

New York State Department of Labor

MONTHLY REVIEW

Division of Industrial Hygiene & Safety Standards

Vol. 28

February, 1949

No. 2

PLAINTIFF'S
EXHIBIT
WCD-115

THE SIGNIFICANCE OF MAXIMUM ALLOWABLE CONCENTRATIONS

by
JOHN E. SILSON, M.D.
Medical Unit

The field of industrial hygiene is concerned, among other things, with the protection of the health of the worker in industry by the elimination of toxic substances from the working atmosphere. Its progress to a highly specialized science has been paced by the development of accurate laboratory methods for the evaluation of air contamination. With the ability to determine these exposures has come the need for standards for interpreting them. This has led to the establishment of tables of maximum allowable concentrations, which are the highest concentrations of substances in the air which will not injure the average individual during a full working day.

BASIC CONSIDERATIONS

These values are usually given in one of three forms: 1) gaseous proportion, 2) weight, and 3) number of particles. Substances which are dispersed in air in true molecular form as *gases* or *vapors*, like chlorine or benzol, are expressed in parts per million, calculated as a gas. On the other hand, *dusts*, *fumes* and *mists*, as for instance lead or chromic acid, consist of particles of varying size and random distribution, and cannot be expressed in these terms. Most of these concentrations are therefore expressed as milligrams per cubic meter of air. Occasionally, the value is given as milligrams per ten cubic meters of air, which is considered the average volume inspired by a worker in an eight-hour working day, and is therefore supposed to give some idea of his actual intake of the toxic substance. A special category has been created for the *mineral dusts*, such as silica, asbestos and talc, which cause proliferative changes in the lungs. Since the important factor in these cases appears to be the number of particles inhaled, they are reported as million particles per cubic foot of air, together with the concentration of offending agent in the mineral.

The promulgation of tables of maximum allowable concentrations, or MACs as they are generally referred to, has been a comparatively recent development. Until about twenty years ago, very few field determinations of air contaminants were being made, other than dust counts. About this time, industrial hygienists began to collect data on injurious indus-

trial exposures and to correlate it with the toxic effects of various gases, vapors, fumes, mists and dusts, determined largely by animal experimentation, and based in most instances on lethal dosage. This material was then organized into tables of maximum allowable concentrations by several State agencies concerned with protecting the health of their workers. The establishment of these criteria created a need for further analytical techniques, and portable equipment for analyzing or sampling air in the field. As these problems were solved one by one, data on exposures under actual working conditions began to be amassed, and more experimental research was undertaken, so that today there has been accumulated considerable material on which the present tables are based.

In order to discuss the means of arriving at a maximum allowable concentration, and its applications and limitations, it is necessary to review the considerations which enter into establishing such a criterion. One is the mode of action on the body. Some substances, such as lead or carbon tetrachloride, are systemic poisons, which are taken up by the blood stream and carried to all the tissues, giving rise to toxic symptoms in many parts of the body. Others, like silica dust, remain in the respiratory tract and exert their primary injurious effect there. Still others, for example ammonia, exhibit mainly a severe irritant reaction on the respiratory tract, which tends to clear up after the individual leaves the environment. Then there is a large group, including many solvents such as the acetates and ketones, which evoke an unpleasant sensory response or a mild irritation to the mucous membranes, but must be considered more obnoxious than toxic.

Another consideration is the tendency of the toxic substance to accumulate in the body. This is determined by the manner of elimination of the substance, and is usually in inverse proportion to the rate of excretion. Some substances, *systemic* poisons like lead or *local* poisons like silica, are cumulative in the tissues, and may only evidence a toxic effect after months or years of exposure. Others, such as carbon monoxide or carbon tetrachloride, exert their toxic effect only during and shortly after exposure. This does not mean, however, that the toxic effect itself is not cumulative, as repeated small insults to an organ may eventually result in considerable disability.

* Presented at the 18th Annual Safety Convention of the Greater New York Safety Council, April 16th, 1948.

PLAINTIFF'S
EXHIBIT

100 No. 5113

VORWALD
BOX 51-7

MONTHLY REVIEW
of the
DIVISION OF INDUSTRIAL HYGIENE
AND SAFETY STANDARDS
NEW YORK STATE
DEPARTMENT OF LABOR
80 CENTRE STREET
NEW YORK 13, N. Y.

Industrial Commissioner
EDWARD CORSI

1st Deputy Industrial Commissioner
THOMAS F. MOORE, JR.

Deputy Industrial Commissioner in Charge
EDWARD A. NYEGAARD

Deputy Industrial Commissioners
ABRAHAM H. GOODMAN
LOIS B. HUNTER

The Division

LEONARD GREENBURG, M.D., Director
MAY R. MAYERS, M.D., Medical Unit
WILLIAM J. BURKE, Chemical Unit
GEORGE P. KEOGH, Code Unit
ARTHUR C. STERN, Engineering Unit

Industrial Hygiene

LEONARD A. PERRIN, Engineering Unit

Building Plans

SOURCES OF DATA

With these considerations in mind, therefore, let us see how the MAC values have been established. The first basis in most instances has been animal experimentation. When a substance is suspected of being toxic, tests are made on a variety of animals by as many routes as is practical: inhalation, feeding, patch testing on the skin and eyelids, and injection under the skin, into the muscles, the veins, the abdominal cavity, the trachea and any other parts of the body that might be indicated. By varying the dosage widely, it is possible to determine, not only how much of the substance is necessary to kill the animals, but also how much causes minimal symptoms and what parts of the body are most sensitive to it. From this are determined the toxic range within which the substance appears to fall, and what signs of poisoning to look for in individuals exposed to it.

There are, however, several limitations inherent in this method. First, the reaction of any one type of animal to a toxic substance is no proof that a human being or any other animal will react similarly. The use of a variety of animals sometimes mitigates this factor to some extent, but frequently the range of response of the various species, not only quantitatively, but even qualitatively, renders the problem even more complex.

A second limitation is the difficulty of fully evaluating the cumulative effects of a toxic compound. For one thing, the life span of most experimental animals is much shorter than that of humans, so that it is impossible to demonstrate the effects which only appear after years of exposure. Even when the exposure can be compressed within their life time, the difficulties of conducting such long drawn out experiments are almost insuperable, particularly in inhalation studies. This, of course, is not a problem where the toxin is known to be non-cumulative.

The other basis for establishing a maximum allowable concentration is by data obtained from observations on humans. Although a few experiments on

laboratory exposure of individuals to toxic substances have been performed, by far the greatest part of this data has been collected by observations in the field. When one or more workers become ill from an exposure which can be determined, an upper limit is established, and a tentative MAC can be set sufficiently below that limit to allow an adequate margin of safety. When a group of workers have been shown to tolerate a determined exposure for an adequate length of time with no toxic signs or symptoms, this can be assumed as a safe exposure. Further information is sometimes obtained by surveying a group of workers for medical evidence of poisoning while simultaneously studying the air contamination. As more data accumulates, the standard can be set more accurately, but it is easy to see that a great many determinations are necessary before any statistical accuracy is possible.

There are many limitations to this technique also. Except for the field surveys just mentioned, exposures are practically never determined at the time the workers become ill, and have to be measured and evaluated after the fact. All the potential errors inherent in determining the concentrations to which the workers are actually exposed, which will be discussed in detail later, affect the validity of any observation. Furthermore, in borderline over-exposures, it is often difficult to differentiate symptoms due to industrial poisoning from those of non-industrial diseases to which any worker might succumb. Then the range of individual idiosyncrasy must be considered. On the one hand, a few individuals will always prove so susceptible to certain toxic substances that it is often unfair to use their reactions as a criterion for an upper limit, and it may be necessary to exclude them from an industry in which they are exposed to substances to which they are hypersensitive. In addition, some workers may be oversusceptible because of disease or personal habits: the ultrasensitivity of chronic alcoholics and people with liver disease to carbon tetrachloride is a good example. On the other hand, it has been found that natural selection tends to eliminate from certain industries all but those who are relatively insensitive to the poisonous substances handled. To use the toxic thresholds of these workers, therefore, as a basis for establishing a safe exposure creates the danger of setting the MAC too high and endangering the worker of average susceptibility entering the occupation. Finally, the disease picture in acute poisoning is often very different from that in the chronic; so that the absence of acute symptoms in a group of workers is no indication that they are not exposed to concentrations of a toxic substance which will cause chronic poisoning in a period of time. As an example, the failure of a worker exposed to benzol vapors to demonstrate acute symptoms severe enough to require medical attention is no guarantee that he may not develop an aplastic anemia several years later.

