medicolegal problems. It is therefore important to control iron oxide exposures even though siderosis is not disabling.

83. Limestone, marble, lime, gypsum, and portland cement dusts apparently have no serious effect even after long exposures. Also, many silicates and other minerals have not caused impairment in individuals inhaling the dusts, and the resulting pneumoconioses are generally classed as benign.

Toxic Dusts and Fumes

84. Systemic reactions are caused by toxic dusts and fumes of various elements and their compounds and by certain organic compounds. All metallic fumes are irritating, especially when freshly generated. Industrially important metals and their compounds that can have a toxic effect when the dust or fume is inhaled include arsenic, antimony, cadmium, chromium, lead, manganese, mercury, selenium, tellurium, thallium, uranium, and a few others.*

85. The effect of some metals, such as magnesium and zinc, appears to be transient. Only limited data are available on the exotic and rare earth metals.

86. Although the dusts and fumes from metals with low toxicity do not need as much attention as the dusts and fumes from highly toxic metals, they should not be neglected or disregarded. The metals with low toxicity are controlled more readily because greater amounts can be tolerated, but their dusts and fumes should be kept at reasonable levels since excessive amounts of any of them can be harmful (Table III).

Lead poisoning

87. Although extremely severe cases of lead poisoning are rare in industry today, lead exposures must be controlled to prevent even the moderate symptoms, which can be troublesome. Inhalation of the dust of lead compounds is the most common mode of entry of lead into the system. Ingestion of lead compounds can add to the problem if personal hygiene is poor. Workers should therefore be encouraged to wash thoroughly before eating, and lunchrooms should be segregated from work areas.

88. It should be recognized that lead is a normal constituent of plants and animals. People ingest and excrete lead daily even though they are not exposed to lead in their daily work. The body can handle

*See the following National Safety Council Data Sheets: *Antimony and Its Compounds*, 408; *Arsenic and Its Inorganic Compounds*, 499; *Cadmium*, 312; *Lead*, 443; *Magnesium*, 426; *Manganese*, 306; *Mercury*, 203; *Titanium*, 485; *Zinc and Zinc Oxide*, 267; *Zirconium Powder*, 382.

and eliminate small amounts without harm. When intake rates exceed the normal excretion level, build-up occurs in the body. There is a safe level of absorption, and if the concentration of lead dust in the air of work areas is kept below the threshold limit, there should be no difficulty.

89. The importance of maintaining the concentration of air-borne lead at a very low value stems from lead's high toxicity and its tendency, in small amounts, to accumulate in the human system. When lead absorption in the body reaches a sufficient degree, symptoms of poisoning or intoxication appear.

Beryllium intoxication

90. Beryllium intoxication is a severe systemic disease that can result from the inhalation of massive doses of dust of metallic beryllium, beryllium oxide, and some soluble beryllium compounds. There are two forms of the disease. One is an acute form of chemical pneumonitis with cough, pain, difficulty in breathing, cyanosis, and loss of weight. In the chronic type, known as beryllosis, there may be loss of appetite and weight, weakness, cough, extreme difficulty in breathing, cyanosis, and cardiac failure. Mortality is high in chronic beryllium intoxication, and many who survive suffer from pulmonary distress.

91. Individual susceptibility apparently is an important factor in the development of the disease. In many instances, one employee has developed the severe symptoms while other employees doing the same work have shown no signs of disability.

92. Beryllium intoxication has never been demonstrated in individuals mining or handling ore only. There is no evidence of intoxication from the ingestion of beryllium oxide, beryllium metal, or any of the beryllium alloys. Only the inhalation of beryllium dust produces systemic disease.

93. Because of the severe nature of the disease and because there is no way of predicting who will develop it, extreme care must be taken to control the dust and fume that arise in the handling of beryllium, its alloys, and its compounds. Beryllium is toxic in such small quantity as to be considered the most toxic of all elements yet investigated.

TABLE III. SELECTED TOXIC DUSTS AND FUMES

Substance	Description and Effects	Threshold Limit in Milligrams per Cubic Meter of Air*
Antimony	Gray metal often associated with lead and arsenic. Hazardous from inhalation and ingestion. Soluble salts may cause dermatitis.	0.5
Arsenic	Silvery brittle crystalline metal. Hazardous from inhalation and ingestion. Usually encountered as arsenic trioxide.	0.5
Barium (soluble compounds)	Soluble barium chloride and sulfide are toxic when taken by mouth.	0.5
Beryllium	Light weight, gray metal. The metal, low-fired oxides, soluble salts, and some alloys are toxic by inhalation.	0.002
Chromic acid and Chromates	Red, brown, or black crystals. Caustic action on mucous membranes or skin.	0.1
Cyanide (as CN)	Nonvolatile cyanides are ingestion hazards. Cyanides inhibit tissue oxidation upon inhalation and cause death.	5.0 (skin**)
Dinitrobenzene	Yellowish crystal. Hazardous from skin absorption, inhalation, and ingestion.	1.0 (skin**)
Fluorides	Inorganic fluorides are highly irritant and toxic.	2.5
Hydroquinone	Colorless hexagonal crystals. Contact with the skin may cause sensitization and irritation. Excessive exposure to dust may cause corneal injury.	2.0
Iron oxide fume	Major sources are cutting and welding.	15.0
Lead	Lead fumes and lead compounds cause poisoning after prolonged exposure. Most important means of entry into body is inhalation. Skin absorption is of significance only from such organic compounds as *lead tetraethyl*.	0.2
Lead arsenate	White crystals—highly toxic.	0.15
Magnesium oxide fume	White powder. Inhalation of freshly generated fume may cause metal fume fever.	15.0

*These threshold limit values were adopted by the American Conference of Governmental Industrial Hygienists in 1962.

