

PROOF AND DISPROOF OF CAUSAL CONNECTION
BETWEEN DISEASE AND AIR-BORNE IRRITANTS:
INVESTIGATION OF INDUSTRIAL PLANTS AND
STANDARD PREVENTIVE CONTROLS

LESLIE SILVERMAN¹

INTRODUCTION

In order to establish proof or disproof of the relationship of occupational disease to atmospheric contaminants or irritants, it is important to consider the nature of the contaminant and its mode of entry into the body. Further, it is essential that the mechanism of the poisoning be considered: namely, how the irritant is absorbed, distributed and eliminated. Knowledge of the latter factors enables the analyst or investigator to assay his findings and interpret the results of atmospheric, blood, or urine analyses.

It is recognized in industrial medical practice that occupational disease is caused by inhalation, ingestion, or skin contact with the contaminant.

Although at present a majority of occupational disease claims are based on skin contact or dermatoses,² very few of these are due to air borne contact with the irritating substance. The chemical warfare agent, mustard gas, is an excellent example of skin irritating agent, which is air-borne; however, industrial exposures to this type of agent are rare. Ingestion likewise is not a major source of entry into the body of air-borne material. Since the lungs inherently have a large absorption surface for respiratory exchange, it is obvious that they play an important part in the absorption of industrial poisons. A knowledge of the fundamentals of respiration and circulation is therefore an essential part of the training of the industrial hygiene analyst.

Types of Industrial Health Contaminants

The industrial worker may be exposed to dusts, gases, vapors, fumes, smokes, or mists, and each of these types of contamination may require different sampling and analytical procedures.

-
1. Assistant Professor of Industrial Hygiene, Department of Industrial Hygiene. School of Public Health, Harvard University, Boston, Mass.
 2. See Schwartz, L.: Problems of Proof in Claims for Recovery for Dermatitis (1943) 41 Mich. L. Rev. 893.
(631)

The distinction between dusts, gases, vapors, fumes, smokes and mists is based upon the nature of their evolution from processes and upon an arbitrary designation of particle size. These materials, when air-borne, are designated as *aerosols* since the dispersing medium is air.

Dust is formed by the mechanical reduction of earthy materials to small size by processes such as crushing, grinding, drilling, and blasting. These particles may range in size from the submicroscopic to the visible, but for hygienic purposes we are interested only in those ranging from 10 mirons (u)³ down to less than 0.5u. Particles larger than 10u are appreciably affected by gravity and do not remain suspended long enough in the air to be of hygienic significance. Particles larger than 10u are also prevented from reaching the lung alveoli⁴ by physiological mechanisms.

Gases and Vapors are the evaporation products of liquids boiling at subnormal or normal temperatures. When the liquid boils at temperatures considerably below the temperatures of human environment, its product is usually considered as a gas, while those which evaporate from liquids at normal temperatures are considered as vapors. While there is no thermodynamic⁵ difference in the physical behavior of these substances, they usually fall into separate groups with respect to physiological action. The particle size in this case is molecular⁶ and the substances diffuse freely in the air and are affected by gravity only under particular circumstances of air temperature, air movement, and gas or vapor concentration. We know definitely that gases and vapors are lighter or heavier than air, but the amounts that are of occupational disease significance mix freely with the air in industrial establishments to form mixtures whose density is nearly that of air. Use of the fact that undiluted gases are lighter or heavier

-
3. A micron is one thousandth of a millimeter, or approximately $\frac{1}{25,000}$ of an inch.
 4. Lung alveoli: The alveoli are the air-cells of the lungs at which gas exchange takes place. The gaseous products of body combustion diffuse outward from the alveoli and the inspired air diffuses inward. They are the terminal dilations of the bronchioles, which are small tubes leading from the larger tubes (bronchi and trachea) through which the respired air passes.
 5. I have not attempted to define a gas in its true thermodynamic conception, but rather as it is considered in industrial hygiene parlance. By "thermodynamic," we mean its behavior under various conditions of temperature, pressure and other physical changes of state.
 6. Molecular: Pertaining to the atomic theory in which atoms combine to form larger units known as molecules. The molecule has a diameter of approximately three ten-thousandths of a micron or 0.3 mu (millimicrons). A millimicron is one thousandth of a micron.

than air is made in their control, which will be described in a later section.

Fumes are formed by processes like combustion, sublimation and condensation. Thus boiling lead will evaporate but the evaporated lead vapor will immediately condense upon contacting room air, and will then form small, condensed, fluffy fume particles. Another good example is the formation of metal fumes in welding arcs by the burning of iron, steel and other materials. Fumes are usually less than 1 μ in size and because of their light, fluffy nature tend to flocculate^r and coalesce, forming larger particles which may then settle out. Thus there is a difference in size and nature of freshly formed fume as compared to "aged" fume. Oxidation may take place in the ageing process. "Fumes" is sometimes used by laymen to describe any noxious condition of gases, mists, or their combination. The present trend in technical parlance is to consider only solid particles as fumes.

Smokes are considered as the products of combustion of systems that are usually organic in nature, such as the smoke from oil, coal, wood or tobacco. The size of smoke particles is usually less than 0.5 μ .

Mists are produced by atomization of liquids, condensation from liquids in gaseous states, or entrainment of liquids by gases evolved from industrial processes. They are analogous to dusts in that they are usually the same as the parent material in composition. In size, mists may range from 25 μ to the sub-microscopic or less than 0.1 μ . Industrially, mists are usually produced by acids or alkalis which boil at high temperatures (above 40° C.^o).

In sampling these atmospheric impurities, it must be realized that it is important that all sampling procedures collect material which is identical in nature and size with that inhaled by the workers exposed to the same environment.

Threshold Limits

In making investigations of the atmospheric contamination in industrial plants, it is necessary to have some in-

-
7. Flocculate: The bunching or flocking of particles due to their electrostatic charge or their affinity for one another.
 8. Entrainment: The transportation or conveyance of material by a fluid stream (in this case, a bubble of air or gas) which carries or entrains some of the parent material. The gas or air usually becomes saturated with the liquid and it is carried out in the form of a fine particle suspension.
 9. Centigrade: The Centigrade scale of temperature has its scale based upon 0°C. at the freezing point of water (32° Fahrenheit) to 100°C. at the boiling point of water (212°F.). Forty degrees Centigrade (40°C.) corresponds to 104°F.

dex or scale of contamination upon which to base the protection of workers. These criteria may be based upon the physical or chemical analysis of the amount of contamination in the air of the industrial plant or upon chemical analysis of blood, urine or expired air samples obtained from individuals exposed to the atmosphere in question.

A useful index of the existence of a health hazard is the actual analysis of air impurities in the workers' environment. Consequently, most of the present accepted standards in this country and abroad are based on limitations in air concentration. Biochemical analyses are used where reliable air samples cannot be obtained or where no atmospheric limit exists, but evidence of abnormal exposure is given by some biological material. Urine and blood analyses are often used as a check on how well the preventive control system is functioning or when the worker has been removed from a known hazardous occupation and an index of the duration of recovery is desired.

The analyst will usually be less apt to excite the worker's suspicions or arouse psychological factors if it is not necessary to use biochemical tests in preliminary appraisal or surveyance of the contamination in an industrial plant. Further, it requires considerable instruction and education of workers to obtain urine samples. In spite of such precautions, there is always doubt as to the reliability of the final sample. There is also the inherent danger of having the sample inadvertently contaminated by the worker.