In the case of those substances characterized by their irritating qualities rather than by specific toxic effects, the establishment of MACs is attended by still further difficulties. The original MAC tables were promulgated on toxic effects, and their extension to the relatively non-toxic solvent vapors has brought in the new concept of considering the discomfort of the workers as well. The result has been that in some cases, the MAC has been set at the sensory limits determined by controlled observations on humans, as

for example, methyl ethyl ketone or turpentine; while in others, a compromise value has been adopted which is lower than necessary to protect a worker from poisoning, and yet too high for optimum working conditions, as was done with acetone and ethyl acetate. A careful evaluation of the basis for one of these MACs is therefore necessary in order to apply it to a particular situation.

Occasionally, correlation between animal experiments and human observation supplies still further information. This is usually done in a series of standardized experiments known as range-finding tests, which are utilized in giving a tentative MAC to new organic compounds which are developed for industrial use. A limited series of acute exposures are made on several groups of animals of different species, using a widely distributed range of dosage. On the basis of pathology, reactions to varying concentrations, and lethal dosage, the toxicity is compared with that of a chemically related poison with an accepted MAC, and an approximate MAC set for the new compound. These tentative MACs can then be used as an indication of the safety of the particular compound, and as a guide in planning adequate control measures.

It should be understood that all MAC values, even those which have been established for many years, are not immutable, and periodic revision of the values is constantly being made by both the governmental agencies and semi-official organizations responsible for their establishment and application.

INDUSTRIAL APPLICATIONS

Having seen how these criteria are established, and arrived at some understanding of their limitations, the next consideration is their application. The primary use is as a yardstick for surveying the hazards of an industrial process. With an adequate means for measuring the concentration of a toxic substance in the air, the presence and location of amounts in excess of the MAC can be determined, and the necessity for control measures established. For example, analysis of lead dust and fumes in the air at the various operations in the manufacture and assembly of storage batteries will indicate where the MAC is being exceeded, and what steps must be taken to render the plant safe. Evaluation of a new potentially hazardous process in the pilot plant stage will often indicate the necessary controls before large scale operations are commenced, and avoid expensive alterations at a later date.

Another use for the MAC is in planning industrial ventilation. If the quantity of a toxic substance which will be released into the workroom atmosphere in a given time is known, then the volume in cubic feet of general ventilation necessary to dilute it below the MAC can be calculated. In this way, a ventilation system can be designed which will afford adequate protection to the workers without the cost and discomfort of an inordinately large circulation of air. A good illustration of this procedure would be planning the ventilation for a paint-dipping operation, under circumstances where the composition of the solvent and the approximate volume of paint to be used daily would be fairly constant.

Quite frequently, the MAC serves as a guide to the selection of a safer solvent. Where the choice of several solvents is available, and other factors need not be considered, then the use of the one with the high-

est MAC is always preferable, both because it is safe and easiest to handle, and because it reduces the ventilation requirements. Due consideration to vapor pressures at room temperatures must be given, however, since a low-boiling liquid, even though it has a higher MAC, may actually result in a more toxic atmosphere because of higher concentrations. Usually the decision is complicated by factors such as effectiveness, cost and availability of the solvent, but the MAC should always be given its proper weight. Similarly, when an excessive exposure to a particular solvent has been shown, substitution of a less toxic substance is a control measure of choice, and the table of MACs is a very helpful guide in making the proper selection.

A further application of an MAC might be in evaluating the exposure of an individual worker. Where certain symptoms were complained of which might or might not be due to a particular toxic substance handled by him, knowledge of whether the air concentrations were significantly below the recognized toxic limits would be very helpful to the physician treating him. A great deal of caution must be used in such an evaluation, however, because of the wide range of individual susceptibility to many substances. In a given situation, where the diagnosis was definite but no evidence of exposure in excess of the MAC could be found, and where the toxic symptoms were confined to one particular worker, the indications might favor transfer to other work of that particular individual because of his hypersensitivity, rather than the installation of unnecessarily severe controls.

LIMITATIONS AND PITFALLS

As has been mentioned before, the basis for both the determination and application of an MAC hinges in most instances on proper determination of air concentrations. It is not the purpose of this paper to discuss in detail the technique of air tests, which is a complete topic in itself; but some consideration of the problems involved is necessary in order to understand fully the limitations of MACs and avoid the pitfalls of faulty application.

Since in almost all instances the portal of entry is the mouth and nose, it is of primary importance that determinations be made *in the breathing zone of the worker*. There are some occasions where the concentration of the toxic substance is uniform throughout the workroom, as for example in many painting operations where no local exhaust ventilation has been installed; but in general, the concentration drops rapidly with distance from the source. In this case, a general room sample would be meaningless. It is necessary to follow the worker for a considerable period of time, with the sampling tube either held close to his face or actually attached to it. The sample thus obtained will correspond fairly exactly with the average contamination of the air breathed in by the worker.

It is also extremely important to have a thorough understanding of the process being surveyed, in order to insure that the sample obtained represents an average exposure of the worker. Many examples of this can be cited. In studying the exposure of foundry workers to metal fumes, it is necessary to follow the worker through an entire cycle of operations, including filling the ladle, drossing, and pouring into the molds, and to be sure that these operations constitute a representative schedule for the particular foundry.

A low melting alloy may be in use for the particular pour tested, or the casting of one large mold instead of a series of small ones may give an entirely different picture than that usually present. The exposure at a degreasing tank is controlled to a great extent by the size of the objects being cleaned, the speed at which they are removed from the tank, and their tendency to trap solvents in concavities. The fact that the concentration is below the MAC for the particular solvent when the parts are neatly stacked with concavities downward and are lifted out slowly is no guarantee of safety unless it is shown that this is normal operating procedure for the plant. Certain types of equipment will have variable exposures even during apparently continuous operation. For example, dust concentrations will be highest *in the beginning* when mixing a dry powder with a solvent, but will *rise steadily* in a crushing operation, as more fine particles are created. In such processes, failure to include a full cycle, including loading and unloading operations, would destroy the value of any sample taken.

Seasonal variation, too, must be evaluated in making air tests. During the warmer months, there is a marked increase in general room ventilation because windows and doors can be kept open, which tends to reduce the concentration of air contaminants. This is partially overcome in the case of solvents, where higher temperatures may cause increased vaporization. A further factor is the seasonal fluctuation in production found in many industries, which may cause concomitant fluctuations in the quantities of toxic substances handled. All these factors should be investigated at the time tests are made, and due allowance made for them, particularly when reconstructing the exposure under which a worker became ill.

With cumulative poisons, such as lead or mercury, a sample of a representative working cycle, taken in the breathing zone of the worker, can be directly compared with the MAC, since it indicates the amount of toxic substance inhaled in a given period of time. With acute irritants and many volatile solvents, however, still another factor has to be considered: fluctuation. A concentration of 50 parts per million over a half-hour sampling period may represent a vapor evenly distributed during that time, or it may equally well represent 200 parts per million for five minutes and 20 for the remainder of the time. The latter exposure to a solvent with an MAC of 50 parts per million might be pronounced safe on the basis of an air test, and yet the workers might be subject to irritation during the brief periods of higher exposure. Furthermore, for complex physiological reasons involving rates and avenues of excretion, and relative solubilities in blood and tissues, a worker might retain a great deal more of a poison when exposed to a fluctuating concentration, than to a constant one of the same average level. For these reasons, there are instances where a technique for rapid sampling is indicated, with frequent observations throughout the working cycle to catch the peaks. Recently, several new instruments for making rapid air analyses have appeared, and the data obtained with them may throw much new light on this problem.

