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1965

National Safety Congress Transactions

Volume 1

GENERAL SESSIONS

ANNUAL MEETING OF MEMBERS

CONGRESS BANQUET

LIST OF EXHIBITORS

GENERAL INDEX OF ALL VOLUMES

NATIONAL SAFETY COUNCIL
425 N. Michigan Avenue
Chicago, Illinois 60611

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1965

National Safety Congress Transactions

Volume 7

COAL MINING

NATIONAL SAFETY COUNCIL
425 N. Michigan Avenue
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GREEN CROSS FOR SAFETY
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ifications. In the future design of new mining equipment, the manufacturers should make their own evaluation of the foreign research and development work performed on machine design to see if it is applicable.

New mining methods using principles of remote control or continuously removing the coal from the face pneumatically offer solutions to the dust problem, but these are long range developments and, many mines will never see such systems employed. Continuing research efforts are required on both the dust and methane problems, although it is felt that the present technology, correctly applied, will allow us to make significant improvements during the next several years.

The material presented in this paper has been accumulated during the course of an investigation of methods for control of float dust in coal mines, sponsored by the Commonwealth of Pennsylvania through a grant in funds by the Pennsylvania Coal Research Board. Permission to publish this information is gratefully acknowledged.

DUST MEASUREMENT AND STANDARDS

By EARLE P. SHOUB

Chief, Division of Accident Prevention and Health, Health and Safety Activity, Bureau of Mines, Interior Department, Washington, D. C.

A consideration of how dusts are measured and of the standards imposed in various places seems to be an integral part of this discussion. Some dusts present ignition hazards, others hygienic hazards, and some involve both dangers. Because of the growing interest in the health hazards of dusts found in the atmosphere in coal mines, this discussion will be limited to hygienic aspects.

For several very valid reasons interest in chest diseases traceable to inhaled dusts has grown considerably among members of the coal mining industry.

First, it is now generally agreed among medical experts that the dusts in the atmosphere of coal mines are harmful if breathed in sufficient quantities over a long enough period of time.

Second, the Public Health Service and the Bureau of Mines are cooperating in a study of coal miners' pneumoconiosis. The Bureau has responsibility for the environmental phases of the study and the Public Health Service for the medical phases. Preliminary information is available from the Public Health Service on a study of chest diseases in bituminous coal miners and former coal miners of the Appalachian Area.

It is reported that about 10 per cent of the currently employer miners in the area have pneumoconiosis and that roughly 20 per cent of men formerly employed in the mines are stricken. Evidence that years of exposure is a factor in the disease can be seen in the following tables:

	Per cent with pneumoconiosis	
Age (years)	Currently employed	Formerly employed
All ages	9.5	18.6
25-34	1.2	
35-44	4.2	2.7
45-54	10.1	19.9
55-64	20.7	19.7

When the same group of subjects is retabulated by years of work underground, we find a similar relationship.

	Per cent with pneumoconiosis	
Years Underground	Currently employed	Formerly employed
All years	9.5	18.6
0-9	2.0	1.9
10-19	4.0	6.3
20-29	8.6	21.3
30-39	20.6	21.4
40 and over	24.2	23.0

Third, is the indication of the widespread nature of the disease in coal mining states to be found in the record of benefits paid for workmen's compensation. An article which appeared in the October 1964 issue of Archives of Environmental Health, an American Medical Association publication, reports all cases for which benefits have been paid for chest diseases of this type and is not limited to bituminous coal miners. Some pertinent parts of one of its tables follows:

State	Disease Compensable	Years Covered	No. Cases	Benefits
Ala.	pneumoconiosis	1952-1960	1,982	$6,744,900
Ill.	silicosis, asbestiosis	1950-1963	402	1,071,979
Ohio	silicosis, other pneumoconiosis	1950-1954; 1958-1962	1,113*	10,427,305*
Pa.	silicosis, asbestiosis, anthrasilicosis	1950-1961	9,126	53,366,827
Utah	silicosis	1950-1959	35	335,616
Va.	silicosis, pneumoconiosis	1950-1960	114	254,775
W. Va.	silicosis	1950-1962	7,802	16,244,433*

*Partially estimated

At the Pennsylvania Governor's Conference on Pneumoconiosis held in Harrisburg late last year, it was stated that the annual compensation payments in Pennsylvania for pneumoconiosis are increasing rapidly each year.