Definition

The threshold or toxic limit for air concentrations is defined as the amount of the contaminant that a worker can be exposed to for an eight-hour working period without incurring any physiological or pathological injury. These limits are based upon four types of information. Henderson and Haggard discuss fully these types of information in their classical monograph.¹⁰ Briefly, it may be stated that these limits are based upon animal experiments, experiments on man, field (industrial) investigations, and estimation of allowable exposure from known dosage data. It is important that these limits not be considered as permanent, although the majority of them have proved satisfactory over a long period.

10. Henderson, Y. and Haggard, H.: *Noxious Gases*, ed. 2, New York, Reinhold Publishing Company, 1943, ch. 6.

TABLE 1

THRESHOLD LIMITS FOR ATMOSPHERIC CONCENTRATIONS

Gases and Vapors	Maximum Allowable Concentrations
<i>Name</i>	<i>Parts per Million</i>
Acetic Acid ¹¹	10
Acetone ¹¹	1500
Acrolein ¹²	1
Acrylonitrile ¹²	20
Ammonia ¹²	100
Amyl Acetate ¹¹	400
Aniline ¹¹	5
Arsine ¹¹	1
Benzene ¹³	75
Butyl Acetate ¹⁴	400
Butyl Alcohol ¹²	200
Carbon Dioxide ¹²	5000
Carbon Disulfide ¹⁵	15
Carbon Monoxide ¹⁶	100
Carbon Tetrachloride ¹¹	100
Chlorine ¹²	1
Dichlorobenzene ¹²	75
Dichloroethyl Ether ¹⁴	15
Dimethyl Aniline ¹²	5
Ethyl Ether ¹¹	400
Ethylene Dichloride ¹⁴	100
Formaldehyde ¹⁴	20
Gasoline ¹⁴	1000
Hydrogen Chloride ¹⁴ (Hydrochloric Acid)	10
Hydrogen Cyanide ¹⁴	20
Hydrogen Fluoride ¹⁴	3
Hydrogen Sulfide ¹⁷	20

11. Sterner, J. H.: Determining Margins of Safety, *Indust. Med.* 12:514, 1943.
12. Gafafer, W. M.: *Manual of Industrial Hygiene*, Philadelphia, W. B. Saunders Co., 1943, p. 264.
13. American Standards: Allowable Concentration of Benzene, Z 37.4-1941, New York, American Standards Association, Approved January 15, 1941.
14. Bowditch, M.; Drinker, C. K.; Drinker, P.; Haggard, H. H., and Hamilton, Alice: Code for Safe Concentrations of Certain Common Toxic Substances Used in Industry, *J. Indust. Hyg. & Toxicol.* 22: 251, 1940.
15. American Standard: Allowable Concentration of Carbon Disulfide, Z 37.3-1941, New York, American Standards Association, Approved January 15, 1941.
16. American Standard: Allowable Concentration of Carbon Monoxide, Z 37.1-1941, New York, American Standards Association. Approved January 15, 1941.
17. American Standard: Allowable Concentration of Hydrogen Sulfide, Z 37.2-1941, New York, American Standards Association. Approved January 15, 1941.

Methyl Alcohol ¹⁴	200
Monochlorobenzene ¹⁴	75
Mononitrotoluene ¹²	5
Nitrobenzene ¹⁴	5
Nitrogen oxides ¹²	40
Ozone ¹⁴	1
Petroleum naphthas ¹²	1000
Phosgene ¹²	1
Phosphine ¹⁴	2
Sulfur Dioxide ¹⁴	10
Tetrachloroethane ¹⁴	10
Tetrachloroethylene ¹⁴	200
Toluene ¹⁴	200
Trichloroethylene ¹⁴	200
Turpentine ¹⁴	200
Xylene ¹⁴	200

Dusts or Fumes	Maximum Allowable Concentrations
<i>Weighted Exposures:</i>	<i>Milligrams per Cubic Meter</i>
Barium Peroxide ¹²	0.5
Cadmium ¹⁸	0.1
Chlorodiphenyl ¹⁹	1.0
Dinitrotoluene ¹²	1.5
Lead ¹⁴	0.15
Manganese ²⁰	6.0
Mercury ²¹	0.1
Pentachloronaphthalene ¹⁹	0.5
Tetryl ¹²	1.5
Trichloronaphthalene ¹⁹	10.0
Trinitrotoluene ¹²	1.5
Zinc oxides ¹¹	15.0
Welding Fumes from Ferrous Metals ¹¹	25.0
<i>Counted Exposures</i>	<i>Millions of particles per cubic foot</i>
Asbestos ¹¹	5
Cement ¹¹	100
Gypsum ¹¹	100
Marble ¹¹	100
Silica ¹¹	5†
Talc ¹¹	100

18. American Defense Emergency Standard: Allowable Concentration of Cadmium, Z 37.5—1941, New York, American Standards Association. Approved November 2, 1941.
19. Drinker, C. K.: Further Observations on the Possible Systematic Toxicity of Certain of the Chlorinated Hydrocarbons with Suggestions for Permissible Concentrations in the Air of Workrooms, *J. Indust. Hyg. & Toxicol.* 21: 155, 1939.
20. American War Standard: Allowable Concentration of Manganese, Z 37.6—1942, New York, American Standards Association. Approved July 16, 1942.
21. American Standard: Allowable Concentration of Mercury, Z 37.8—1943, New York, American Standards Association. Approved January 6, 1943.

Mists	Maximum Allowable Concentrations <i>Milligrams per Cubic Meter</i>	
Chromic Acid ¹²		0.1
Sulfuric Acid (as SO ₃) ¹¹		5.0
<i>Radiation Thresholds</i>		
Radium (Gamma radiation) ²³	0.1 r (Roentgen)	
Radon (Gas) ²³	10-11 Curie per liter	
Thorium ²³	0.1 r (Roentgen)	
Thoron ²³	10-11 Curie per liter	
X-ray ²⁴	1 r per week	

Table 1 gives a list of the most important limits and references for the types of contamination already discussed. Some of these limits have been set as regular standards by the American Standards Association and others as emergency defense standards for the war period only.

Proof that these standards are not considered as fixed and absolute is shown in the recent discussion about the present limit for carbon tetrachloride.²⁵ American practice has been employing 100 P.P.M. (parts per million) as a limit, whereas the German authorities (Lehmann and Flur-

22. American Standard: Allowable Concentration of Chromic Acid and Chromates, Z 37.7—1943, New York, American Standards Association. Approved January 6, 1943.

23. Safe Handling of Radioactive Luminous Compound, National Bureau of Standards Handbook H27, Washington, U.S. Department of Commerce, 1941.

24. Radium Protection and Recommendations of the British X-ray and Radium Protection Committee, National Bureau of Standards Handbook H23, rev. ed. 5, Washington, U.S. Department of Commerce, 1938.

† The U. S. Department of Labor has established a standard²⁵ with references to the control of dust concentrations in air based upon their free silica content and concentration. This standard can be stated as follows:

Multiply the percentage of free silica expressed as a decimal by the total dust particle count. If the result is under five million, the conditions may be regarded as permissible for working exposures. If the result is over five million, the condition may be considered too high. For example, 10 per cent free silica and a concentration of 25 million particles per cubic foot gives 0.1 x 25 which equals 2.5 million and is good practice, whereas 40 per cent free silica and the same concentration gives 10 million, which is unsatisfactory. The above formula does not apply to dusts containing less than 5 per cent free silica.