In the case of many inorganic compounds, their solubility products and other chemical properties must also be considered. For example, lead borosilicate has been substituted for other, more toxic, lead salts in

the manufacture of pottery glazes because of its great insolubility, which causes it to be absorbed more slowly from the lungs after deposition. On the other hand, occasionally certain salts of a metal appear to be more toxic than the metal itself, due to the added effect of the acid radical. Barium peroxide and possibly lead chromate are instances of this.

One final word of caution. In using an MAC to determine whether a particular substance can be used safely in a given situation, the question of exposure over and above that produced by the established operating procedure must be evaluated. Where leaks, spills or other accidents are frequent, they may expose the workers to dangerous concentrations of vapor which would not be picked up by a single air test. Also, the natural tendency of a worker to disregard safety precautions when they inconvenience him must be allowed for.

CONCLUSIONS

In conclusion, then, there are a number of fields of application in industrial hygiene for the tables of maximum allowable concentrations. They can be used as a yardstick in surveying industrial processes and electing organic solvents from the point of view of safety. They are useful in planning ventilation for many potentially hazardous operations. They will often be of value in determining whether a worker might have been poisoned. Care must be taken, however, to consider all the variables which might affect the application of an MAC to a particular situation, and to insure that the air tests with which it is compared truly represents the concentration of toxic substances to which the worker is exposed. Lastly, it must be remembered that the MACs are not unchangeable constants, but rather values which have been established on the basis of limited experience with animal experimentation and human observation, and therefore subject to revision as further information throws new light on their reliability. For this reason, it is in general preferable not to seek to have fixed values established by law or written into codes, but rather to use them as guides for purposes of control; so that due allowance can be made for special circumstances, developing concepts or new data.

Bibliography

1. Cook, Warren A.: Maximum Allowable Concentrations of Industrial Atmospheric Contaminants. *Industrial Medicine*, 14: 936 to 946, November, 1945.
2. Fairhall, Lawrence T.: Comments on 1947 MAC Values. *Industrial Hygiene Newsletter*, 8:8 and 9, February, 1948.
3. Nelson, K. W., Ege, J. F., Ross, Morwick, Woodman, L. E. and Silverman, Leslie: Sensory Response to Certain Industrial Solvent Vapors. *Journal of Industrial Hygiene and Toxicology*, 25: 282 to 285, September, 1943.
4. Sterner, James H.: Determining Margins of Safety. *Industrial Medicine*, 12: 514 to 518, August, 1943.
5. Teleky, Ludwig: Toxic Limits. *Industrial Hygiene Supplement of Industrial Medicine*, 9: 68 to 71, October, 1940.

ERRATUM

In the November 1948 issue of the Monthly Review, in an article by Harris on Paints, Lacquers and Lumber, Talc was listed in Table 3 under "Highly Toxic" materials. This was an error. It should have appeared in the record column under "Less Toxic" natures.

MONTHLY REVIEW

Division of Industrial Hygiene & Safety Standards

Vol. 28

February, 1949

No. 2

THE SIGNIFICANCE OF MAXIMUM ALLOWABLE CONCENTRATIONS

by

JOHN E. SILSON, M.D.

Medical Unit

The field of industrial hygiene is concerned, among other things, with the protection of the health of the worker in industry by the elimination of toxic substances from the working atmosphere. Its progress to a highly specialized science has been paced by the development of accurate laboratory methods for the evaluation of air contamination. With the ability to determine these exposures has come the need for standards for interpreting them. This has led to the establishment of tables of maximum allowable concentrations, which are the highest concentrations of substances in the air which will not injure the average individual during a full working day.

BASIC CONSIDERATIONS

These values are usually given in one of three forms: 1) gaseous proportion, 2) weight, and 3) number of particles. Substances which are dispersed in air in true molecular form as *gases* or *vapors*, like chlorine or benzol, are expressed in parts per million, calculated as a gas. On the other hand, *dusts*, *fumes* and *mists*, as for instance lead or chromic acid, consist of particles of varying size and random distribution, and cannot be expressed in these terms. Most of these concentrations are therefore expressed as milligrams per cubic meter of air. Occasionally, the value is given as milligrams per ten cubic meters of air, which is considered the average volume inspired by a worker in an eight-hour working day, and is therefore supposed to give some idea of his actual intake of the toxic substance. A special category has been created for the *mineral dusts*, such as silica, asbestos and talc, which cause proliferative changes in the lungs. Since the important factor in these cases appears to be the number of particles inhaled, they are reported as million particles per cubic foot of air, together with the concentration of offending agent in the mineral.

The promulgation of tables of maximum allowable concentrations, or MACs as they are generally referred to, has been a comparatively recent development. Until about twenty years ago, very few field determinations of air contaminants were being made, other than dust counts. About this time, industrial hygienists began to collect data on injurious indus-

trial exposures and to correlate it with the toxic effects of various gases, vapors, fumes, mists and dusts, determined largely by animal experimentation, and based in most instances on lethal dosage. This material was then organized into tables of maximum allowable concentrations by several State agencies concerned with protecting the health of their workers. The establishment of these criteria created a need for further analytical techniques, and portable equipment for analyzing or sampling air in the field. As these problems were solved one by one, data on exposures under actual working conditions began to be amassed, and more experimental research was undertaken, so that today there has been accumulated considerable material on which the present tables are based.

In order to discuss the means of arriving at a maximum allowable concentration, and its applications and limitations, it is necessary to review the considerations which enter into establishing such a criterion. One is the mode of action on the body. Some substances, such as lead or carbon tetrachloride, are systemic poisons, which are taken up by the blood stream and carried to all the tissues, giving rise to toxic symptoms in many parts of the body. Others, like silica dust, remain in the respiratory tract and exert their primary injurious effect there. Still others, for example ammonia, exhibit mainly a severe irritant reaction on the respiratory tract, which tends to clear up after the individual leaves the environment. Then there is a large group, including many solvents such as the acetates and ketones, which evoke an unpleasant sensory response or a mild irritation to the mucous membranes, but must be considered more obnoxious than toxic.

Another consideration is the tendency of the toxic substance to accumulate in the body. This is determined by the manner of elimination of the substance, and is usually in inverse proportion to the rate of excretion. Some substances, *systemic* poisons like lead or *local* poisons like silica, are cumulative in the tissues, and may only evidence a toxic effect after months or years of exposure. Others, such as carbon monoxide or carbon tetrachloride, exert their toxic effect only during and shortly after exposure. This does not mean, however, that the toxic effect itself is not cumulative, as repeated small insults to an organ may eventually result in considerable disability.

* Presented at the 18th Annual Safety Convention of the Greater New York Safety Council, April 16th, 1948.

for example, methyl ethyl ketone or turpentine; while in others, a compromise value has been adopted which is lower than necessary to protect a worker from poisoning, and yet too high for optimum working conditions, as was done with acetone and ethyl acetate. A careful evaluation of the basis for one of these MACs is therefore necessary in order to apply it to a particular situation.

Occasionally, correlation between animal experiments and human observation supplies still further information. This is usually done in a series of standardized experiments known as range-finding tests, which are utilized in giving a tentative MAC to new organic compounds which are developed for industrial use. A limited series of acute exposures are made on several groups of animals of different species, using a widely distributed range of dosage. On the basis of pathology, reactions to varying concentrations, and lethal dosage, the toxicity is compared with that of a chemically related poison with an accepted MAC, and an approximate MAC set for the new compound. These tentative MACs can then be used as an indication of the safety of the particular compound, and as a guide in planning adequate control measures.