In the United States, one of the widely accepted standards of acceptable dust exposure for bituminous coal miners is one suggested by Westfield, Anderson, Owings, Harmon, and Johnson in Bureau of Mines Information Circular 7615, Roof Bolting and Dust Control:

> "In bituminous coal and lignite mines, the average full shift concentration of atmospheric dust to which a workman may be exposed should not exceed 20 million particles per cubic foot of air, and a maximum concentration for any single operation should not exceed 40 million particles per cubic foot of air. When the dust contains silica, not more than 5 million particles of silica per cubic foot of air should be present in the above limiting concentrations. The dust count my be multiplied by the percentage of silica concentration, and if the result is less than 5 million, the dust concentration will be considered safe. The above limiting concentrations are based on impinger samples in which light-field counts are made under a microscope."

The actual origins of this recommendation are not clear. A search of the still available records leads to the conclusion that they stem from field observations by C. W. Owings of the Bureau of Mines which were described in Mechanization of November 1946, and from findings reported by the Public Health Service in its Bulletins 221 and 270. There is also an earlier reference to the 20 million particle figure in Bureau of Mines Report of Investigations 3631 published in 1942. The method of evaluating silica exposure by multiplying the dust count by the percentage of free silica had been suggested some years before, was also suggested in the transactions of the National Silicosis Conference in 1937, and is mentioned in Industrial Hygiene and Toxicology by Patty.

A 1965 publication of the International Labour Office, Guide to the Prevention and Suppression of Dust in Mining, Tunnelling and Quarrying, includes standards of Australia, Canada, Poland, the United Kingdom, and of the United States. From this publication, we learn the following:

Australia

In New South Wales dust is measured in particles under 5 microns in size per cubic centimeter. The number of particles may not exceed 700 when the free silica content of the parent rock (including coal and oil shale) does not exceed 10 per cent and decreases by 100 particles per cubic centimeter as the silica content increases in units of 10 per cent. Thus at 50 per cent or more free silica, the dust count of 5 microns and smaller particles may not exceed 200 per cubic centimeter. (Nothing is said about the method of dust sampling and counting to be used.)

Canada

The midget impinger is used in Quebec where 5 million particles per cubic foot is permitted when the dust composition is above 40 per cent silica. Between 5 and 40 per cent silica, 10 million particles per cubic foot is permitted and below 5 per cent silica in the dust, 50 million particles per cubic foot is allowed.

Poland

The Polish standards apply to particles of 0.5 to 5 microns in size per cubic centimeter of air. Workplaces are classified as coal faces or rock faces. The dust is classified on the basis of its content of stable incumbustible material. Up to 10 per cent rock, that is incumbustible, 1500 particles per cubic centimeter is allowed. The number of particles decreases in steps to 500 when 70, or more, per cent rock is involved. When sampling the airborne dust shows silicon dioxide is present, the limits are based on the amounts of silica present. For 25 per cent, or more, SiO_2 500 particles per cubic centimeter from 0.5 to 5 microns is permitted. From 15 to 20 per cent silica, the number is raised to 850. In the 5 to 15 per cent range, it is increased to 1200. When the silica content is 5 per cent or less, 1500 particles per cubic centimeter is allowed.

United Kingdom

Conditions are "approved" if they comply with standards of dustiness. Anthracite dust clouds are not to exceed 650 particles between 1 to 5 microns in size per cubic centimeter. Other coal dusts, which include bituminous coal, are restricted to 850 particles in the same size range per cubic centimeter. In stone drifts and hard headings, the maximum is reduced to 450. Measurements are made with the thermal precipitator and the limits apply to periods of maximum dust production.

The British are experimenting with a standard which would approve a working place, provided the limit is not exceeded on more than one shift in ten. In the case of bituminous mines, where the 850 particle per cubic centimeter standard applies, this would work out as follows:

A face would be approved if:

(1) the mean concentration on a single shift is a less than 450 particles per cubic centimeter in the range 1 to 5 microns; or

(2) the mean concentration on each of two successive visits to the face is less than 700 particles per cubic centimeter in the range 1 to 5 microns.

