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We are faced with the need to develop new techniques; new equipment; and new thinking if we are to develop and produce the mineral materials which remain immediately available to us, let alone find new deposits covered by hundreds of feet of overburden.

Contrary to the situation which existed 50 years ago, there is, today, a real dearth of qualified candidates for the jobs available in our industry. There is an acute lack of young people training for technical or supervisory positions. The closing of mining schools, due to a lack of students, is shocking. I cannot help but attribute these conditions to the unfortunate image which has been created.

Our Nation is committed to assist new nations in their efforts to improve living standards and our industry is dedicated to do its part in meeting domestic needs as well. Neither of these objectives can be met unless we make a dramatic change in manpower availability. Competent technical skills will be needed to help the emerging countries develop and produce their resources as well as find-ore-bodies not readily apparent from surface manifestations. Similar talents will be urgently needed at home if we are to maintain our own standards of living.

As a result of these almost unprecedented demands, every effort must be made to present to the potential candidate for a natural resource career a true story of the opportunities that exist within our industry.

Conservatives in the mining industry have been slow to recognize that a revolution has hit our industry. Science has been let in the back door with seeming reluctance. The mining engineer is, too often, regarded as a doer rather than as a thinker, and little credit has been given to the development of the mineral sciences.

In modern mining one can see at least three distinct fields of scientific application which are rapidly becoming apparent. The first requires an approach from pure mathematics and physics to rock mechanics and environmental engineering. The second requires an approach from statistical mathematics to valuation, control and economic engineering. The third embraces the social sciences with applied physiology, ergonomics and even psychology invading the field.

All of these revolutionary changes 50 years ago can do little if we neg provide a safe and stable working en ment. Where our fathers designed an ported their workings by shrewd and experience, we can today add qualitative knowledge; and our sons add growing precision in numerical tion.

With so many obvious opportunities challenges facing our industry, the talent is at once apparent. We must out to our sons that these opportunities and that they are as fully challeng any which are publicized in the exc sophisticated fields of space or comm tion. We must emphasize that ultimate edy is not the reward for a minerals and this is attested to by the recen have made. We must point out that mining communities offer families opp nities to develop under the influence best academic, medical, religious, and recreational facilities.

This is not a new problem, but gency is more acute than when Agric 1556, reported as follows:

"Many persons hold the opinion metals industries are fortuitous and the occupation is one of the sordi and altogether a business requiring much skill a labour. But as for when I reflect carefully upon its points one by one, it appears to otherwise. For the miner must have greatest skill in his work. . ."

Modern nations, like man, do not bread alone, but by the evergrowing sumption of metals for tools and products. Nations desperate for these often take ill-conceived measures to them. A hungry world is not a pe world—and the world is hungry for with which to produce.

We must, therefore, be in a position assist in the orderly location and dev ment of new ore deposits wherever may occur in the world. Only a well-tr cadre of skills, available to our neig will allow our industry to make sign contributions to world stability.

The Russians, like the Roman of day, put political prisoners and conq peoples in their mines. God grant that Nation will never be faced with su native, but be assured that our national welfare would be seriously jeopardized without mineral products and survival could well dictate such actions.

Even though Agricola pointed up our problem over 400 years ago, little progress has since been made in appraising the public of our importance to them. Our vote potential is so much less than "other minority groups" that our voice is seldom heard or our problems considered in political circles. Commitments of national minerals significance are too often made without painstaking consultation and analysis which under emergency circumstances can dangerously deplete our existing mineral supplies without feasible plans for replacement.

I cannot help but repeat again and again —we must not let another 400 years go by before effectively appraising the public and its political representatives of our industry's significance to national well-being, its opportunities, its challenges, its security, its true family environmental advantages, and its working conditions.

You men in this accident prevention field, closely cooperating with industrial relations people, have laid a firm foundation and have built a sound structure. You have a marketable product for America and the world.