25. National Silicosis Conference, Report on Medical Control, Bulletin No. 21, part 1, Washington, U. S. Department of Labor, 1938.

26. Carbon tetrachloride: Carbon tetrachloride (CCl₄) is a volatile solvent with excellent degreasing and cleaning properties. It is used widely in industry as a solvent for oil, grease, fat and organic compounds. It has been marketed commercially as a spot remover ("Carbona") and as a fire-extinguishing fluid, particularly for electrical fires ("Pyrene").

ry)²⁷ have proposed 30 P.P.M. Recent field observations in this country by Elkins²⁸ have shown that concentrations below 100 P.P.M. can cause gastric disturbances,²⁹ so that the German authorities are probably closer to the truth.

A large number of these threshold limits are based on animal experiments and are applied to man on a basis of weight relationship. While it might be argued that a metabolic relationship³⁰ is more desirable for conversion of allowable exposures, it is evident that neither basis can, on the results of animal experiments alone, predict sensory effects on humans. A recent series of experiments³¹ in which the writer took part showed that some of the present threshold limit concentrations for acetates³² and other solvents were quite irritating to the mucous membranes for short exposures. While these solvent concentrations may not produce any pathological change or damage, they may nevertheless form a source of workers' complaints and thus lead to possible legal action. It is wise, therefore, to consider such sensory response in the installation of controlling ventilation or other types of industrial health protection. Since the emergency period has required the introduction of women into many hazardous operations, complaints of sensory irritation have become more frequent. Women are usually more sensitive to gas and solvent exposures than men.

Because industrial hygiene is a fairly new field, new advances are made each day and present accepted standards may be revised downward or upward, depending upon the

27. Lehmann, K. B., and Flury, F., *Toxicology and Hygiene of Industrial Solvents*, Berlin, Julius Springer, 1938, p. 248.
28. Elkins, H.B.: Maximal Allowable Concentrations, I. Carbon Tetrachloride, *J. Indust. Hyg. & Toxicol.* 24, 233, 1942.
29. Gastric disturbances: In this case, the gastric disturbances caused are nausea, vomiting and loss of appetite.
30. Metabolic relationship: A metabolic relationship is one which is based on the relative heat production of animals of varying species as compared to the heat production of man.
31. Nelson, K. W.; Ege, J. F., Jr.; Ross, M.; Woodman, L. E., and Silverman, L.: Sensory Response to Certain Industrial Solvent Vapors, *J. Indust. Hyg. & Toxicol.* 25: 282, 1943.
32. Acetates: Acetates are organic compounds. Those which have the widest use have the following formulas: ethyl ($\text{CH}_3\text{COOC}_2\text{H}_5$), butyl [$\text{CH}_3\text{COO}(\text{CH}_2)_3\text{CH}_3$], and amyl [$\text{CH}_3\text{COO}(\text{CH}_2)_4\text{CH}_3$]. Their principal use is as paint vehicles and solvents. They are also used in cements and adhesives. Acetates are members of an organic chemical group known as esters and they all have a fruity odor. The most familiar of the group is amyl acetate, which is described in the trade as "banana oil."

new findings. It is important, therefore, that the legal profession, in attempting to establish proof or disproof of causation of injury by an air-borne irritant, compare the air analyses with the latest accepted standards. The introduction of new solvents, chemicals, and materials into industry has made it necessary for industrial hygienists to ascertain their toxicity³³ as soon as possible so that adequate control methods can be introduced to safeguard the workers exposed to these substances.

Expression of Threshold Limits

Explanation of the terms used in Table 1 will undoubtedly be of help to those not familiar with the terms and units employed. Unfortunately, American industrial hygienists have units which are mixed. Although a majority of our expressions are based on the metric system, a few English units have become firmly established. Thus most of the chemical terminology has metric units, while the engineering terminology has English units. Gases and vapors are expressed in P.P.M., or parts per million parts of air. Since the amounts in question are so small, it is convenient to use one million as the multiplier rather than one hundred, which would put the results in per cent but the value would still be decimals. One P.P.M. represents one cubic centimeter³⁴ or milliliter³⁵ of the gas in a million cubic centimeters (one cubic meter), or any other equivalent volume ratios multiplied by one million; viz., cubic feet of gas per cubic foot of air times 1,000,000.

Continental literature gives gas and vapor concentrations in milligrams per liter of air. The weight expression is somewhat easier to use technically; however, one unit can easily be converted to the other by any engineer or chemist. Dust and fume concentrations in which particle size is of no hygienic importance are usually given as milligrams per cubic meter or weight per volume of air. Here again, a

-
33. **Toxicity:** Toxicity is a term applied to indicate the potentialities of the substance as a harmful or toxic agent. In establishing toxicity data, it is necessary to find the minimum lethal dose and other important physiological reactions to various concentrations until an innocuous dosage is found.
 34. **Cubic centimeter.** A cubic centimeter is equal to 0.061 cubic inches.
 35. **Milliliter:** A milliliter is equivalent to a cubic centimeter or one thousandth of a liter. A liter is approximately 1.06 quarts.

large air volume is used to avoid small decimals. Dust concentrations in which particle size is very significant, such as siliceous dusts or asbestos dust, are given as millions of particles per cubic foot of air. English practice usually gives this as particles per cubic centimeter. While counts based on any given air volume are easily converted to other air volumes, there is a wide variation in the performance of different types of instruments used, and standards of other countries and newly developed devices may not be used as legal evidence in this country. These differences will be pointed out in detail later.

Radiation hazards are expressed in physicists' radiation units, although some of them such as radon and thoron, are gases. For practical purposes, the curie is considered a unit of volume (one curie occupies 0.7 cubic millimeters at room temperature 70°F. or 21.1° C.) A roentgen is a unit of x-ray emission.

Limits Applicable to Biochemical Analyses

While biochemical analyses are usually used only as a substitute for air analyses, there are some contaminants which have established limits of absorption based on biochemical changes or excretion.

The action of irritants which are systemic poisons,³⁶ such as solvents and rapidly soluble dusts and fumes, may be placed in two basic groups. The exceptions to these groups, of course, are the siliceous dusts and materials which produce local irritation or damage near their portal of entry. The first group includes those materials which are absorbed and remain relatively unchanged and are excreted without change. Examples of this group are metals like lead and mercury. The other group includes those materials which react with other compounds in the body and are oxidized³⁷ or reduced³⁸ and their degradation products³⁹ are excreted. This second

36. Systemic poisons: Systemic poisons are those agents which are carried by the blood circulating system to vital organs or are agents which affect the circulatory or nervous system.

37. Oxidized: When a compound is oxidized it is acted upon by oxygen. Thus, the simple process of iron rusting is due to oxidation or the action of the addition of oxygen atoms to the material.

38. Reduced: When a compound is reduced it loses oxygen atoms in contrast to oxidation where oxygen is added.

39. Degradation products: Degradation products are products or new compounds formed from the reaction of the toxic agent in the body compounds, or they may simply be acted upon by oxygen in the blood system and change their chemical nature.

group may also cause a change in the normal excretion products because of their reaction in the body. Examples of the second group are certain solvents, such as benzene⁴⁰ and carbon disulfide,⁴¹ and explosive materials such as trinitrotoluene.⁴² Some of the materials in the second group may also be excreted in an unchanged state, but in general the amounts are quite small unless the exposure is excessive.