A working face would not be approved if:

(1) the mean concentration on a single shift is greater than 850 particles per cubic centimeter; or

(2) the mean concentration on each of two successive visits is over 700 particles per cubic centimeter

United States

This ILO publication refers to the Threshold Limit Values established for silica by the American Conference of Governmental Industrial Hygienists and describes the standard last used in Threshold Limit Values for 1961. That is, when the airborne silica is 50 per cent or higher, the limit is 5 million particles per cubic foot; between 5 and 50 per cent silica, 20 million, and below 5 per cent silica, 50 million particles per cubic foot.

More recent edictions of the same publication of the American Conference of Governmental Industrial Hygienists set the limit in millions of particles per cubic foot by a formula, $\frac{250}{\%SiO_2+5}$. In both the older and new publications the ACGIH specifies the use of the midget impinger and light field counting.

It is interesting to note that in 1961 the limit on silica was carried under the heading "Mineral and Non-Metallic Inorganic Dusts." In the current edition of the ACGIH publication, the title of the portion just described is "Respirable Dusts Evaluated by Count."

From other sources, there is information regarding standards in other countries.

Soviet Union

It is said that the dust concentration standard in the U.S.S.R. is gravimetric in nature, but it is not clear whether the limits apply to total airborne dust or to the respirable portion only. Visual observations by visitors to Soviet mines lead to the assumption that a selected size fraction is involved. Two limits are reported. Above 70 per cent free silica, 1 milligram per cubic meter is permitted; and below 70 per cent free silica, 2 milligrams per cubic meter (mg/m^3) is allowed.

Germany

The Tyndalloscope is in general use for routine measurement in coal mines. They feel the Tyndalloscope gives readings which are directly related to surface area especially in the 1 to 2 micron range. Because of the empirical nature of the readings, the instrument must be carefully standardized in a central laboratory. The instrument scale is divided into four ranges or categories, very high, high, medium, and low, which in millions of particles per cubic foot, represent over 30, 15 to 30, 7 to 15, and less than 7, respectively. Workplaces in the very high category are tested every three weeks. High category places are tested every six weeks, medium category workplaces are examined at three-month intervals, and low category, every six months. It is mandatory that the dust of places in the very high category be analyzed for silica and recommended that this also be done for places in the high category.

Medical surveillance of the miners includes a detailed record of workplaces and dust categories. Men who show no evidence of pneumoconiosis are permitted to work in the high and very high concentration areas. Miners with marginal pneumoconiosis are permitted to work only in low and medium category areas. Those with definite diagnosis of pneumoconiosis are barred from working underground.

France

In French coal mines filter samples are taken and microscopically counted with a 40x objective. Only particles from 0.5 to 5 microns are counted. The decision as to which particles fall within this range is essentially one of the judgments of the person doing the counting.

In general their limits appear to be close to the ones set by the ACGIH formula except that two different methods of analysis are involved.

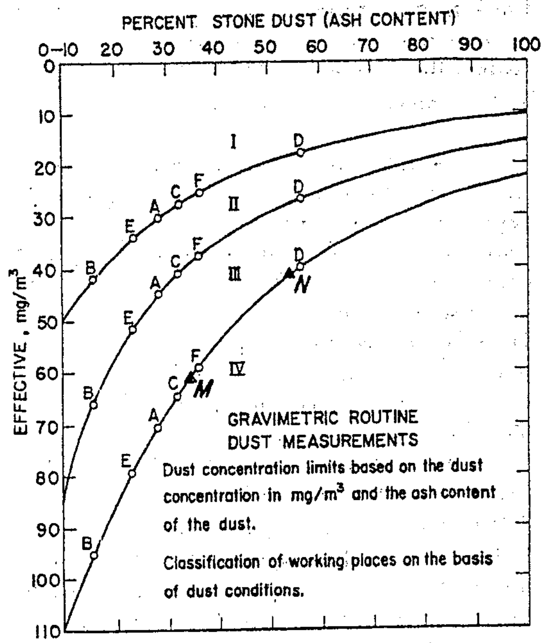
The Netherlands

Dustiness standards were developed after a consideration of the following beliefs:

1. Quartz is the most dangerous of the silicogenic materials. Silicates are also dangerous, but less than quartz.
2. The harmfulness of coal dust comes from the mineral contaminants, and because its respiration overburdens the lungs.
3. Modern thinking is that the number of particles per unit volume is less meaningful than the surface area per volume of air, or than the weight of the particles in a unit volume of air.
4. Silicosis is caused by the inhalation of fine dust.