Our job is now to sell ourselves. Only in this manner can we hope to have men in the mines and minerals available to avert national disaster and meet our world commitments to bring an enduring peace to a mineral-hungry world.

DUST HAZARDS RELATED TO HEALTH

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The overall problem of dust hazards related to health is only partially solved. Much has been learned in the past and put to use; much remains to be done. The complex problems which remain require combined efforts in the fields of engineering, physics, chemistry, toxicology, physiology, pathology, and medicine.

The link, or relationship, between hazards and their adverse effects on health is the measurement of exposures to predict their biologic effects. Precise and specific means of measurement would permit accurate predictions of effects, and economical and effective control of the hazards. Completely satisfactory methods for the assessment of exposures to dusts are not yet proved or in use.

Precise definition of the cause-and-effect relationships in the pneumoconioses is especially difficult, because disease may first appear a number of years after initial exposures.

This discussion reviews some of the relationships between dust hazards and health by [illegible] the nature of dust, the way the respiratory system copes with dust particles which are inhaled, some of the aspects of sampling to measure degree of exposure, and some of the effects on health which may result from excessive exposures.

The Nature of Dusts

Dust particles which are hazardous to health when inhaled are invisible to the unaided eye. The smallest particles ordinarily seen without magnifying devices are about 30 or 40 microns in size; those which are hazardous are ordinarily smaller than 5 or 10 microns. (1 micron is approximately 1/25,000 inch.)

Small particles, those in the range of 1-micron diameter, behave in air much differently than do particles which are large enough to be seen. These small particles, once airborne, remain in the air for long periods of time. For example, quartz particles of 1-micron diameter settle only 0.01 foot per minute in still air. In turbulent air, if sedimentation is the only mechanism of removal, half of the 1-micron quartz particles in a 7-foot-high space would still be airborne 8 hours after generation of dust had stopped. A 1-micron quartz particle projected into still air with an initial velocity of 10,000 feet per minute (about 100 miles per hour) will lose its momentum in a distance of 0.01 inch and will thereafter settle or move with air currents. Particles smaller than about ½ micron (0.3 micron for quartz, 0.7 micron for coal) in diameter are affected more by forces of diffusion than by the force of gravity. At ordinary temperatures, the Brownian displacement in air of particles of this size is about the same as their Stokes settling velocity, about 1 millimeter per minute. Thus, the dynamic characteristics of small particles are such that once airborne, for all practical purposes, they move with air currents. Sedimentation has a negligible effect upon dust particle concentrations in normal work situations, and the kinetic energy they possess at generation is quickly dissipated.

Particle size is also important in matters involving the composition of dust. Dust produced by drilling or crushing rock does not necessarily have the same composition as a sample of the parent rock. Even in dust which has become airborne the small particles may have composition different from the larger ones. Three kinds of samples, host rock, settled dust, and airborne dust were obtained from each of nine locations in metal mines. Two fractions of the settled dust samples were analyzed; one fraction contained all particles which passed through a 325-mesh screen (−325 mesh fraction), the other contained only particles smaller than about 5-microns diameter (−5 µ fraction). The airborne samples were taken well downstream from the points of generation to permit large particles to settle prior to sampling. These results indicate decreasing free silica content with decreasing particle size.

Data from some coal mines show more ash in airborne dust than in the coal being mined. In the airborne dust from these mines, the sample fractions containing only particles of small size have a lower percentage of free silica than do the fractions with particles of larger size. For example, the fraction containing only particles smaller than 5 microns may contain 2 percent free silica, whereas the gross airborne sample may contain up to 20 percent.

The coal seems to break along seams of high impurity or high ash content, but in the dust generated, the particles of quartz tend to be larger than those of the other minerals. These data illustrate that mechanics and particle dynamics have effects upon the composition of dusts.