It should be understood that all MAC values, even those which have been established for many years, are not immutable, and periodic revision of the values is constantly being made by both the governmental agencies and semi-official organizations responsible for their establishment and application.

INDUSTRIAL APPLICATIONS

Having seen how these criteria are established, and arrived at some understanding of their limitations, the next consideration is their application. The primary use is as a yardstick for surveying the hazards of an industrial process. With an adequate means for measuring the concentration of a toxic substance in the air, the presence and location of amounts in excess of the MAC can be determined, and the necessity for control measures established. For example, analysis of lead dust and fumes in the air at the various operations in the manufacture and assembly of storage batteries will indicate where the MAC is being exceeded, and what steps must be taken to render the plant safe. Evaluation of a new potentially hazardous process in the pilot plant stage will often indicate the necessary controls before large scale operations are commenced, and avoid expensive alterations at a later date.

Another use for the MAC is in planning industrial ventilation. If the quantity of a toxic substance which will be released into the workroom atmosphere in a given time is known, then the volume in cubic feet of general ventilation necessary to dilute it below the MAC can be calculated. In this way, a ventilation system can be designed which will afford adequate protection to the workers without the cost and discomfort of an inordinately large circulation of air. A good illustration of this procedure would be planning the ventilation for a paint-dipping operation, under circumstances where the composition of the solvent and the approximate volume of paint to be used daily would be fairly constant.

Quite frequently, the MAC serves as a guide to the selection of a safer solvent. Where the choice of several solvents is available, and other factors need not be considered, then the use of the one with the high-

est MAC is always preferable, both because it is safest and easiest to handle, and because it reduces the ventilation requirements. Due consideration to vapor pressures at room temperatures must be given, however, since a low-boiling liquid, even though it has a higher MAC, may actually result in a more toxic atmosphere because of higher concentrations. Usually the decision is complicated by factors such as effectiveness, cost and availability of the solvent, but the MAC should always be given its proper weight. Similarly, when an excessive exposure to a particular solvent has been shown, substitution of a less toxic substance is a control measure of choice, and the table of MACs is a very helpful guide in making the proper selection.

A further application of an MAC might be in evaluating the exposure of an individual worker. Where certain symptoms were complained of which might or might not be due to a particular toxic substance handled by him, knowledge of whether the air concentrations were significantly below the recognized toxic limits would be very helpful to the physician treating him. A great deal of caution must be used in such an evaluation, however, because of the wide range of individual susceptibility to many substances. In a given situation, where the diagnosis was definite but no evidence of exposure in excess of the MAC could be found, and where the toxic symptoms were confined to one particular worker, the indications might favor transfer to other work of that particular individual because of his hypersensitivity, rather than the installation of unnecessarily severe controls.

LIMITATIONS AND PITFALLS

As has been mentioned before, the basis for both the determination and application of an MAC hinges in most instances on proper determination of air concentrations. It is not the purpose of this paper to discuss in detail the technique of air tests, which is a complete topic in itself; but some consideration of the problems involved is necessary in order to understand fully the limitations of MACs and avoid the pitfalls of faulty application.

Since in almost all instances the portal of entry is the mouth and nose, it is of primary importance that determinations be made *in the breathing zone of the worker*. There are some occasions where the concentration of the toxic substance is uniform throughout the workroom, as for example in many painting operations where no local exhaust ventilation has been installed; but in general, the concentration drops rapidly with distance from the source. In this case, a general room sample would be meaningless. It is necessary to follow the worker for a considerable period of time, with the sampling tube either held close to his face or actually attached to it. The sample thus obtained will correspond fairly exactly with the average contamination of the air breathed in by the worker.

It is also extremely important to have a thorough understanding of the process being surveyed, in order to insure that the sample obtained represents an average exposure of the worker. Many examples of this can be cited. In studying the exposure of foundry workers to metal fumes, it is necessary to follow the worker through an entire cycle of operations, including filling the ladle, drossing, and pouring into the molds, and to be sure that these operations constitute a representative schedule for the particular foundry.

MONTHLY REVIEW
of the
DIVISION OF INDUSTRIAL HYGIENE
AND SAFETY STANDARDS
NEW YORK STATE
DEPARTMENT OF LABOR
80 CENTRE STREET
NEW YORK 13, N. Y.

Industrial Commissioner
EDWARD CORSI

1st Deputy Industrial Commissioner
THOMAS F. MOORE, JR.

Deputy Industrial Commissioner in Charge
EDWARD A. NYEGAARD

Deputy Industrial Commissioners
ABRAHAM H. GOODMAN
LOIS B. HUNTER

The Division

LEONARD GREENBURG, M.D., Director
MAY R. MAYERS, M.D., Medical Unit
WILLIAM J. BURKE, Chemical Unit
GEORGE P. KEOGH, Code Unit
ARTHUR C. STERN, Engineering Unit

Industrial Hygiene

LEONARD A. PERRIN, Engineering Unit

Building Plans

SOURCES OF DATA

With these considerations in mind, therefore, let us see how the MAC values have been established. The first basis in most instances has been animal experimentation. When a substance is suspected of being toxic, tests are made on a variety of animals by as many routes as is practical: inhalation, feeding, patch testing on the skin and eyelids, and injection under the skin, into the muscles, the veins, the abdominal cavity, the trachea and any other parts of the body that might be indicated. By varying the dosage widely, it is possible to determine, not only how much of the substance is necessary to kill the animals, but also how much causes minimal symptoms and what parts of the body are most sensitive to it. From this are determined the toxic range within which the substance appears to fall, and what signs of poisoning to look for in individuals exposed to it.

There are, however, several limitations inherent in this method. First, the reaction of any one type of animal to a toxic substance is no proof that a human being or any other animal will react similarly. The use of a variety of animals sometimes mitigates this factor to some extent, but frequently the range of response of the various species, not only quantitatively, but even qualitatively, renders the problem even more complex.

A second limitation is the difficulty of fully evaluating the cumulative effects of a toxic compound. For one thing, the life span of most experimental animals is much shorter than that of humans, so that it is impossible to demonstrate the effects which only appear after years of exposure. Even when the exposure can be compressed within their life time, the difficulties of conducting such long drawn out experiments are almost insuperable, particularly in inhalation studies. This, of course, is not a problem where the toxin is known to be non-cumulative.

The other basis for establishing a maximum allowable concentration is by data obtained from observations on humans. Although a few experiments on

laboratory exposure of individuals to toxic substances have been performed, by far the greatest part of this data has been collected by observations in the field. When one or more workers become ill from an exposure which can be determined, an upper limit is established, and a tentative MAC can be set sufficiently below that limit to allow an adequate margin of safety. When a group of workers have been shown to tolerate a determined exposure for an adequate length of time with no toxic signs or symptoms, this can be assumed as a safe exposure. Further information is sometimes obtained by surveying a group of workers for medical evidence of poisoning while simultaneously studying the air contamination. As more data accumulates, the standard can be set more accurately, but it is easy to see that a great many determinations are necessary before any statistical accuracy is possible.

There are many limitations to this technique also. Except for the field surveys just mentioned, exposures are practically never determined at the time the workers become ill, and have to be measured and evaluated after the fact. All the potential errors inherent in determining the concentrations to which the workers are actually exposed, which will be discussed in detail later, affect the validity of any observation. Furthermore, in borderline over-exposures, it is often difficult to differentiate symptoms due to industrial poisoning from those of non-industrial diseases to which any worker might succumb. Then the range of individual idiosyncrasy must be considered. On the one hand, a few individuals will always prove so susceptible to certain toxic substances that it is often unfair to use their reactions as a criterion for an upper limit, and it may be necessary to exclude them from an industry in which they are exposed to substances to which they are hypersensitive. In addition, some workers may be oversusceptible because of disease or personal habits: the ultrasensitivity of chronic alcoholics and people with liver disease to carbon tetrachloride is a good example. On the other hand, it has been found that natural selection tends to eliminate from certain industries all but those who are relatively insensitive to the poisonous substances handled. To use the toxic thresholds of these workers, therefore, as a basis for establishing a safe exposure creates the danger of setting the MAC too high and endangering the worker of average susceptibility entering the occupation. Finally, the disease picture in acute poisoning is often very different from that in the chronic; so that the absence of acute symptoms in a group of workers is no indication that they are not exposed to concentrations of a toxic substance which will cause chronic poisoning in a period of time. As an example, the failure of a worker exposed to benzol vapors to demonstrate acute symptoms severe enough to require medical attention is no guarantee that he may not develop an aplastic anemia several years later.