Based on appropriate consideration of these factors as they apply to the coal mines in the Netherlands, there was introduced a "dust index" for evaluating the results of routine dust measurements.

"The dust index is the content of fine dust, smaller than 5 microns, in milligram per cubic meter of air, awarding multiplication factors to the components of the dust, notably 5 for quartz, 3 for other mineral components, and 1 for coal dust. This means that a dust composed of X milligrams of fine quartz, Y milligrams of other fine minerals, and Z milligrams of fine coal dust per cubic meter of air, has a dust index of $5X + 3Y + Z$; this index is expressed in effective milligrams per cubic meter of air (eff. mg/m^3)."



This can be expressed for the minus 5 micron fractions as:

$$\frac{5\,(\text{mg quartz}) + 3\,(\text{mg other minerals}) + \text{mg coal dust}}{\text{cubic meters of air}} =$$

Effective milligrams per cubic meter = Eff. mg/m^3

Limits were established for four categories, class I (dust free), class II (low dust content), class III (dusty), class IV (very dusty). Originally these were preliminarily fixed at 0-15 eff. mg/m^3, 15-30 eff. mg/m^3, 30-45 eff. mg/m^3, and over 45 eff. mg/m^3.

Other sets of limits were established for stone dust. Stone dust is usually taken as the weight of the residue after ignition (ash). Four categories were set:

dust free	0-10 mg/m^3
low dust content	10-15 mg/m^3
dusty	15-22 mg/m^3
very dusty	over 22 mg/m^3

In recognition of the ability of coal dust to overload the lungs, these limits are lowered at intervals until at 10 per cent ash they are about 50 per cent of the ones for stone dust.

Even these limits would permit the inhalation of large amounts of coal dust and stone dust containing less than 10 per cent ash. In actual practice, the avoidance of overburdening the lungs by dust of any kind is considered so important that a further reduction is made for situations in which there is less than 10 per cent ash.

The curves of the previously shown graph each represent what is believed to be the same hazard and are the boundaries between the four categories. For example, point M represents a man inhaling 60 mg/m^3 of dust with an ash content of 35 per cent; Point N represents another man inhaling 40 mg/m^3 of dust with an ash content of 55 per cent. It is contended that both men are being exposed to the same hazard. Also points A, B, C, D, E, and F are the results of a total of 296 dust measurement experiments involving various types of work using the dust index in effective milligrams per cubic meter as a reference.

The standards described in this paper do not include those of still other coal producing countries, but are sufficient to show there is generally little agreement among them when taken collectively. They differ on particle size range, what is meant by particle size, on method of collection, on method of determining concentration, and on the importance of composition.

Particle size may be determined in two ways. One is to examine the particle under a microscope and from linear measurements or from a judgment of the cross-sectional area estimate the size and volume of the particle. The other is to relate the performance of a particle suspended in air to the size of a sphere of unit density which would behave identically if it were suspended in air. The latter method can be called size equivalent to unit density spheres and is a way of expressing the aerodynamic qualities of a dust.

The respiratory system, we are told, generally conforms to the laws of aerodynamics. Also, medical testimony says that if we expose an average or normal human to a cloud of unit density spheres of all sizes, most of the particles below 20 microns (in diameter) will enter the nasal passages. Nasal retention will remove a goodly portion of this cloud. Eliminated will be about 75 per cent of the particles 10 microns and larger, about 55 per cent of the 5 micron particles, about 25 per cent of the 2 micron particles, and around 10 per cent of the 1 micron particles.

Further screening occurs in the ciliated portion of the respiratory system between the nose and the lower lungs. By the time the dust cloud reaches the part of the lungs with which we are most concerned, essentially all the 10 micron particles will have been screened out, and the lower lungs will receive about 35 per cent of the 5 micron particles, about 75 per cent of the 2 micron particles, and approximately 90 per cent of the 1 micron particles.

Remember, these are unit density spheres. Quartz has a specific gravity of 2.65 and coal from which the mineral matter is removed approximately 1.25. This means that the equivalent of 5 micron unit density spheres are spheres of quartz about 3.6 microns in diameter and of coal about 4.6 microns in diameter. It also means that spheres of quartz about 3.6 microns in size will behave in air similarly to spheres of coal a full micron larger.