Much of the work in establishing limits on biological excretion is in the evolutionary and developmental stage, but a few outstanding examples are now in common use.

The most important of these in the first group is the close correlation between lead absorption and the amount of lead in the urine and blood. Since there are many opportunities for the normal person to obtain lead in his regular diet, it has been necessary to establish normal values. The mere presence of lead in a urine sample therefore is not significant. Kehoe and his co-workers⁴³ and other authorities⁴⁴ believe that the normal urinary excretion of lead in North Americans averages 0.03 milligrams (mg.) per liter of urine, with values ranging from 0.01 to 0.08 mg. per liter. Normal blood contains an average of 0.03 mgs. of lead per 100 grams of whole blood and the range is from 0.01 to 0.06 mgs. Concentrations over these amounts indicate an abnormal exposure and absorption of lead which may cause pathological conditions. It is now recognized⁴⁴ that lead intoxication will rarely occur if the *mean* urinary lead excretion of a representative group of workers is kept below 0.10 mg. per liter and below 0.15 mgs. per liter for individual results. Blood levels of 0.09 mgs. per 100 grams of blood and higher definitely indicate lead intoxication.

-
40. Benzene: Benzene or benzol is a volatile aromatic hydrocarbon having the formula C_6H_6 . It is an excellent solvent and paint vehicle used in artificial leather manufacture, paints, cleaners, rubber cements, printing inks, and for other purposes.
 41. Carbon Disulfide: Carbon disulfide or carbon bisulfide, CS_2 , is a volatile solvent used in the viscose rayon and rubber industries.
 42. Trinitrotoluene: Trinitrotoluene or T.N.T. has the chemical formula $(NO_2)_3C_6H_2CH_3$. Its greatest use is as an explosive for munitions.
 43. Kehoe, R. A.; Cholak, J., and Story, R. V.: Manganese, Lead, Tin, Aluminum, Copper and Silver in Normal Biological Material, *J. Nutrition* 20: 85, 1940.
 44. American Public Health Association: Lead Poisoning—The Recognition of Hazardous Industrial Lead Exposure, A Report Prepared by the Committee on Lead Poisoning, Industrial Hygiene Section, 1942.

Changes in blood cell morphology⁴⁵ such as stippling⁴⁶ and basophilic aggregation⁴⁷ have also been widely used in establishing proof of lead intoxication. Meek and others⁴⁸ have correlated basophilic aggregation with urinary lead and have found good correlation.

Kehoe, Cholak and Story⁴⁹ have indicated what normal amounts of certain metals may be expected in biological material, but most of these materials are relatively non-toxic with the exceptions of manganese and lead. In the case of mercury, another heavy metal, there is not as complete a record as for lead; however, it can be stated from the recent work of Storlazzi and Elkins⁵⁰ that the value for urinary mercury excretion which correlates with air concentration is expressed by the ratio U/A equal to a constant or 0.26. Ratio U/A represents the ratio of urinary concentrations in milligrams per liter of urine (U) to the air concentration in milligrams per 10 cubic meters (A). Since Table 1 shows that the atmospheric threshold has been established as 0.1 mg. per cubic meter, or 1 mg. per 10 cubic meters, it follows that the biological limit for safe urinary concentrations is about 0.26 milligrams per liter.

One of the most important applications in the second group of contaminants, that is, those which undergo a change and are excreted as degradation products, is the use of the urine sulfate test for benzene (benzol) exposure control. While it is well known in industrial medical work that the aromatic compounds,⁵¹ particularly benzene, are capable of producing anemias and subsequent disability and

-
45. Blood cell morphology: Blood cell morphology refers to blood cell structure or configuration.
 46. Stippling: Stippling is a term applied to the speckling of a blood cell with fine dots.
 47. Basophilic aggregation. Basophiles are a type of blood cell which are normally present in human blood. Basophilic aggregation is understood to mean a clumping of basophilic material into an intracellular form.
 48. Meek, S. F.; Collins, G. R., and Harrold, G. C.: Correlation Coefficient between Basophilic Aggregation Test and Lead in Urine, *J. Indust. Hyg. & Toxicol.* 22: 401, 1940.
 49. Kehoe, R. A.; Cholak, J., and Story, R. V., loc. cit. supra, f.n. 43.
 50. Storlazzi, E. D., and Elkins, H. B.: The Significance of Urinary Mercury, *J. Indust. Hyg. & Toxicol.* 23: 459, 1941.
 51. Aromatic compounds: Aromatic compounds are a group of organic compounds with a particular chemical structure. The common aromatic compounds are benzene, toluene, and xylene. They are all good solvents for paints and other purposes.

death, it is usually too late when the blood changes occur to prevent temporary disability, or even death. However, the recently developed^{52, 53} urine sulfate test will indicate very rapidly that abnormal benzene exposures are present. It has been determined that exposure to benzene causes a rapid and marked decrease in the normal sulfate ratio in urine. The normal ratio of inorganic sulfates to total sulfates varies from 0.85 to 0.90. A ratio less than these values indicates benzene exposure and the degree of exposure is somewhat in proportion to the value of the ratio. It is pointed out by the originators of the test that this test does not *prove* benzene exposure because other factors can greatly affect the sulfate ratio; however, it can be used as supporting evidence if the case history shows an industrial benzene exposure.

Urine sulfate ratios are of considerable value and, in the opinion of Bowditch and Elkins,⁵⁴ will, when properly carried out, give similar results to air analyses. The choice of the method for determining benzene exposure will depend upon the amount of time available and the feasibility of obtaining urine samples.

Since the pioneer work on the urine sulfate test for benzene exposure, research workers have been investigating other possibilities in conjugation of organic compounds⁵⁵ in the mammalian body. The development of a reliable quantitative estimation of the glucuronates⁵⁶ in urine by Deichmann⁵⁷ has led to recent research on this procedure for evaluating exposure to certain organic compounds. It has been known for many years that conjugation of organic compounds with glucuronic acid occurs, but a reliable test for

-
52. Yant, W. P.; Schrenk, H. H.; Sayers, R. R.; Horvath, A. A., and Reinhart, W. H.: Urine Sulfate Determinations as a Measure of Benzene Exposure, *J. Indust. Hyg. & Toxicol.* 18, 69, 1936.
 53. Yant, W. P.; Schrenk, H. H., and Patty, F. A.: A Plant Study of Urine Sulfate Determinations as a Measure of Benzene Exposure, *J. Indust. Hyg. & Toxicol.* 18: 349, 1936.
 54. Bowditch, M., and Elkins, H. B.: Chronic Exposure to Benzene (Benzol). I. The Industrial Aspects, *J. Indust. Hyg. & Toxicol.* 21: 321, 1939.
 55. Conjugation of organic compounds: Conjugation is a fusion or uniting process by which organic compounds are joined with other compounds.
 56. Glucuronates: Glucuronates are organic compounds produced in the body by the action of glucuronic acid which is a normal acid formed during human metabolism.
 57. Deichmann, W.: The Quantitative Estimation of Glucuronates in Urine, *J. Lab. & Clin. Med.* 28, 770, 1943.

their estimation was necessary. Deichmann and Thomas⁵⁸ have made a study of several compounds and found that several of industrial significance cause a marked increase in the excretion of glucuronic acid and organic sulfates.

It is their opinion that the determination of glucuronic acid in urine may constitute a means of detecting absorption and of measuring the severity of industrial exposure. While this work is very recent, it represents the type of tests which are now being developed and which will be offered as evidence of exposure in the near future.