In the case of those substances characterized by their irritating qualities rather than by specific toxic effects, the establishment of MACs is attended by still further difficulties. The original MAC tables were promulgated on toxic effects, and their extension to the relatively non-toxic solvent vapors has brought in the new concept of considering the discomfort of the workers as well. The result has been that in some cases, the MAC has been set at the sensory limits determined by controlled observations on humans, as

for example, methyl ethyl ketone or turpentine; while in others, a compromise value has been adopted which is lower than necessary to protect a worker from poisoning, and yet too high for optimum working conditions, as was done with acetone and ethyl acetate. A careful evaluation of the basis for one of these MACs is therefore necessary in order to apply it to a particular situation.

Occasionally, correlation between animal experiments and human observation supplies still further information. This is usually done in a series of standardized experiments known as range-finding tests, which are utilized in giving a tentative MAC to new organic compounds which are developed for industrial use. A limited series of acute exposures are made on several groups of animals of different species, using a widely distributed range of dosage. On the basis of pathology, reactions to varying concentrations, and lethal dosage, the toxicity is compared with that of a chemically related poison with an accepted MAC, and an approximate MAC set for the new compound. These tentative MACs can then be used as an indication of the safety of the particular compound, and as a guide in planning adequate control measures.

It should be understood that all MAC values, even those which have been established for many years, are not immutable, and periodic revision of the values is constantly being made by both the governmental agencies and semi-official organizations responsible for their establishment and application.

INDUSTRIAL APPLICATIONS

Having seen how these criteria are established, and arrived at some understanding of their limitations, the next consideration is their application. The primary use is as a yardstick for surveying the hazards of an industrial process. With an adequate means for measuring the concentration of a toxic substance in the air, the presence and location of amounts in excess of the MAC can be determined, and the necessity for control measures established. For example, analysis of lead dust and fumes in the air at the various operations in the manufacture and assembly of storage batteries will indicate where the MAC is being exceeded, and what steps must be taken to render the plant safe. Evaluation of a new potentially hazardous process in the pilot plant stage will often indicate the necessary controls before large scale operations are commenced, and avoid expensive alterations at a later date.

Another use for the MAC is in planning industrial ventilation. If the quantity of a toxic substance which will be released into the workroom atmosphere in a given time is known, then the volume in cubic feet of general ventilation necessary to dilute it below the MAC can be calculated. In this way, a ventilation system can be designed which will afford adequate protection to the workers without the cost and discomfort of an inordinately large circulation of air. A good illustration of this procedure would be planning the ventilation for a paint-dipping operation, under circumstances where the composition of the solvent and the approximate volume of paint to be used daily would be fairly constant.

Quite frequently, the MAC serves as a guide to the selection of a safer solvent. Where the choice of several solvents is available, and other factors need not be considered, then the use of the one with the high-

est MAC is always preferable, both because it is safest and easiest to handle, and because it reduces the ventilation requirements. Due consideration to vapor pressures at room temperatures must be given, however, since a low-boiling liquid, even though it has a higher MAC, may actually result in a more toxic atmosphere because of higher concentrations. Usually the decision is complicated by factors such as effectiveness, cost and availability of the solvent, but the MAC should always be given its proper weight. Similarly, when an excessive exposure to a particular solvent has been shown, substitution of a less toxic substance is a control measure of choice, and the table of MACs is a very helpful guide in making the proper selection.

A further application of an MAC might be in evaluating the exposure of an individual worker. Where certain symptoms were complained of which might or might not be due to a particular toxic substance handled by him, knowledge of whether the air concentrations were significantly below the recognized toxic limits would be very helpful to the physician treating him. A great deal of caution must be used in such an evaluation, however, because of the wide range of individual susceptibility to many substances. In a given situation, where the diagnosis was definite but no evidence of exposure in excess of the MAC could be found, and where the toxic symptoms were confined to one particular worker, the indications might favor transfer to other work of that particular individual because of his hypersensitivity, rather than the installation of unnecessarily severe controls.

LIMITATIONS AND PITFALLS

As has been mentioned before, the basis for both the determination and application of an MAC hinges in most instances on proper determination of air concentrations. It is not the purpose of this paper to discuss in detail the technique of air tests, which is a complete topic in itself; but some consideration of the problems involved is necessary in order to understand fully the limitations of MACs and avoid the pitfalls of faulty application.

Since in almost all instances the portal of entry is the mouth and nose, it is of primary importance that determinations be made *in the breathing zone of the worker*. There are some occasions where the concentration of the toxic substance is uniform throughout the workroom, as for example in many painting operations where no local exhaust ventilation has been installed; but in general, the concentration drops rapidly with distance from the source. In this case, a general room sample would be meaningless. It is necessary to follow the worker for a considerable period of time, with the sampling tube either held close to his face or actually attached to it. The sample thus obtained will correspond fairly exactly with the average contamination of the air breathed in by the worker.

It is also extremely important to have a thorough understanding of the process being surveyed, in order to insure that the sample obtained represents an average exposure of the worker. Many examples of this can be cited. In studying the exposure of foundry workers to metal fumes, it is necessary to follow the worker through an entire cycle of operations, including filling the ladle, drossing, and pouring into the molds, and to be sure that these operations constitute a representative schedule for the particular foundry.

A low melting alloy may be in use for the particular pour tested, or the casting of one large mold instead of a series of small ones may give an entirely different picture than that usually present. The exposure at a degreasing tank is controlled to a great extent by the size of the objects being cleaned, the speed at which they are removed from the tank, and their tendency to trap solvents in concavities. The fact that the concentration is below the MAC for the particular solvent when the parts are neatly stacked with concavities downward and are lifted out slowly is no guarantee of safety unless it is shown that this is normal operating procedure for the plant. Certain types of equipment will have variable exposures even during apparently continuous operation. For example, dust concentrations will be highest *in the beginning* when mixing a dry powder with a solvent, but will *rise steadily* in a crushing operation, as more fine particles are created. In such processes, failure to include a full cycle, including loading and unloading operations, would destroy the value of any sample taken.

Seasonal variation, too, must be evaluated in making air tests. During the warmer months, there is a marked increase in general room ventilation because windows and doors can be kept open, which tends to reduce the concentration of air contaminants. This is partially overcome in the case of solvents, where higher temperatures may cause increased vaporization. A further factor is the seasonal fluctuation in production found in many industries, which may cause concomitant fluctuations in the quantities of toxic substances handled. All these factors should be investigated at the time tests are made, and due allowance made for them, particularly when reconstructing the exposure under which a worker became ill.

With cumulative poisons, such as lead or mercury, a sample of a representative working cycle, taken in the breathing zone of the worker, can be directly compared with the MAC, since it indicates the amount of toxic substance inhaled in a given period of time. With acute irritants and many volatile solvents, however, still another factor has to be considered: fluctuation. A concentration of 50 parts per million over a half-hour sampling period may represent a vapor evenly distributed during that time, or it may equally well represent 200 parts per million for five minutes and 20 for the remainder of the time. The latter exposure to a solvent with an MAC of 50 parts per million might be pronounced safe on the basis of an air test, and yet the workers might be subject to irritation during the brief periods of higher exposure. Furthermore, for complex physiological reasons involving rates and avenues of excretion, and relative solubilities in blood and tissues, a worker might retain a great deal more of a poison when exposed to a fluctuating concentration, than to a constant one of the same average level. For these reasons, there are instances where a technique for rapid sampling is indicated, with frequent observations throughout the working cycle to catch the peaks. Recently, several new instruments for making rapid air analyses have appeared, and the data obtained with them may throw much new light on this problem.