Another area of difference which should be considered involves the relative significance of counting the number of particles as compared to measuring surface area or determining the weight or mass of the particles, all on a unit volume basis. There has probably been more work done in the United Kingdom on this question than elsewhere. In 1943 the Medical Research Council which made a study in the South Wales coalfield concluded that the mass of particles *not exceeding* 5 microns in size provides the best measure of the hazard to health. However, for administrative reasons they recommended the standard should be given in terms of numerical concentration of particles not less than 1 micron in size.

Other work has supported the conclusion that the mass or weight of particles reaching the lower lungs is more important than the number of particles. One of these is that the examination of post mortem lungs of pneumoconiotics showed a correlation between severity measured by X-ray with the mass of dust retained in the lungs.

This subject was one of the topics of the 1959 Johannesburg Pneumoconiosis Conference. The Dust/Engineering Group of participants at the Conference recommended:

> "that in the light of present available evidence the best descriptive parameter to measure be considered

(a) in the case of coal dust to be the mass concentration of the respirable dust,

(b) in the case of quartz dust to be the surface area of the respirable dust."

The same conference concluded that respirable dust should be defined in terms of the aerodynamic equivalent to unit density spheres and, that on this basis the respirable fraction of the dust is the portion which conforms to a curve running from 0 per cent at 7 microns, through 50 per cent of the 5 micron particles, to 100 per cent at a fraction of a micron. This curve is not identical with one developed for deposition by particle size in the alveolar area (or lower portion) of the lungs but does approximate it reasonably well in a direct relationship.

The administrative reasons for selecting particle count standards in the United Kingdom have largely disappeared, and in their place there are now strong reasons to adopt gravimetric standards. Among these are that counting is time consuming, requires special training, and is subject to considerable personal bias whereas the gravimetric methods are cheaper, quicker, and more objective. They also gather a sample large enough to permit compositional analysis of the dust. I will have more to say about these points later.

One question which immediately presents itself is—is there a definite relationship between the results of particle counting and gravimetric dust determinations? Setting aside any questions about the precision of the measurements in each case, the answer appears to be that although there seems to be a reasonably constant relationship when the same operation, mining method, and coal seam is involved, there is considerable variation among different coals, methods, and operations. J. Cartwright of the Safety in the Mines Research Establishment, Sheffield, England, has published a two part paper, Relationships Between Mass and Number Concentrations of Respirable Airborne Dust in British Coal Mines, in the Annuals of Occupational Hygiene of 1965. He has chosen the term "Mass/Number Index" (MNI) to express the relationship of mass concentration in milligrams per cubic meter divided by the number concentration in thousands of particles per cubic centimeter all multiplied by 1000. "For example," he says, "a dust cloud whose mass concentration is 10 mg/m^3 and whose number concentration is 500 particles per cubic centimeter has a MNI of 20." That is, 10 over 500, all times 1000. He goes on to say "Typical values of the MNI so far measured in British coal mines lie between 10 and 30; but values up to 100 have been encountered."

I have made several references to the vagaries of counting techniques. Some of them are mine and some came to me from responsible persons in the United States and abroad. The British use the thermal precipitator, a device which causes the dust in the air passing through it to be deposited on a glass slide. The slide is examined by projection microscopy and counts made in a manner similar to that employed in the United States for midget impinger samples except that they count as one each group of touching, overlaying or agglomerated particles. They conduct workshops and training sessions for the persons who count thermal precipitator slides. From personal discussions, I have learned that at the end of a training session the technicians are reasonably in agreement in counting of test slides, but that by the time they assemble for the next session, three or four months later, there is significant disagreement among them.

We have had similar experience in counting midget impinger samples of coal dust and of silica dust. Experiments were conducted in June 1964 in which about a dozen experienced, highly trained persons were assembled with their own equipment and each given a midget impinger which had sampled a common dust cloud simultaneously. Each person was requested to count in the same manner as was his custom. In the case of the coal sample, there were twelve counts ranging from 4.3 to 32.5 million particles per cubic foot (mppcf). There were differences in the usual procedures which may account for some of the variation. These included the impinger liquid, the settling time, the counting chamber, and the microscope. Nevertheless, we can not ignore the fact that a variation of about 8 to 1 resulted when truly competent persons performed in their normal manner. Somewhat better agreement was found in the case of the silica dust. Here the variation among 10 operators was from 11.4 to 44 mppcf, only about 4 to 1.