While urine analyses are becoming more widely used, there are some instances of blood analysis as supporting evidence. The blood change accompanying carbon monoxide exposure is well known and established, and if it is found that the analysis of the blood shows over 5% carbon monoxide hemoglobin, it is conclusive evidence that there is exposure to a carbon monoxide hazard. The concentration of carbon monoxide in blood is directly related to air concentration and in the absence of air samples the exposed individual is an excellent sampling unit. Changes in blood cell morphology always occur in heavy or high exposures to irritants of a systemic nature, but this phase of blood analysis is not used to any extent as a control procedure.⁵⁹ In most cases, significant changes in cell morphology are accompanied by other symptoms. Stippled cell counts and basophilic aggregation tests have been used for lead absorption tests, but urine analyses are more reliable procedures.

One other important biological method is the sampling of expired air. If possible, this type of sampling is preferable to other biological procedures because it does not involve any inconvenience to the worker. Since many materials do not react in the body, they are eliminated by the same pathway as they are absorbed. A sample of expired air while the worker is exposed to the hazard will therefore yield his equilibrium condition with the exposure. A sample of expired air taken after the individual has been removed from a known exposure will indicate his rate of desaturation.

58. Deichmann, W., and Thomas, G.: Glucuronic Acid in the Urine as a Measure of the Absorption of Certain Organic Compounds, *J. Indust. Hyg. & Toxicol.* 25: 286, 1943.

59. Control procedure: A control procedure is an analytical method which is applied to routine checking of workers to determine if any abnormal changes occur due to their environment.

As yet, this type of sampling has not had any appreciable use in industrial practice, with one notable exception—radium. The use of radioactive materials in industry due to new methods and war requirements has made rigid control measures necessary, since these materials are very toxic. These substances are well adapted to expired air analyses since very sensitive detection instruments have been devised, and because it takes several hours for the radium or thorium inhaled in the workroom to become dissipated. It is stated in the Bureau of Standards Handbook on "Safe Handling of Radioactive Luminous Compounds",⁶⁰ that "*No one shall be engaged as a dial painter who shows more than 0.1 microgram of deposited radium, as revealed by the expired air test. This corresponds to 1 micro-micro-curie of radon per liter of expired air. If, after employment, any operator shows a radon content of the exhaled air of this amount, a complete investigation shall be made at once to determine the cause.*"

One of the chief reasons why expired air analysis has not yet been widely used for other substances for which it would be applicable is the lack of sensitive enough analytical methods and also inadequate data on rates of saturation and desaturation.

In summarizing the information on biological limits and their application, it can be stated that the tests now in common use are those for lead, benzol, carbon monoxide and radon. Other procedures are under investigation and may receive wide use and acceptance in the future.

Plant Investigations

In performing an investigation of a specific industrial plant, it is important that the investigator familiarize himself with the type of operations performed and the materials used. As a rough guide to the hazard involved, Dublin and Vane⁶¹ may be consulted, but the experienced investigator will note all usual and unusual exposures and evaluate unknown materials from the toxicological literature available. In ascertaining the hazards, toxicology and health aspects of airborne materials, the important references of industrial medicine should be consulted. The Massachusetts Division of Oc-

60. Loc. cit. supra, f.n. 23, p. 6.

61. Dublin, L. I., and Vane, R. J.: *Occupation Hazards and Diagnostic Signs*, Division of Labor Standards Bulletin No. 41, Washington, U. S. Department of Labor, 1941.

cupational Hygiene has published a list of its important reference volumes⁶² and it is the writer's opinion that this list leaves little to be desired by the industrial hygiene analyst. In addition to these, the recent books by Johnstone,⁶³ Sappington,⁶⁴ Wampler,⁶⁵ and Gafafer⁶⁶ are of value.

The purpose of this section is to describe the salient points to be noted in the individual plant under consideration for a specific legal case. The subject of general surveys and plant investigation for public health purposes and industrial hygiene control is adequately described by Bloomfield^{67,68}.

In making his first survey of the individual plant in question, the industrial hygiene analyst usually is able to observe whether or not a specific hazard is present and whether prompt action is necessary to prevent immediate injury. The analyst will use his ordinary senses in this preliminary survey, in particular, the olfactory sense for gases and vapors, the visual sense for dust concentrations. The experienced investigator can estimate quite closely the order of magnitude of solvent and dust exposures by these simple means. Such evidence, while not suitable for legal purposes, will aid the analyst in selection of his sampling locations and general appraisal of the plant hygiene. Other significant points that the analyst will note on his preliminary survey are: the amount of "housekeeping" performed in the plant, how well the control devices such as local exhaust ventilation hoods and ducts are maintained, and whether or not the personal protective devices such as respirators are properly supplied, maintained, and used by the workers. The maintenance of good or bad "housekeeping" in a specific plant

-
62. Division of Occupational Hygiene, Commonwealth of Massachusetts. Reference Library—Important Reference Volumes. Publication No. 261, Boston, May, 1942.
 63. Johnstone, R. T.: *Occupational Diseases*, Philadelphia, W. B. Saunders Company, 1941.
 64. Sappington, C. O.: *Essentials of Industrial Health*, Philadelphia, J. B. Lippincott Company, 1943.
 65. Wampler, F. J.: *Industrial Medicine*, Baltimore, Williams & Wilkins Company, 1943.
 66. Gafafer, W. M., loc. cit. supra, f.n. 12.
 67. Bloomfield, J. J.: Preliminary Surveys of the Industrial Environment, *Public Health Report* 48: 44, (November 3, 1933).
 68. Bloomfield, J. J.: *Methods Employed in the Appraisal and Control of Industrial Health Hazards*. *The Medical Clinics of North America*, Philadelphia, W. B. Saunders Company, July, 1942, pp. 1161-1178. See also same article reproduced in Wampler, F. J., loc. cit. supra, f.n. 65.

is an important fact in establishing management's efforts to keep conditions under control.

If the investigator should make an unannounced visit to the plant in question and find the plant clean and orderly and management applying all known safety and health protective measures, it is evident that reasonable care has been used to prevent occupational disease. An announced visit, on the other hand, may show that the plant has been purposely cleaned. Such details as unswept rafters or recently cleaned rafters may easily show that an attempt has recently been made to improve conditions for the investigator's benefit. These facts are pointed out because it is important that the air samples submitted for evidence be taken under conditions similar to the worker's usual exposure, if samples taken during the course of his employment are not available. It has been shown by Hatch, Williams and Dolin⁶⁹ that "good housekeeping" procedures such as wetting down, spraying, and other control measures correlate well with air concentrations of dust in foundries.

Another important point the first inspection may show is that the plant is using materials which they believe to be innocuous merely because their composition is unknown to their users. Proper labeling of dangerous solvents and materials is now required by law in some states, but many concerns still use materials which they know only by their trade names. The investigator normally takes samples of unknown solvents and other materials, and, if the composition is unprocurable from the manufacturer, he will perform an analysis in the laboratory. Many manufacturers are hesitant to disclose compositions because they consider their products as trade secrets. An explanation of the use that will be made of the composition and a statement that their confidence will not be violated will usually bring cooperation.

The second, or analytical survey, involves the taking of air samples and other data which correspond to the workers' environmental exposure. These samples, of course, may be taken along with the preliminary survey if rapid analytical procedures are available, or if only a small operation is under study. The second survey is quite often made an integral

69. Hatch, T.; Williams, C. E., and Dolin, B. G.: Dust Concentrations in Foundries, Industrial Bulletin, New York State Department of Labor 18: 89, 1939.

part of the original survey if circumstances will permit samples to be taken at the same time.