In the case of many inorganic compounds, their solubility products and other chemical properties must also be considered. For example, lead borosilicate has been substituted for other, more toxic, lead salts in

the manufacture of pottery glazes because of its great insolubility, which causes it to be absorbed more slowly from the lungs after deposition. On the other hand, occasionally certain salts of a metal appear to be more toxic than the metal itself, due to the added effect of the acid radical. Barium peroxide and possibly lead chromate are instances of this.

One final word of caution. In using an MAC to determine whether a particular substance can be used safely in a given situation, the question of exposure over and above that produced by the established operating procedure must be evaluated. Where leaks, spills or other accidents are frequent, they may expose the workers to dangerous concentrations of vapor which would not be picked up by a single air test. Also, the natural tendency of a worker to disregard safety precautions when they inconvenience him must be allowed for.

CONCLUSIONS

In conclusion, then, there are a number of fields of application in industrial hygiene for the tables of maximum allowable concentrations. They can be used as a yardstick in surveying industrial processes and electing organic solvents from the point of view of safety. They are useful in planning ventilation for many potentially hazardous operations. They will often be of value in determining whether a worker might have been poisoned. Care must be taken, however, to consider all the variables which might affect the application of an MAC to a particular situation, and to insure that the air tests with which it is compared truly represents the concentration of toxic substances to which the worker is exposed. Lastly, it must be remembered that the MACs are not unchangeable constants, but rather values which have been established on the basis of limited experience with animal experimentation and human observation, and therefore subject to revision as further information throws new light on their reliability. For this reason, it is, in general preferable not to seek to have fixed values established by law or written into codes, but rather to use them as guides for purposes of control; so that due allowance can be made for special circumstances, developing concepts or new data.

Bibliography

1. Cook, Warren A.: Maximum Allowable Concentrations of Industrial Atmospheric Contaminants. *Industrial Medicine*, 14: 936 to 946, November, 1946.
2. Fairhall, Lawrence T.: Comments on 1947 MAC Values. *Industrial Hygiene Newsletter*, 8:8 and 9, February, 1948.
3. Nelson, K. W., Ege, J. F., Ross, Morwick, Woodman, L. E. and Silverman, Leslie: Sensory Response to Certain Industrial Solvent Vapors. *Journal of Industrial Hygiene and Toxicology*, 25: 282 to 285, September, 1943.
4. Sterner, James H.: Determining Margins of Safety. *Industrial Medicine*, 12: 514 to 518, August, 1943.
5. Teleky, Ludwig: Toxic Limits. *Industrial Hygiene Supplement of Industrial Medicine*, 9: 68 to 71, October, 1940.

ERRATUM

In the November 1948 issue of the Monthly Review, in an article by Harris on Paints, Lacquers and Lumber, Tale was listed in Table 3 under "Highly Toxic" materials. This was an error. It should have appeared in the record column under "Less Toxic" natures.

More Toxic Than You Think

Many common solvents and chemicals used in labs and plants are extremely toxic and should be handled with caution. The maximum allowable concentrations for many of these chemicals are listed in the table following. The concentrations listed have been determined from experience and experimentation. If you are using any of these materials worker exposure should be determined routinely. Even the best designed ventilation system may not be doing a good enough job. A small investment in Air Sampling Equipment may prevent loss of skilled employees, compensation payments and besides is just plain humanitarian. We will be happy to suggest analytical methods.

Threshold limits should be used as guides in the control of health hazards and should not be regarded as fine lines between safe and dangerous concentrations. They represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effect. The values listed refer to time-weighted average concentrations for a normal workday. The amount by which these figures may be exceeded for short periods without injury to health depends upon a number of factors such as the nature of the contaminant, whether very high concentrations even for short periods produce acute poisoning, whether the effects are cumulative, the frequency with which high concentrations occur, and the duration of such periods. All must be taken into consideration in arriving at a decision as to whether a hazardous situation exists. Special consideration should be given to the application of these values in assessing the health hazards which may be associated with exposure to combinations of two or more substances.

Threshold limits are based on the best available information from industrial experience, from experimental studies, and, when possible, from a combination of the two. These values are based on various criteria of toxic effects or on marked discomfort; thus, they should not be used as a common denominator of toxicity, nor should they be considered as the sole criterion in proving or disproving diagnosis of suspected occupational disease.

These limits are intended for use in the field of industrial hygiene and should be employed by persons trained in this field. They are not intended for use, or for modification for use, in the evaluation or control of community air pollution or air pollution nuisances.

The Threshold Limit Values for 1961 have been copyrighted and published by the American Conference of Governmental Industrial Hygienists. This publication is reprinted here with the permission of the American Conference of Governmental Industrial Hygienists. Inquiries and reprint orders should be directed to Secretary-Treasurer, American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati 2, Ohio.

These values are reviewed annually by the Committee on Threshold Limits for changes, revisions, or additions as further information becomes available. The Committee welcomes the suggestion of substances to be added to the list and also comments, references, or reports of experience with these materials.

Recommended Values
GASES AND VAPORS

Substance	P.P.M.*	Approx. Mg. per Cu. M.†
Acetaldehyde.....	200	380
Acetic acid.....	10	25
Acetic anhydride.....	5	20
Acetone.....	1,000	2,400
Acetylene tetrabromide.....	1	14
Acrolein.....	0.5	1.3
Acrylonitrile—Skin.....	20	45
Allyl alcohol—Skin.....	2	5
Allyl chloride.....	5	15
Allyl propyl disulfide.....	2	12
Ammonia.....	100	70
Amyl acetate.....	200	1,050
Amyl alcohol (isoamyl alcohol).....	100	360
Aniline—Skin.....	5	19
Arsine.....	0.05	0.2
Benzene (benzol).....	25	80
Benzyl chloride.....	1	5
Boron trifluoride.....	1	3
Bromine.....	0.1	0.7
Butadiene (1,3-butadiene).....	1,000	2,200
2-Butanone (methyl ethyl ketone).....	200	590
Butyl acetate (n-butyl acetate).....	200	950
Butyl alcohol (n-butanol).....	100	300
tert. Butyl alcohol.....	100	300
Butylamine.....	5	15
Butyl cellosolve (2-butoxyethanol).....	50	240
p-tert. Butyltoluene.....	10	60
Carbon dioxide.....	5,000	9,000
Carbon disulfide—Skin.....	20	60
Carbon monoxide.....	100	110
Carbon tetrachloride—Skin.....	25	160
Cellosolve (2-ethoxyethanol).....	200	740
Cellosolve acetate (2-ethoxyethyl acetate).....	100	540
Chlorine.....	1	3
Chlorine dioxide.....	0.1	0.3
Chlorine trifluoride.....	0.1	0.4
Chlorobenzene (monochlorobenzene).....	75	350
Chloroform (trichloromethane).....	50	240
1-Chloro-1-nitropropane.....	20	100