There have also been several references to gravimetric sampling, but very little said about the instruments for the purpose. The simplest method is to draw the air to be sampled at a known rate for a specific time through a membrane or other non-hygroscopic filter. By weighing the filter before and after the test period, the weight of the dust is determined. The weight of the dust divided by the volume of air gives the weight or mass concentration. This method measures all the dust, regardless of size, including that which is beyond the respirable fraction. There are three instruments which are designed to screen out the larger size particles so that the portion of the airborne dust which is ultimately weighed conforms to the curve of particle size vs. percent retention established by the Johannesburg Conference of 1959.

All three employ horizontal elutriators through which the incoming air passes to remove the undesired portion. Horizontal elutriators are stacks of rectangular plates of such dimensions that for the selected velocity of the dusty air passing through them a unit density sphere of predetermined size will have sufficient residence time to drop to a plate and be retained on it.

The Hexhlet instrument utilizes compressed air of at least 40 pounds per square inch pressure to energize the instrument. Its elutriator is a stacked bank of aluminum plates each separated by 0.032 in. There is an effective floor area of 1690 square inches with a length of 10 inches. Flow rate of sampled air is 100 liters per minute or 6 cubic meters per hour. The respirable dust sample is collected in a Soxhlet thimble of a single thickness extraction type, 41x123 millimeters. For several reasons this instrument does not appear attractive for use in U.S. coal mines. First, many of them do not have compressed air at the pressure and volume required. Second, the filter paper thimble can absorb water from the air. It is therefore necessary to remove the sample of dust for weighing. Third, the Dutch have tested this instrument and say in one of their reports,

> "It is seen that the so-called coarse fraction of the Hexhlet instrument contains much fine dust; in most cases even more than half of the total fine dust is found in this fraction. . . . It has further been proved that the fine fraction obtained in the Hexhlet instrument contains much coarse dust; roughly 60-70% by weight of the fine dust fraction has a diameter above 10 microns."

For all these reasons, it appears that the Hexhlet instrument, one of the first on the market, is not suitable for use in U.S. coal mines.

Another instrument which also avoids the use of electric power is called SIMGARD and was developed at the Safety in Mines Research Establishment at Sheffield. It was designed to collect, during one shift, a sample of respirable dust sufficiently large to weigh and on which some compositional measurements can be made. The basic components are an elutriator, membrane filter, and an ejector powered by compressed carbon dioxide from two small cylinders. Air is drawn at 3 liters per minute through the elutriator and filter by the suction created in the ejector. The elutriator consists of a stack of 35 plates, each 6.0x1.56 centimeters spaced 0.125 centimeter apart. The total floor or settling area is 327 square centimeters giving a 50 per cent cut-off of 5 micron unit density spheres at the design flow rate. Other parts of the instrument include a pressure regulator-control, a timer, and a fiber glass two-part case.

The cylinders (935 cubic centimeters each) hold enough liquid carbon dioxide to operate the unit for almost 12 hours. A slightly smaller model is now being produced in the laboratory which has an 8 hour supply of carbon dioxide. Neither the 12 hour nor the 8 hour model is yet being produced commercially. It is reported, however, that negotiations are under way to make them commercially available.

Eight units were hand made and tests indicate that they all performed in the same manner. We have been able to borrow two of the eight and are evaluating them in our Government laboratories.

Finally, there is a battery powered, intrinsically safe instrument developed at the Mining Research Establishment of the National Coal Board at Isleworth. This instrument is now being manufactured and sold by C. F. Casella and Co., Ltd. of London.

Air is sampled at a rate of 2.5 liters per minute. Over a full shift sufficient dust is collected to be well above the limits of precision weighing with a balance having a sensitivity of 0.01 milligram.

The horizontal elutriator consists of four identical rectangular sections, one above the other, with a total floor area of 275 square centimeters. Each section is 17.19 centimeters long x 4 centimeters wide x 0.238 centimeter high. Overall area tolerance is 0.5 per cent.

The dust is collected on a 5.5 centimeter circle of Whatman's GF/A glass fiber paper. The air is drawn through the fiber by a reciprocating pump driven by a constant speed electric motor. A ratemeter on the outlet side of the pump indicates air flow, and the total volume of air sample is recorded on a counter.