*Sampling Methods and Procedures Employed in
Industrial Air Analysis*

Sampling Methods

In describing sampling methods and procedures it is not intended that analytical methods and apparatus shall be described in detail, but rather to outline the broad principles involved in air sampling and other types of sampling related to air-borne contamination. For a brief survey of routine sampling techniques, the reader should consult the recent Air Hygiene Foundation Bulletin⁷⁰ on routine sampling. More elaborate descriptions of sampling procedures and analytical methods, and methods for less common hazards are given in Jacobs,⁷¹ Zhitkova,⁷² and Ficklen.⁷³

Industrial air samples may be divided into two principal groups based upon the time element involved in sample collection. Air samples may be taken instantaneously or over a period of time ranging from one minute to several hours. Instantaneous samples are sometimes denoted by other descriptive names such as "grab samples", "spot samples", or "snap samples". Samples taken over a definite and measured period of time are designated as "continuous" or "integrated" samples.

Each of these types of samples has definite advantages and limitations. An instantaneous sample has the advantage of indicating the concentration of dust, gases or fumes at a precise moment and thus may prove very valuable in identifying a specific source of contamination. A series of samples of this type when taken over a known period will show whether or not the operation produces cyclic variations in concentration, is a steady or an increasing source of con-

70. Air Hygiene Foundation of America, Inc. (now Industrial Hygiene Foundation): Routine Sampling for Control of Atmospheric Impurities, Preventive Engineering Series, Bulletin No. 2, Part 8, Pittsburgh, 1939.
71. Jacobs, M. B.: The Analytical Chemistry of Industrial Poisons, Hazards and Solvents, New York, Interscience Publishers, Inc., 1941.
72. Zhitkova, A. S.; Kaplun, S. I., and Ficklen, J. B.: Some Methods for the Detection and Estimation of Poisonous Gases and Vapors in the Air, West Hartford, Conn., Service to Industry, 1936.
73. Ficklen, J. B.: Manual of Industrial Health Hazards, West Hartford, Conn., Service to Industry, 1940.

tamination. Further, the results of this series of samples, when averaged, will yield approximately the same results as a continuous sample taken over the same period and in the same location. Instantaneous samples are usually taken by means of a previously evacuated flask or bottle which can be opened to the atmosphere in an instant. They may also be taken by a hand or spring operated pump or rubber bulb which can draw in a sample as fast as the operator is able to manipulate the device. One of the disadvantages of instantaneous samples is that in order to evaluate the workers' daily exposure, a series of samples are necessary, which usually requires that a large amount of sampling apparatus and equipment be taken into the plant. Another limitation to this type of sampling is that the instantaneous sample can only be taken when the concentration to be analyzed is within the sensitivity of the analytical method; in other words, to make them practical for field use, instantaneous samples are usually limited to air samples not greater than one liter. The analytical procedure employed therefore must be sensitive enough to determine accurately the amount of contaminant in this size of sample for a concentration at least equal to the hygienic threshold limit of the substance being analyzed.

Continuous samples represent more nearly the type of exposure to which the worker is subjected. At one time, the belief was prevalent that air sampling instruments should sample at rates equivalent to human respiration volumes, but for obvious reasons this type of thought has fallen into discard. The only important factor in continuous samples is the time relationship. These samples are taken at a constant rate and at a known sampling efficiency of the sampling instrument for a definite period of time. With this information, the volume of air sampled is easily obtained and the trapped sample of the contaminant is removed to the laboratory and analyzed. Continuous samples can also be taken for longer periods, if necessary, in order to compensate for the sensitivity of the analytical method. *Their most important advantage is their correlation with the average exposure of the worker.* The chief limitations of the continuous sample are that it does not indicate peak or sudden concentrations, and that it requires more elaborate sampling equipment and attention during sampling than the instantaneous sample.

The equipment for taking instantaneous or continuous samples varies widely and depends upon the type of contamination to be analyzed. Except for instantaneous samples where the contaminated air is drawn into an evacuated flask or chamber, all of the sampling procedures depend upon some physical method of collection such as absorption, precipitation, condensation, or other physical principles which are involved in the separation of the contaminant from the sampled air stream or air volume. The type of instantaneous sample described above is usually taken back to the laboratory before any of the above physical principles are applied in its analysis, but the same methods are used in the ultimate analysis in each case, only the time of application of the method varying between instantaneous and continuous samples.

Dusts are usually sampled by continuous methods for chemical analysis, but insoluble dusts in which particle size is the important factor may be taken by continuous or instantaneous methods. Application of continuous methods to sampling soluble dusts is necessary to obtain enough sample for chemical analysis. The counting of dust samples requires much less material, since the normal air contains several thousand particles per cubic foot; however, it requires several million particles of respirable size to give enough weight for sample for analytical methods. Dusts are commonly sampled by the impinger technique,⁷⁴ which consists of drawing the dusty air through a small flask with a nozzle projecting into a volume of water or absorbing liquid. The velocity of the air causes the particles to be separated and trapped by the confined liquid in the flask. The liquid is subsequently removed for analysis and the dust caught in it is counted microscopically or analyzed chemically. The instantaneous dust sampling instruments impinge the dust laden air against a moistened or oiled glass surface to which the dust particles stick upon contact. The glass surface is then removed for microscopic counting. Other dust sampling instruments use thermal or electrostatic properties of the dust particles for their separation or the dust is filtered from the sampled air stream.

74. Brown, C. E., and Schrenk, H. H.: A Technique for Use of the Impinger Method, Information Circular 7026, Washington, U.S. Bureau of Mines, 1938.

Because all of the dust sampling instruments devised have different sampling velocities, or collection principles and microscopic techniques, it has been found difficult to correlate the results obtained with each instrument except when a given operation has been examined by simultaneous samples on each kind of instrument. Since there is such a wide variety of dust-producing operations, which means an extremely large number of correlations would be necessary, American investigators have largely adopted as a standard procedure one of the early methods, the impinger with lightfield microscopic counting.⁷⁵ There have been a few minor modifications and simplifications of this method, but none of these changes has basically affected the sampling instrument's performance, and, in general, they are improvements to make the technique less tedious and laborious.

Fumes, because of their smaller size, are either caught by electrostatic methods or by filtration. Gases and vapors are absorbed by bubbling them through liquids with which they react or are soluble. Gases and vapors which are very reactive or very soluble can be sampled at fast rates and in simple absorbers. Gases and vapors which are relatively insoluble require slower rates and more elaborate absorption equipment. In some cases, the gases or vapors may be heated to high temperatures and decomposed before absorption, or they may be condensed out of the air by very low temperature absorbers. Mists are usually absorbed like gases, whereas smokes are handled in the same manner as fumes.

In taking air samples it is important for the investigator to note carefully all unusual conditions at the time of the sample and to make certain that the sampling conditions represent normal plant operation. Summer sampling on an operation may yield lower concentrations than winter sampling because windows are opened or because of variations in atmospheric conditions such as wind, dust and rain. It is also very important that the workers be kept at their usual tasks. There is, of course, a psychosocial factor to contend with in the workmen's curiosity as to why samples are being taken and the fact that they feel disturbed while

75. Lightfield microscopic counting: Lightfield microscopic counting is the enumeration of the dust particles in a given microscopic field while the dust sample is suspended in water in a thin glass counting chamber and illumination is passed through the glass cell. The particles then appear as black specks in a white field.

they are being taken. A simple explanation is usually best, although occasionally some workers are inclined purposely to make things appear better or worse than they actually are by doing the operations abnormally. Fortunately the latter type of individual is rare.