Respiratory System

The respiratory surface in the lungs of a normal man ranges from about 400 square feet at rest to about 1000 square feet at deepest inspiration. The membrane separating the alveolar air space from circulating blood may be only one or two cells in thickness. In the course of an 8-hour day of moderate work, a man breathes about 400 cubic feet of air. Contrast the forced ventilation exposure of the large delicate lung surface with the ambient air exposure of the skin, which has some 20 square feet of surface and a thickness measured in millimeters. It is evident that the lung represents by far the most extensive and intimate contact of the body with the ambient atmosphere.

The respiratory tract of man branches successively from the trachea to some 50 to 100 million ultimate branches. These branches terminate in some 300 million air sacs, or alveoli. The cross section of the trachea is about 2 square centimeters, and the combined cross sections of the alveolar ducts, which handle about the same quantity of air, are about 8,000 square centimeters.

The aerodynamic behavior of particles varies with size, density, and shape. Discussion of dust deposition in the respiratory system is simplified by the concept of "equivalent size" of particles. The equivalent size of a particle is the diameter of a unit density sphere which has the same terminal falling velocity in still air as does the particle.

The respiratory tract, with its successive branches and tortuous passageways, is a highly efficient dust collector. Essentially all particles greater than 4 or 5 microns equivalent size which enter the respiratory system are deposited in it. About half of those of 1-micron equivalent size appear to be deposited and the other half exhaled. The sites of deposition in the system are different for various sizes.

Some studies indicate that particles greater than 2½ or 3 microns equivalent size are deposited, for the most part, in the upper respiratory system, that is the nasal cavity, the trachea, the bronchial tubes, and other air passages; whereas particles 2 microns in equivalent size are deposited about equally in the upper respiratory system and in the alveolar or pulmonary air spaces. Particles about 1 micron in size are deposited more frequently in the alveolar spaces than elsewhere; essentially none are collected in the upper respiratory system.

Although the respiratory system is a very efficient dust collector, all of the dust collected is not retained. The system has a highly efficient mechanism for removing the deposited dust. For example, during 30 years of work a coal miner may inhale and collect in his respiratory system 10 to 15 pounds of dust, but after this 30 years, his lungs may contain only 0.1 to 0.15 pound of dust. The efficiency of removal is thus in the order of 99 percent.

The primary mechanism of clearance in the upper respiratory system is ciliary action. The respiratory tract, from the epiglottis to the terminal bronchioles, is lined with cells having minute hair-like processes called cilia. The cilia, by continuous whip-like motion, cause a blanket of mucous-like fluid to flow upward on the surfaces of the air passages. This blanket carries dust particles and other foreign material upward and out of the respiratory tract to be swallowed.

Surfaces in the alveolar spaces do not have cilia. The primary clearance mechanism here is phagocytosis. Phagocytes are cells which engulf foreign materials such as dust particles. These cells appear in the lungs, possibly by disengaging from the surface lining, and migrate with their burdens of foreign material either to the pulmonary lymph system or outward to the ciliated air passages, where they are carried away by the ciliary action.

Because the efficiency of lung clearance is so great, a small decrease in it may result in a great increase in the amount of material retained in the lungs. Several observations of interference with lung clearance have been made. The efficiency of lung clearance appears to decrease with increasing lung dust burden. Irritant gases have been shown to decrease or stop ciliary action in animals. Some materials which appear to be toxic to phagocytes reduce their effectiveness in removal of material from the pulmonary spaces. The mechanism of pulmonary deposition and clearance deserve, and undoubtedly will receive, a great deal more study.

Dust Sampling

Any program for control or reduction of exposures to dust requires a means of assessing exposures. Since the etiologies of some occupational diseases, particularly the pneumoconioses, are not fully known, it is not possible to define all the characteristics that contribute to the toxicities or biologic effects of dust. All of the sampling methods used in different parts of the world for estimating exposures to mineral dusts are empirical. None is an absolute method which will yield data from which the hygienic significance of exposures can be precisely judged.