Recent word from MRE indicates that they have successfully substituted a membrane filter for the glass fiber one. This will permit examining the collected dust for silica without fear of contamination from glass fibers.

Both of the new instruments will operate satisfactorily in air flows up to 1000 feet per minute into the wind and cross wind with no detectable difference in sampling efficiency. At somewhat higher air speeds errors are detectable.

The principal goal of the Bureau of Mines and the Public Health Service is:

> to conduct a meaningful integrated study of the medical and environmental aspects of chest diseases in bituminous coal miners due to the inhalation of dusts.

The study should lead to rational recommendations of maximum dustiness for hygienic reasons which would provide adequate protection under economically feasible conditions.

Unfortunately, although we can list the important factors which should be included in the development of recommendations, we are not yet able to quantify all of them. We are not prepared to state, for example, how much silica free coal dust a normal person can breathe over an extended period without harm. Also we are not able to state with conviction the relationship between quantity and time. That is, is a given concentration of dust breathed for 5 years equivalent in hazard to half as much dust breathed for 10 years?

A purpose of the environmental study, which is a phase of the joint endeavor, is to obtain sufficient data to make possible a valid statistical study of dust levels in relation to the occurrence of disease to obtain answers to these and other similar questions. Those answers must be pertinent to American coals and American mining methods.

Another purpose of the survey is to develop a simple, instrumental control method which bears a direct relationship to what coal miners breathe. To accomplish this we believe the survey should be based on certain fundamental concepts as follows:

1. This survey is concerned only with hygienically significant dust.
2. It should determine, as best possible, the hygienically significant dust in the breathing zone of coal mine workers.
3. It should simultaneously determine the hygienically significant dust in the work area.
4. The relationship between data obtained from the breathing zone and corresponding information obtained in the work area, must be established.
5. Measurements should be made on a time weighted, full shift basis.
6. The survey should separately identify the dustiness exposure of significantly different mining operations.
7. Compositional analysis, especially for silica and ash, should be made.

Since there is reasonable agreement between the theoretical retention-size curve for the alveolar (or lower) portion of human lungs with the corresponding curve for the dust which is not trapped in the horizontal elutriators, devices so equipped can be accepted as means of selecting the hygienically significant portion of the dust. But because these devices must be kept horizontal during operation and the sampling rate maintained at the design value, and because sampling in the breathing zone of a workman requires instruments which are compact, light, and unaffected by position when properly applied, none of the size-selective samplers I have so far mentioned is suitable for monitoring the breathing zone of an active, mobile person. For this purpose, we plan to use an intrinsically safe, personal monitor equipped with a membrane filter and a 10 millimeter cyclone separator.

The retention curve of the cyclone size selector differs from that of the horizontal elutriators. It is somewhat concave whereas the elutriators are convex, and the particle size cut-offs are also slightly different. Because the findings of Cartwright in connection with determining what he calls the Mass/Number Index suggest that the particle size distribution varies from place to place and depends on the operation, we will take simultaneous control samples, as necessary, to provide a reliable conversion factor for each part of each survey.

It is not our plan to abandon casually or reject the midget impinger—light field counting method of dust measurement. We will utilize it in a parallel fashion in laboratory studies to provide a bridge of knowledge with previous surveys and with all the other valuable data developed in the United States over the years.

Some of you may feel that I've outlined a situation in which we appear to be groping in the dark. This isn't true. Advancements of the last few years make it possible to reduce considerably the uncertainties which have plagued dust work in the past and have brought into focus the problems and methods of sampling and analysis in terms of reliability and meaningfulness.

To anyone who still feels that darkness surrounds a program leading to the establishment of sound recommendations of maximum dustiness, I'd like to say:

"Let us remember that there have been dark days in the past. There was a famous one in New England in 1780 when the sun scarcely appeared at all. Thousands of people took it for the end of the world. Among them were many in the Connecticut Assembly, in which Colonel Abraham Davenport was sitting. It was proposed that the Assembly adjourn. Colonel Davenport said, 'The Day of Judgement is either approaching, or it is not. If it is not, there is no cause for adjournment. If it is, I choose to be found doing my duty. I wish therefore that candles may be brought.'"

WILL THAT EXTINGUISHER WORK WHEN I NEED IT?