GASES AND VAPORS—Continued

Substance	P.P.M.*	Approx. Mg. per Cu. M.†	Substance	P.P.M.*	Approx. Mg. per Cu. M.†
Chloropierin.....	0.1	0.7	Isopropylamine.....	5	12
Chloroprene (2-chloro-1,3-butadiene).....	25	90	Mesityl oxide.....	25	100
Cresol (all isomers)—Skin.....	5	22	Methyl acetate.....	200	610
Cyclohexane.....	400	1,400	Methyl acetylene.....	1,000	1,650
Cyclohexanol.....	50	200	Methyl acrylate—Skin.....	10	35
Cyclohexanone.....	50	200	Methylal (dimethoxymethane).....	1,000	3,100
Cyclohexene.....	400	1,350	Methyl alcohol (methanol).....	200	260
Decaborane—Skin.....	0.05	0.3	Methyl bromide—Skin.....	20	80
Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone).....	50	240	Methyl cellosolve (2-methoxyethanol).....	25	80
Diborane.....	0.1	0.1	Methyl cellosolve acetate (ethylene glycol monomethyl ether acetate).....	25	120
o-Dichlorobenzene.....	50	300	Methyl chloride.....	100	210
p-Dichlorobenzene.....	75	450	Methyl chloroform (1,1,1-trichloroethane).....	500	2,700
Dichlorodifluoromethane.....	1,000	4,950	Methylcyclohexane.....	500	2,000
1,1-Dichloroethane.....	100	400	Methylcyclohexanol.....	100	470
1,2-Dichloroethane (ethylene dichloride).....	100	400	Methylcyclohexanone.....	100	460
1,2-Dichloroethylene.....	200	790	Methyl formate.....	100	250
Dichloroethyl ether.....	15	90	Methyl isobutyl carbinol (methyl amyl alcohol).....	25	100
Dichloromonofluoromethane.....	1,000	4,200	α-Methyl styrene.....	100	480
1,1-Dichloro-1-nitroethane.....	10	60	Methylene chloride (dichloromethane).....	500	1,750
Dichlorotetrafluoroethane.....	1,000	7,000	Monomethyl aniline—Skin.....	2	9
Diethylamine.....	25	75	Naphtha (coal tar).....	200	800
Difluorodibromomethane.....	100	860	Naphtha (petroleum).....	500	2,000
Diisobutyl ketone.....	50	290	Nickel carbonyl.....	0.001	0.007
Dimethylaniline			Nitric acid.....	10	25
(N-dimethylaniline)—Skin.....	5	25	p-Nitroaniline—Skin.....	1	6
Dimethylformamide.....	20	60	Nitrobenzene—Skin.....	1	5
1,1-Dimethylhydrazine—Skin.....	0.5	1	Nitroethane.....	100	310
Dimethylsulfate—Skin.....	1	5	Nitrogen dioxide.....	5	9
Dipropylene glycol methyl ether.....	100	600	Nitroglycerin.....	0.5	5
Dioxane (diethylene dioxide).....	100	360	Nitromethane.....	100	250
Ethyl acetate.....	400	1,400	2-Nitropropane.....	25	90
Ethyl acrylate—Skin.....	25	100	Nitrotoluene—Skin.....	5	30
Ethyl alcohol (ethanol).....	1,000	1,900	Octane.....—Skin.....	500	2,350
Ethylamine.....	25	45	Ozone.....	0.1	0.2
Ethylbenzene.....	200	870	Pentane.....	1,000	2,950
Ethyl bromide.....	200	890	Pentanone (methyl propyl ketone).....	200	700
Ethyl chloride.....	1,000	2,600	Perchloroethylene (tetrachloroethylene).....	100	670
Ethyl ether.....	400	1,200	Phenol—Skin.....	5	19
Ethyl formate.....	100	300	Phenylhydrazine—Skin.....	5	22
Ethyl silicate.....	100	850	Phosgene (carbonyl chloride).....	1	4
Ethylene chlorohydrin—Skin.....	5	16	Phosphine.....	0.05	0.07
Ethylenediamine.....	10	30	Phosphorus trichloride.....	0.5	3
Ethylene dibromide (1,2-dibromoethane).....	25	100	Propyl acetate.....	200	840
Ethylene imine—Skin.....	5	9	Propyl alcohol (isopropyl alcohol).....	400	980
Ethylene oxide.....	50	90	Propyl ether (isopropyl ether).....	500	2,100
Fluorine.....	0.1	0.2	Propylene dichloride (1,2-dichloropropane).....	75	350
Fluorotrichloromethane.....	1,000	5,600	Propylene imine—Skin.....	25	60
Formaldehyde.....	5	6	Propylene oxide.....	100	240
Furfural.....	5	20	Pyridine.....	5	15
Furfuryl alcohol.....	50	200	Quinone.....	0.1	0.4
Gasoline.....	500	2,000	Stibine.....	0.1	0.5
Heptane (n-heptane).....	500	2,000	Stoddard solvent.....	500	2,300
Hexane (n-hexane).....	500	1,800	Styrene monomer (phenylethylene).....	100	420
Hexanone (methyl butyl ketone).....	100	410	Sulfur dioxide.....	5	13
Hexone (methyl isobutyl ketone).....	100	410	Sulfur hexafluoride.....	1,000	6,000
Hydrazine—Skin.....	1	1.3	Sulfur monochloride.....	1	6
Hydrogen bromide.....	3	10	Sulfur pentafluoride.....	0.025	0.25
Hydrogen chloride.....	5	7	1,1,2,2-Tetrachloroethane—Skin.....	5	35
Hydrogen cyanide—Skin.....	10	11	Tetrahydrofuran.....	200	590
Hydrogen fluoride.....	3	2	Tetranitromethane.....	1	8
Hydrogen peroxide, 90%.....	1	1.4	Toluene (toluol).....	200	750
Hydrogen selenide.....	0.05	0.2	o-Toluidine—Skin.....	5	22
Hydrogen sulfide.....	20	30	Tolylene-2,4-diisocyanate.....	0.02†	0.14†
Iodine.....	0.1	1	Trichloroethylene.....	100	520
Isonphorone.....	25	140	Triethylamine.....	25	100
			Trifluoromonobromomethane.....	1,000	6,100
			Turpentine.....	100	560
			Vinyl chloride (chloroethylene).....	500	1,300

Note: The word "Skin" following a compound's name indicates that the liquid compound can penetrate the skin to cause systemic effects.

Calcite.....	50
Dolomite.....	50
Limestone.....	50
Marble.....	50
Silicon Carbide.....	50
Other inert dusts.....	50

‡ Millions of particles per cubic foot of air based on impinger samples counted by light-field techniques.

TENTATIVE VALUES

Substance	P.P.M.†	Approx. Mg. per Cu. M.‡‡
Acetonitrile.....	40	70
Allyl glycidyl ether (AGE).....	10	45
Boron oxide.....		15
tert. Butyl chromate (as CrO ₃).....		0.1
n-Butyl glycidyl ether (BGE).....	50	270
Butyl mercaptan.....	10	35
Chloroacetaldehyde.....	1	3
Chlorobromomethane.....	200	1,050
DDVP (O,O-Dimethyl-2,2-Dichlorodi-vinyl phosphate).....		1
Diglycidyl ether (DGE).....	10	55
Dimethyl acetamide.....	10	35
Endrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octa hydro-1,4-endo, endo-5,8-dimethano-naphthalene).....		0.25

Ethanol amine.....	0.5	1
Ethyl mercaptan.....	250	640
Glycidol.....	50	150
Heptachlor (1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene).....		0.25
sec-Hexyl acetate.....	100	590
Isopropyl glycidyl ether (IGE).....	50	240
Ketene.....	0.5	0.9
Methyl mercaptan.....	50	100
1-Nitropropane.....	25	90
Pentaborane.....	0.005	0.01
Perchloromethyl mercaptan.....	0.1	0.8
Phenyl glycidyl ether (PGE).....	50	310
Phosdrin (2-carbomethoxy-1-methyl vinyl dimethyl phosphate).....		0.1
n-Propyl nitrate.....	25	110
Systox.....		0.2
2,4,5T (2,4,5-trichlorophenoxy acetic acid).....		10
Teflon decomposition products (as F).....		0.05
1,2,3-Trichloropropane.....	50	300
1,1,2-Trichloro-1,2,2-trifluoroethane.....	1,000	7,600
Triorthocresyl phosphate.....		0.1
Triphenyl phosphate.....		3

† Parts of vapor or gas per million parts of air by volume at 25° C and 760 mm. Hg pressure.

‡‡ Approximate milligrams per cubic meter of air.