In the United States, the American Conference of Governmental Industrial Hygienists promulgates Threshold Limit Values for toxic materials for use by industrial hygienists as guides in devising control of occupational exposures. Threshold Limit Values have been developed for a number of toxic dusts. The Threshold Limit Values for dusts with systemic toxicities, lead or cadmium, for example, are ordinarily expressed in mass units, i.e., in milligrams per cubic meter of air.

Sampling for such materials may be by filter or other means which collect all of the airborne material. The Threshold Limit Values for pneumoconiosis-producing mineral dusts, on the other hand, are expressed in terms of particle count; the customary unit of concentration is millions of particles per cubic foot of air (mppcf).

The Threshold Limit Values for mineral dusts can be used to judge only data yielded by a standard procedure of impinger sampling in liquid medium and lightfield microscopic counting of the collected dust. The Threshold Limit Values for mineral dusts cannot be applied to data from other particle count methods of sampling.

The standard method of impinger sampling and counting was presented in 1942 at a meeting of the National Conference of Governmental Industrial Hygienists. Because the method is empirical, it must be followed closely by all its users if data obtained by one person are to be comparable to those obtained by another. Even then, variables in sampling and counting within the method as it is described may permit two investigators, both applying the method skillfully and conscientiously, to obtain quite different results to represent the same environment.

Sampling may have different purposes, which merit employing different techniques. These generally fall into two major categories: (1) sampling for engineering surveillance, testing, or control and (2) sampling for health research or epidemiologic purposes.

Engineering applications of sampling may include locating sources of contamination, monitoring performance of environmental control systems, or doing research in such problems as collection efficiencies of air cleaners. A sampling program for engineering purposes should be designed to yield the specific information desired. For example, one might need only a single sample before and another after a change in ventilation to determine whether the change has had the desired effect.

Hygienic applications of sampling, on the other hand, may be directed at predicting the health effects of an exposure by comparing sampling results with hygienic guides, determining compliance with health codes or regulations, or research to define as precisely as possible environmental factors for comparison with observed medical effects. In the latter case, sampling may provide the basis for development or refinement of hygienic guides such as Threshold Limit Values.

Sampling for atmospheric particulates presents quite different from those of sampling for gases and vapors. Gases and vapors, when inhaled, can penetrate all portions of the pulmonary system and follow the laws of distribution by diffusion and absorption. The sizes and densities of particles, on the other hand, are major influences in determining the sites at which they will be deposited in the pulmonary system. Since the effects produced by particles trapped in the nasal passages or deposited in the ciliated portions of the pulmonary system may be quite different from those of particles which are deposited deeper in the pulmonary system, size-selective sampling is generating increasing interest among industrial hygienists.

At the Pneumoconiosis Conference held at Johannesburg, South Africa, in 1959, in which experts in pneumoconiosis from all over the world participated, it was concluded that in the light of present available evidence the best single parameter to measure in the case of coal dust, is the mass concentration of respirable dust, and in the case of quartz dust, is the surface area of the respirable dust.[3]

The respirable fraction of a dust cloud was then defined as all particles smaller than 1 micron, half of those of 5 microns, and none of those 7 microns or larger in equivalent diameter. Sampling devices have been developed to sample this respirable fraction. They either reject particles too large to penetrate to the deeper portions of the lung or collect larger particles in a pre-sampler so that the respirable portion can be collected separately for weighing and analysis.[4]

The results of sampling for dust, using such devices, either for gravimetric determinations or for determination of composites cannot be interpreted by use of our current Threshold Limit Values or similar guides for judging exposures. Such sampling, however, may represent a sensitive method for predicting the disease-producing potential of exposures to mineral dust.

The devices might also be used to distinguish the portion of an exposure to toxic dusts which results from pulmonary absorption and the portion which results from absorption through the gastrointestinal tract. Such samplers are worthy of much greater study and use than they now receive in this country.