By S. E. AUCK
Associate Managing Engineer, Underwriters' Laboratories, Chicago, Ill.

I am sure that many times, you have looked at a fire extinguisher, all shiny and bright, hanging on the wall, and said to yourself, "Will that thing work when I need it?"

If we assume that it will work, the next question is usually, "How good is it?" or "How much fire can I extinguish with that device?"

All of these questions are important because, if the people who will someday be called upon to use these extinguishers have no faith in them, they will not be used.

Let us examine these questions in the light of the methods used in rating the efficiency of fire extinguishers, the test methods used to insure that an extinguisher will work, and a brief history or resume of how these various tests and methods were developed.

For over 30 years, Underwriters' Laboratories, Inc. followed a classification program of its own invention in evaluating fire extinguishers. The results of this program were reflected in a letter and numeral designation on the UL portion of the extinguisher name plate. The letters, A, B, and C, were intended to denote the type of fire for which the extinguisher was suitable. The numerals were used as a measure of the effectiveness or extinguishing potential of that extinguisher.

The numerals were used also by the National Fire Protection Association as a means of indicating the number of such appliances required to form what was then called a "Unit of First-Aid Fire Appliance." That is to say, an extinguisher which was rated B-2, would be located in an area to protect against flammable liquid hazards in that area on the basis of two such devices for 2500 sq. ft. of floor area to be protected. If it was rated B-1, then only one such device was required for the same 2500-sq. ft. area.

This system was of service for many years, but as the science of fire protection progressed, the system began to develop serious weaknesses. For example, the old classification method for flammable liquid fires had only two basic Class B fire tests.

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alternative, 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

By ROBERT L. HARRIS, JR.
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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.

One link, or relationship, between hazards and their adverse effects on health is the assessment of exposures to predict their biologic effects. Precise and specific means of assessment 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 pneumoconises 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 considering 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 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 300 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 300 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 lungs represent 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 25 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 efficiently 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 collected 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 on 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 in 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.[5]

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.[1]

The results of sampling for dusts using such devices, either for gravimetric determinations or for determination of composition, 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 reaction 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 2.2 percent. Underground face workers showed an overall crude prevalence of about 5 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, 0.1 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 did 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 miners 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 upon 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.

Dust sampling may be undertaken for either of two rather distinct purposes, for engineering testing and control or for health studies. The objectives of sampling program should be kept well in mind while it is being planned and carried out.

Because only the relatively fine dust reaches the lungs, size-selective sampling devices intended to simulate the deposition characteristics of the lungs have been developed. The mass concentration or surface area of particles of such size that they penetrate to, and are deposited in, the deeper portions of the lungs may prove to be a sensitive index of hazard from exposures to pneumoconiosis-producing dusts. Although data derived from such sampling cannot be interpreted by standards based on count, size-selective gravimetric sampling may eventually represent a major refinement in assessment methods.

The effects of exposure to pneumoconiosis-producing dusts is similar for the various dusts and are irreversible. Chemical intoxications vary with the toxic material absorbed and ordinarily improve with medical treatment and removal from exposure.

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CAN COST CONTROLS SABOTAGE SAFETY?— FACT OR FANCY

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To eliminate waste in administration, cost control is absolutely essential. Without it management lacks the foundation for knowing which costs are excessive or unproductive, and the mechanics for keeping them under constant observation. Top Management has no other proper means of controlling and fixing the responsibility for excesses.

A cost control system has as its objective a means by which intelligent management is kept informed. The system of control in itself will not solve problems, and solutions are derived from the system only after enthusiastic administration and intelligent interpretation. If the controls are properly administered, any variations between the actual and estimated costs will become conspicuous in time to be corrected before significant losses develop. Complete cost control is based on certain criteria or standards which are used as a basis for comparison and as measurement units to provide essential information for the modern functions of management.

When a significant variation appears, management is in a position to analyse it and determine where it occurred, why it happened, and who was responsible. The fact that, because of a proper cost system, management can put the finger on the person or a new policy responsible for the variation is one of the greatest factors in efficient operation. It eliminates "guessing" or "passing the buck."

The establishment of cost control within an organization sets in motion cost reduction. They are different entities and should not be confused as being the same thing. Cost control is concerned with the maintenance of costs in accordance with standards that have already been established through cost reduction programs; it is a device to hold the line in accordance with these standards,

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