94. When the soluble salts of beryllium, especially beryllium fluoride, come in contact with cuts or abrasions on the skin, deep ulcers may be formed that heal very slowly. Complete surgical excision of the ulcer is sometimes required in order to effect healing.

Metal fume fever

95. Metal fume fever is an acute condition of short duration caused by a brief high exposure to the freshly generated fumes of metals such as zinc or magnesium or their oxides. Symptoms appear from four to twelve hours after exposure and consist of fever and shaking chills. There is complete recovery usually within one day, and ordinarily the employee can return to the same job without recurrence. However, after a period in which there has been no contact with the fume, for example, after a layoff, resumption of exposure is likely to bring on an attack.

TABLE III. SELECTED TOXIC DUSTS AND FUMES (Continued)

Substance	Description and Effects	Threshold Limit in Milligrams per Cubic Meter of Air*
Manganese	Silvery gray metal. Hazardous from inhalation of fumes or dust.	5.0
Pentachlorophenol	Dark-colored flakes. Harmful dust. Emits toxic fumes when heated.	0.5 (skin**)
Phosphorus (yellow)	Poisonous mainly by inhalation. Severe burn hazard from skin contact.	0.1
Picric acid	Yellow crystals or liquid. Explosive—particularly metallic salts. Emits toxic fumes on decomposition.	0.1 (skin**)
Selenium compounds	Toxicity varies somewhat according to the solubility of the specific compound. Often causes contact dermatitis.	0.1
Sodium hydroxide	White, deliquescent pieces or lumps. Has severe action upon all body tissue.	2.0
Tellurium	Similar to selenium chemically and in physiological effects.	0.1
Titanium dioxide	White to black powder. Considered in the nuisance category.	15.0
Trinitrotoluene	Colorless to yellow monoclinic crystals. Emits toxic fumes of oxides of nitrogen when heated to decomposition. Highly poisonous explosive.	1.5 (skin**)
Uranium	Highly toxic and a radiation hazard that requires special consideration.	0.05 (soluble compounds) 0.25 (insoluble compounds)
Vanadium pentoxide	Yellow to red crystals. Acts chiefly as an irritant to the conjunctiva and respiratory tract.	0.5 (dust) 0.1 (fume)
Zinc oxide fume	Amorphous white or yellow powder. The powder is essentially nontoxic, but freshly generated fume may cause metal fume fever.	5.0
Zirconium compounds	Most compounds are insoluble and have low toxicity.	5.0

*These threshold limit values were adopted by the American Conference of Governmental Industrial Hygienists in 1962.

**The word "skin" in this table indicates that the substance can penetrate the skin to contribute to the exposure.

96. To cause metal fume fever, heavy concentrations of fumes are required. Zinc oxide fume is the most common source, but cases caused by the inhalation of fumes from magnesium oxide, copper oxide, and other metallic oxides have also been reported. The condition does not occur from the handling of these oxides in powder form. Apparently, it results only from the inhalation of extremely fine particles freshly formed as fume (nascent fume).

97. Nickel, mercury, and other metals may also produce a fever followed by the toxic effects of the element.

Allergic Reactions

98. When in the form of dust, a large number of materials may cause various allergic reactions in susceptible individuals. Examples of such agents are certain animal products, foods, drugs, and chemicals. The bodily systems usually involved in allergic reactions, which may be quite severe, are the skin, respiratory system, and gastrointestinal system. Occasionally, two or more systems are involved. Some of the allergic reactions are dermatitis, hay fever, asthma, and hives.

99. Usually, the victim is subjected to a series of exposures without any reactions during which sensitization is built up. These exposures may occur continuously for years. Then, at the end of the "incubation period," which varies according to the individual, a reaction is produced.

100. For a true allergic reaction two factors are required:

a. A history of prior exposure to the material involved (sometimes not known by affected employees).
b. A "challenge dose" of the material, which provokes the allergic reaction.

101. Continuous exposures may act as "desensitizing doses," and under these conditions an allergic individual may work without incident for long periods of time only to find that re-exposure after removal from the sensitizing material (such as after a vacation) causes an allergic response to recur.

102. Medical and engineering recommendations to prevent allergic reactions are based on prevention of exposure by means of personal protective equipment, ventilation methods, or removal of sensitized individuals from the exposure.

Infections

Infection and pneumoconiosis

103. The presence of pulmonary disease that significantly interferes with the natural defenses against foreign particles may increase susceptibility to pneumoconiosis. Conversely, a pneumoconiotic lung is more prone to infection. For example, tuberculosis occurs more frequently among silicotics than among normal persons. Severe disability or death of a silicotic, when caused by pulmonary conditions, usually results from complicating tuberculosis either alone or combined with other infections.

Bacteria and fungi

104. The possibility of lung in-