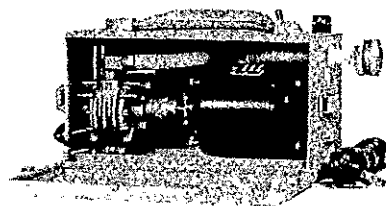
William L. Ball Hervey B. Elkins
W. Clark Cooper Russel G. Scovill
Herbert E. Stokinger William F. Reindollar
Keith H. Jacobson Allan L. Coleman, Chairman

A Brief Review of Air Sampling Necessities

BANTAM AIR SAMPLER

For routine air sampling and inspection especially worker breathing zone sampling. Combines high air flow with light weight. 115 v 60 cy. Complete with 1" filter holder, flowmeter, on-off switch, fuse.

Cat	Air Flow (liters/min)	Duty	Price
19100-1	16	Continuous	\$128.00
19002	30	"	130.00
19001-1	45	Intermittant	130.00



HIGH VOLUME AIR SAMPLER

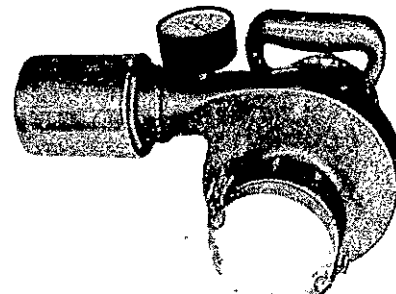
For air sampling where extremely high volumes of air are required. Will collect sufficient sample for analysis in a short time. This single speed sampler has a nominal capacity of 150 cfm, is powered by a 3/4 H. P. universal motor, weighs only 12 lbs, and measures 7 3/4 x 7 1/4 x 8 1/2" overall. Complete with dial reading flow gauge, 2 orifice plates, on-off switch, and 20 foot line cord.

16002 HURRICANE SAMPLER, 150 cfm, 115 volts, 25-60 cycles . . . \$99.00

This two-speed sampler has nominal capacities of 196 cfm at high speed and 150 cfm at low speed. It is powered by a universal motor developing 1 H. P. at full speed, weighs 15 lbs. and measures 7 3/4 x 7 1/4 x 8 1/2". Complete with dial reading flow gauge, set of 3 orifice plates, on-off switch, and 20 foot line cord.

#16003 HURRICANE SAMPLER, two-speeds, 115 volts, 25-60 cycles . \$136.00

NOTE: Hurricane samplers are supplied without filterholders. Choose the filterholder best suited to your application from those listed.



GASES AND VAPORS—Continued

Vinyl toluene.....	100	480
Xylene (xylo).....	200	870
Xylidine—Skin.....	5	25

* Parts of vapor or gas per million parts of air by volume at 25° C and 760 mm. Hg pressure.

† Approximate milligrams per cubic meter of air.

‡ Probably sufficiently low to protect against primary sensitization, but may not protect persons specifically sensitized.

DUST, FUMES AND MISTS

Substance	Mg. per Cu. M.‡
Aldrin (1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-1,4,5,8-dimethanonaphthalene)—Skin.....	0.25
Ammate (ammonium sulfamate).....	15
Antimony.....	0.5
ANTU (alpha-naphthyl-thiourea).....	0.3
Arsenic.....	0.5
Barium (soluble compounds).....	0.5
Beryllium.....	0.002
Cadmium oxide fume.....	0.1
Calcium arsenate.....	0.1
Chlordane (1,2,4,5,6,7,8,8-octachloro-3a,4,7,7a-tetra-hydro-4,7-methanoindane).....	2
Chlorinated camphene, 80%.....	0.5
Chlorinated diphenyl oxide.....	0.5
Chlorodiphenyl (42% chlorine)—Skin.....	1
Chlorodiphenyl (54% chlorine)—Skin.....	0.5
Chromic acid and chromates (as CrO ₃).....	0.1
Crag herbicide (sodium 2-[2,4-dichlorophenoxy] ethanol hydrogen sulfate).....	15
Cyanide (as CN)—Skin.....	5
2,4-D (2,4-dichlorophenoxyacetic acid).....	10
DDT (2,2-bis [p-chlorophenyl]-1,1,1-trichloroethane).....	1
Dieldrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4,5,8-dimethanonaphthalene)—Skin.....	0.25
Dinitrobenzene—Skin.....	1
Dinitrotoluene—Skin.....	1.5
Dinitro- <i>o</i> -cresol—Skin.....	0.2
EPN (O-ethyl O- <i>p</i> -nitrophenyl thiocarbonylphosphonate)—Skin.....	0.5
Ferbam (ferric dimethyl dithiocarbamate).....	15
Ferrovandium dust.....	1
Fluoride.....	2.5
Hydroquinone.....	2
Iron oxide fume.....	15
Lead.....	0.2
Lead arsenate.....	0.15
Lindane (hexachlorocyclohexane, gamma isomer).....	0.5
Lithium hydride.....	0.025
Magnesium oxide fume.....	15
Malathion (O,O-dimethyl dithiophosphate of diethyl mercaptosuccinate)—Skin.....	15
Manganese.....	5
Mercury.....	0.1
Mercury (organic compounds)—Skin.....	0.01
Methoxychlor (2,2-di- <i>p</i> -methoxyphenyl-1,1,1-trichloroethane).....	15
Molybdenum (soluble compounds).....	5
(insoluble compounds).....	15
Nicotine—Skin.....	0.5
Parathion (O,O-diethyl-O- <i>p</i> -nitrophenylthiophosphate)—Skin.....	0.1
Pentachloronaphthalene—Skin.....	0.5
Pentachlorophenol—Skin.....	0.5
Phosphoric acid.....	1

DUST, FUMES AND MISTS—Continued

Substance	Mg. per Cu. M.‡
Phosphorus (yellow).....	0.1
Phosphorus pentachloride.....	1
Phosphorus pentasulfide.....	1
Picric acid—Skin.....	0.1
Pyrethrum.....	2
Rotenone.....	5
Selenium compounds (as Se).....	0.1
Sodium fluoroacetate (1080)—Skin.....	0.1
Sodium hydroxide.....	2
Strychnine.....	0.15
Sulfuric acid.....	1
TEDP (tetraethyl dithionopyrophosphate)—Skin.....	0.2
TEPP (tetraethyl pyrophosphate)—Skin.....	0.05
Tellurium.....	0.1
Tetryl (2,4,6-trinitrophenylmethylnitramine)—Skin.....	1.5
Thallium (soluble compounds).....	0.1
Thiram (tetramethyl thiuram disulfide).....	5
Titanium dioxide.....	15
Trichloronaphthalene—Skin.....	5
Trinitrotoluene—Skin.....	1.5
Uranium (soluble compounds).....	0.05
(insoluble compounds).....	0.25
Vanadium (V ₂ O ₅ dust).....	0.5
(V ₂ O ₅ fume).....	0.1
Warfarin (3-(α -acetylbenzyl)-4-hydroxycoumarin).....	0.5
Yttrium.....	5
Zinc oxide fume.....	15
Zirconium compounds (as Zr).....	5

‡ Milligrams of dust, fume, or mist per cubic meter of air.

Radioactivity: For permissible concentrations of radioisotopes in air, see U. S. Department of Commerce, National Bureau of Standards, Handbook 69, "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure", June 5, 1959. Also, see U. S. Department of Commerce, National Bureau of Standards, Handbook 59, "Permissible Dose from External Sources of Ionizing Radiation", September 24, 1954, and addendum of April 15, 1958.

MINERAL AND NON-METALLIC INORGANIC DUSTS

Substance	M.P.P.C.F.‡
Silica	
Quartz	
High (above 50% free silica).....	5
Medium (5 to 50% free silica).....	20
Low (below 5% free silica).....	50
Cristobalite (above 5%).....	5
Amorphous.....	20
Silicates	
Asbestos.....	5
Mica.....	20
Portland Cement.....	50
Soapstone.....	20
Talc.....	20
Miscellaneous:	
Aluminum Oxide.....	50