Procedures

Analytical procedures for the analysis of air samples may also be placed into two distinct groups. These are, physical procedures and chemical methods. In the first group, we include methods of analysis which depend upon some physical property of the contaminant such as its light-obscuring power or its heat of combustion. Many physical properties have been applied to atmospheric contaminant analysis. The chief advantage of physical methods is that in most cases they are direct-reading, that is, they give the concentration of the air-borne material directly while the material is being sampled. Such instruments enable the investigator to know the magnitude of the contamination while the plant is being examined and thus to advise the plant operators immediately if the operation is very dangerous, or if the contamination is high enough to require immediate action. The present trend in industrial air analysis is toward the use of physical instruments whenever they are applicable. The only disadvantage to this type of instrument is its calibration. These instruments depend upon a known physical relationship, or are calibrated⁷⁶ against prepared mixtures which are checked dynamically or chemically. Since there is always a danger of the calibration's being affected by extended use or handling damage, it is necessary to check the calibrations at frequent intervals. Physical instruments employ either instantaneous or continuous sampling. The most commonly used physical instrument is the carbon monoxide indicator, which is employed quite widely in vehicular tunnel control work and in many other industrial applications.

Radiation hazards are determined, as might be expected, by elaborate physical instruments. Air samples of radioactive radon and thoron are taken by evacuated flasks and shipped to a central analyzing laboratory where an accurate device can determine their radio-activity. Most portable radio-

76. Calibrated: By calibration we mean a standardization procedure applied to the instrument in order to obtain a definite value for each increment of the instrument's response.

activity detection instruments are only useful for exploratory work as they are not sensitive enough for smaller amounts. The measurement of exposure to x-rays and other harmful radiation is now made by portable electrometers resembling fountain pens which are worn by the worker while he is exposed and are then removed at the end of the day for analysis. The latter instrument, known as the "Minometer",⁷⁷ is far superior to the old method of letting the operator carry a piece of unexposed film in his clothing.

Chemical methods applied to air analysis are simply quantitative chemical analyses applied to the collected samples. In most cases, the amounts being analyzed are quite small so that microchemical procedures are employed to give greater precision and accuracy.

Biological material for analysis is collected in several ways. The most common types of samples are those for urine and expired air. Blood samples are not taken except by medically trained personnel and then by sterile finger tip puncture or syringe methods. Urine samples may be collected as "spot" samples and their content per liter based on the volume obtained for analysis. Eight and twenty-four hour samples, however, are more often used, and in some cases even larger samples may be collected. Analysis has shown that morning urine samples give the best results. Expired air samples are taken by having the individual breathe through a one liter or smaller volume flask several times and then sealing the flask off for later analysis. Evans⁷⁸ in a recent paper fully describes this technique for breath radon samples, and he emphasizes the precautions necessary for reliable results.

Standard Procedures for Air Analysis

At present it may be stated that only a few procedures have been "standardized" or recommended as approved procedures, although the number is increasing rapidly. Some of the standards for threshold limits stated in Table 1, particularly those of the American Standards Association,⁷⁹ give

77. Victoreen Minometer manufactured by the Victoreen Instrument Company, Cleveland, Ohio.

78. Evans, R. B.: Protection of Radium Dial Workers and Radiologists from Injury by Radium, *J. Indust. Hyg. & Toxicol.* 25: 253. 1943.

79. American Standards Association Standards, loc. cit. supra, f.n. 13, 15, 16, 17, 18, 20, 21, and 22.

recommended or approved references in which analytical procedures and methods are described. Several committees of the American Public Health Association Industrial Hygiene Section publish yearly reports⁸⁰ on acceptable procedures for dust and chemical analysis and ventilation. Several commercial instruments have had wide use and careful scientific development, and have been, by their continued use, accepted as implied standard methods. The most widely used standard method is the impinger for siliceous and other dust sampling. Since this was one of the early methods developed in this country for dust sampling, it has been used in numerous dust surveys and field studies. The concentrations of atmospheric dust determined by this instrument have thus been correlated with roentgenological studies of silicosis and other dust diseases and also used as legal evidence so that it has become an actual standard. In addition to this, the method is recommended by certain state codes, for example, the New York Code⁸¹ for the Control of Silica Dust in Stone Crushing Operations states under "Section 34—1.6, Determination of Atmospheric Dust Concentration":

"Notless than three (3) dust samples, of at least ten (10) minutes duration, spaced at intervals to yield a fair average measurement of exposure over the entire cycle of operations, shall be collected in the normal breathing zone on the premises by a standard type impinger, or other equivalent sampling instrument. The atmospheric dust concentration shall be deemed to be the average concentration as determined from the samples by the use of the lightfield, low power technic count or its equivalent.

Where, because of the nature of operations, it is not practical to secure samples of ten (10) minutes duration, the use of any other method providing equivalent representative samples shall be permitted."

Codes of this type also specify sampling procedures for determination of the free silica content of the rock or stone used. Equivalent procedures refer to other methods which have been correlated with silicosis. In England, Canada,

80. See for example American Public Health Association Yearbook 1939-1940, 1940-1941, or 1941-1942, Ventilation and Atmospheric Pollution, Industrial Hygiene Section.

81. Industrial Code Rule No. 34 (Effective July 1, 1942), Rules Relating to the Control of Silica Dust in Stone Crushing Operations, State of New York Department of Labor Board of Standards and Appeals, New York, 1942.

Australia and South Africa, for example, an apparatus known as the thermal precipitator has been used for several years and has been correlated with the incidence of dust disease in collieries and other dusty industries. Results based on this instrument might be accepted in this country, using the British information, if the American instrument were not available. Other types of instruments have been used in this country and, if sufficient information is available, the results may be presented as legal evidence. To avoid complications, however, it is practical to use evidence based upon the most widely used instrument.

Standard Preventive Controls

Methods Employed for Prevention of Hazardous Air Contamination

In the prevention of occupational disease due to air-borne irritants, there are several recommended procedures for control and maintenance of healthful working conditions. These procedures depend upon the nature of the hazardous operation, the type of material handled, the frequency of exposure, and economic factors.

In establishing legal proof or disproof of adequate control measures to prevent occupational disease, it is necessary that evidence should be presented as to whether the procedure or process meets what is established as the best modern practice. The following section outlines what are now considered as approved measures or methods of control. In order of their recommended application these control procedures are as follows:

(1) Substitution of a Non-toxic Material for the Toxic Substance. This is a procedure which is always recommended if it is believed that a substitution is possible. The use of non-toxic or relatively non-toxic solvents for benzol has been tried successfully in operations such as artificial leather manufacture. Another example is the use of artificial abrasives instead of sand in abrasive cleaning operations. A recent example of substitution which has been stimulated by the health risk involved is the development of a non-mercurial carrot⁸² for the felt hatting industry. In this case, a group

82. Beal, G. D.; McGregor, R. R., and Harvey, A.W.: Elimination of Mercury Hazard in the Felt Hat Industry, *Chem. & Eng. News* 19: 1239, 1941.

of hatters fur cutters established a Fur Fellowship at the Mellon Institute for the purpose of developing a non-mercurial substitute for their needs. There are many cases, however, when it is impractical to change the material or the process because others will not work, or because the changes would result in inferior products.