Some Effects from Exposure to Dust

The two types of occupational diseases which may result from exposure to dust are the pneumoconioses and chemical intoxications. Pneumoconioses are diseases of the lungs which result from exposure to dust. Chemical intoxications are not limited to the lungs and are characterized by local or systematic effects, which result from contact to, or absorption of, toxic material.

The most common pneumoconioses are silicosis, coal workers pneumoconiosis, and asbestosis. These diseases are characterized by pulmonary fibrosis, which is detected by chest X-ray examination, and by impairment of pulmonary function as the disease progresses.

In 1963 the Public Health Service published a report by the Service and the Bureau of Mines on a study of silicosis in the metal mining industry.[2] In this study some 14,000 workers at some 50 metal mines were examined. X-ray examinations showed a crude prevalence of 3.4 percent silicosis among the study population. The prevalence of silicosis among underground workers was about twice that among surface workers, 4 percent versus 2 percent. Underground face workers showed an overall crude prevalence of about 7 percent silicosis.

In a further breakdown of these data the rates for face workers according to years of work were: less than 10 years of work, 1 percent silicosis; 10 to 20 years, 2.5 percent; 20 to 30 years, 11 percent; and more than 30 years, 26 percent.

It is reasonable to suspect that older men suffered higher dust exposures in earlier years than are common in the industry now. This matter was examined in some degree by comparing silicosis rates among men who worked in metal mines at some time prior to the year 1935 with rates among men who worked only after that year. The examination showed 8 percent silicosis among men with 10 to 15 years of total work in metal mining, but with some work prior to 1935. Among men with all of their work experience after 1935, 20 to 25 years of work produced a silicosis rate of 7 to 8 percent.

Thus, the earlier exposures seem to have resulted in the 8 percent rate of silicosis with about 10 years less work experience than with the later exposure.

In May of this year, the Division of Occupational Health, Public Health Service, announced the results of a study of coal workers pneumoconiosis among a sample of Appalachian bituminous coal miners. The prevalence of the disease among the active workers examined is about 10 percent; among retired and other inactive miners examined the rate is almost 20 percent. More than 20 percent of active miners in the 55- to 64 age group are affected. The duration of exposure seems to be very significant, the prevalence of cases increase markedly among groups with more than 20 years of underground work.

The problem of pneumoconioses is far from solved. Control of the disease depends on control of exposure. All presently available knowledge should be applied toward control, but this is not sufficient to assure that the disease can be economically controlled in all cases. Additional medical and engineering studies are needed to find the most reasonable, economical, and sure means of control.

Relatively few problems of intoxications from dust arise in actual mining operations, but they are not infrequent in milling and smelting operations. The effects of absorption of toxic dust are extremely variable. Effects may range from muscle and joint pain from antimony compounds to chills and fever from zinc fumes. Some chromium compounds may cause lung cancers and perforation of the nasal septum; manganese may cause staggering, high stepping, and other gait disturbances; and mercury may cause irritability and emotional instability.

In contrast to the pneumoconioses, which do not regress with any known treatment, most chemical intoxications respond favorably to medical treatment and cessation of exposure.

Summary

Human lungs are size-selective dust collectors. Only relatively small particles, generally those less than 5 microns in diameter, reach the alveolar spaces. Such small particles move with the air currents; they settle very slowly in still air, and even when thrown into the air with high velocity they travel through the air only a short distance. The lungs have a very large surface, 300 to 1,000 square feet of very delicate tissue. This surface is exposed to contaminants in the air breathed. The lungs have good defenses against particulates; when unimpaired, these clearance mechanisms remove about 99 percent of the insoluble dust deposited in the lungs.

The control of exposures to dust requires a means of assessing dust concentrations in the air. Methods used for sampling and quantitating mineral dust concentrations are empirical, and results yielded by one method cannot be judged by standards based on another. Even with a single method, for example, the impinger sampling and counting method, differences in application can cause differences in results obtained by two investigators.