(2) Mechanization, Enclosure, or Isolation of an Operation. The operation may be mechanized through the hazardous exposure operations such as plating, dipping and drying so that the workers are not exposed to the contamination. The chief drawbacks to this method are that it may not be economically feasible to mechanize the process, or that the product may require constant attention. Enclosure is employed wherever possible. This procedure requires that the process be partially or completely closed so that the escape of the contaminant is prevented. However, if some processes are completely enclosed, the result may be an explosion or fire hazard of greater magnitude than the health hazard. The wide use of x-rays in industry for examination of castings and other products has made it necessary to install protective enclosures using lead or concrete barriers to protect the workers from direct or stray radiation.

(3) Wet Methods and Addition Procedures. Wet methods are widely used for dusty operations since it has been shown that dust produced in the handling, grinding, and drilling of dust-producing materials can be effectively controlled if these operations are conducted under constant wetting. In the rock drilling industries such as mining and quarrying,⁸³ we have wet drills which are drills provided with a central hole through the drill through which water is continually pumped. Wet drilling is effective in all cases except those where the operator must drill over head. In this case, the water is not confined to the drill hole and the driller is exposed to the escaping water spray. The use of sprays and nozzles is also quite effective in wetting down dust from shovelling, mucking, pulverizing, or grinding operations. The chief disadvantages to wet operations are that in many cases they can only be applied seasonally because of climatic conditions, and also that, in some operations, it is not feasible

83. Owings, C. W.: *Methods of Allaying Dust in Underground Mining Operations*, Report of Investigation 3631, Washington, U. S. Bureau of Mines, 1942.

to wet the product. Bagging operations are a good example of the latter case.

Addition operations have not been used to any extent in this country except for the Randall⁸⁴ process which was recently developed for controlling mercury hazards in mining operations. This method consists of adding chemicals to the sprays which, when sprayed on exposed mercury surfaces, prevent them from evaporating and causing contamination. Russian investigators have reported two methods using addition agents. In one method, paraffin oil is added to plating baths and floats on the surface to prevent the escape of plating mists; however, technical difficulties in keeping the parts to be plated clean limit this application. The other method is the addition of chemicals to rayon spinning baths which combine with the generated gases and prevent their escape into the workroom.

(4) Ventilation of the Plant or Process. Ventilation is by far the most widely used method for atmospheric contamination control. We usually consider industrial ventilation to be of two types: general ventilation, in which the whole plant or workroom is ventilated and the concentration of the contaminant is *diluted* below the safe limit, and local exhaust ventilation, in which separate operations or processes are enclosed as much as possible and ventilated by exhaust hoods connected to an independent exhaust system. Local exhaust is the most widely used type of ventilation because it is most efficient and economical. Most plants are provided with general ventilation to produce comfortable working conditions of temperature, humidity, and air movement. It is in most cases too expensive to increase the capacity of these systems to dilute the contamination due to processes because of the large air volumes necessary. Local exhaust is effective because it controls the contaminants at their source. Local exhaust may be applied to almost every type of operation and small exhaust hoods have even been used for individual rock drills in winter quarrying.

(5) Personal Protective Devices. This type of device is an individual piece of equipment which is worn by the worker to supply or purify his respired air—consequently, they

84. Randall, M., and Humphrey, H. B.: New Process of Controlling Mercury Vapor. Information Circular 7206, Washington, U. S. Bureau of Mines, 1942.

are termed respirators. There are, however, some respiratory protective devices which are helmets or hoods worn over the worker's head. Respirator usually refers to the mask type of apparatus. Respirators are used whenever unknown hazards are to be encountered, as in entering manholes and tank cars, or when exposures to high concentrations are unavoidable or infrequent. There are several kinds of respirators, although they may be considered as of two basic types. The supplied-air type furnishes the wearer air or oxygen from an outside source or a portable supply. The filter, or purifier type, filters and cleans the ambient air so that it is respirable. Despite manufacturers' claims, they are not liked by workmen in general because they feel that their breathing is restricted. When their use is necessary, they will be worn if the workers are given proper instruction. For adequate protection, these devices should be serviced and maintained frequently. Their use should be recommended only when other protective methods are impracticable or the cost of installing ventilation for the operation makes the use of the process economically unsound.

(6) Shifting and Rotation of Workers. This type of occupational disease control should only be used when other methods have no application. In using this procedure, medical control and frequent air analysis are absolutely necessary. Of course, the shifting of a susceptible individual from an irritating exposure is recommended, regardless of the control methods installed. Workers who have acquired incurable occupational disease which are not completely disabling can be prevented from further injury by shifting them to non-hazardous exposures, even though control measures have been installed since the acquisition of the disease.

The measurement of the effectiveness of control procedures other than personal protective measures is carried out by the use of air analyses as described above and by investigation of the ventilation by means of air flow measuring instruments. The latter measurements are conducted by a ventilation engineer or industrial hygienist.

Many large organizations which do routine sampling have found it profitable to keep graphical records of air concentrations. These records show seasonal variations and the effectiveness of the control systems which have been installed. They also give positive evidence of management's

efforts to preserve its employees health. In some cases, automatic and continuous sampling devices and recorders have been installed for this purpose.

Standard Control Procedures

Standard procedures for control of occupational disease are the result of sound engineering principles and effective empirical data. Most of the methods described above may be considered as standard if the situation requires their specific use. The American Standards Association, in two publications^{85,86}, has tried to formulate certain minimum requirements and procedures for design and installation of ventilation and sanitation equipment. These codes recommend certain minimum controlling air velocities and air quantities for capturing and removing air-borne contaminants. While this information is not complete and is constantly being revised, there is enough data in existence to enable a competent engineer to install an adequate local or general ventilation system which will prevent occupational disease from air-borne contaminants. Undoubtedly other standards of this type will appear in the future.

For personal protective devices, a standard safety code has been published by the Bureau of Standards.⁸⁷ Lists of approved respiratory protective devices are published yearly by the Health and Safety Division of the U.S. Bureau of Mines. This agency has a testing laboratory for these devices in Pittsburgh. It is recommended procedure when hazardous exposures are encountered, to use an approved type of respirator for prevention of injury. Manufacturers of protective equipment are always willing to increase their sales and consequently always submit their products for approval.

The question of air-borne bacterial contamination has not been discussed in this article because it has not yet reached a stage of development comparable with that of the

-
85. American Engineering and Industrial Standards, Fundamentals Relating to the Design and Operation of Exhaust Systems, Z 9, Preliminary Ed., New York, American Standards Association, 1936.
 86. American Standards for Grinding, Polishing and Buffing Equipment Sanitation Z 43—1941, New York, American Standards Association. Approved August 14, 1941.
 87. American Standard Safety Code for the Protection of Heads, Eyes, and Respiratory Organs, National Bureau of Standards Handbook H24, Washington, U. S. Department of Commerce, 1938.

investigation of other air-borne contaminants. There are, of course, some specific industrial bacterial exposures such as anthrax in the tanning and hide industries. This type of contamination in general has been due to contact rather than air-borne modes of entry. We do have, however, several procedures for examination of air for bacterial pollution and the use of ultra-violet light rays for its control has been quite effective. Perhaps in the future it may be necessary to present data on air-borne bacterial contamination as legal evidence.