Dust, Fumes, Gases and Vapors

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Maintenance of Exhaust Systems An Important Safety Measure

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In recent years the safety engineer's responsibilities have increased by leaps and bounds. Under his widening control logically comes the checking of exhaust systems for the control of hazardous dusts and fumes.

This discussion will assume that such hazards are evaluated by the industrial hygienist or safety engineer. Where exhaust ventilation is required, the ventilation engineer makes recommendations for exhaust capacities, system and hood design to control the condition. It will be further assumed that this coordination results in an effective exhaust system removing the dust or fumes at the points of generation and preventing their dispersion to the workroom. Consequently, unless the process is changed, the hoods or enclosures altered, or the method of material handling revised, the hazard should remain controlled as long as the exhaust system functions *properly*. The word "properly" can rightly be underscored because in many cases little attention is given to such an installation after the project has been completed. Yet mechanical exhaust equipment and dust collectors require the same attention that machine tool and other plant equipment require and usually receive.

If this precept is correct, a discussion of fundamentals may assist the safety engineer in quickly setting up a routine check on the performance of an exhaust system and catching any reduction in the system's effectiveness. The tools required under most cases are a manometer (U-Gage), and a short piece of rubber tubing. The engineer must also have an understanding of static pressure losses and hood suction.

While hood suction readings have rightfully fallen into a state of ill repute as a means of measuring air flow, they do offer a quick and accurate method of measuring relative air flow. If the hood suction is known while an exhaust system is functioning properly, its continued effectiveness can be assured as long as the hood suction does not reduce from its original value. An expansion of this statement should indicate why this simple measurement can be used as a ready check.

The Exhaust System

Exhaust ventilation is by far the most predominant means of controlling dust hazards. The fundamental elements and the design are not altered, whether the purpose of the exhaust system is to remove toxic or explosive particles, or simply to prevent dispersion for reduction in workman fatigue, improvement of visibility or general betterment of working conditions. In most cases the system will

include hoods or enclosures that surround dust producing areas as completely as possible and as close to the source of dust generation as feasible and branch ducts that are connected to the hood so an indraft of air can be maintained through the necessary hood openings—the velocity of the incoming air sufficiently high to prevent material flying outward. These velocities vary from 50 to 100 fpm for fumes and fine dusts, to 2000 fpm for large particles forcefully thrown toward openings in the enclosure.

The size of the duct connection is determined by the cubic feet of air to be exhausted and the velocity necessary to prevent settling in the ducts. Such velocities vary from 1000 fpm for fumes to 5000 fpm for heavy loads of coarse material.

Note that velocities have been gaged by smallness of particles and method of generation. Dust and fume particles are too small and have too great surface area to be influenced greatly by the specific gravity of the material. The same velocities are generally used to confine or convey the same size particle of wood or steel.

An exhauster is the usual air moving equipment that maintains the flow of air through hood and branches. It must have sufficient capacity to maintain the indraft at the hoods, and develop enough pressure to move that volume, overcoming the resistance to flow of air from inertia, turbulence, duct resistance and collector loss. A dust collector removes the entrained material from the exhaust system, concentrating the material for disposal, and preventing its re-entry to the workroom.

Definition of Hood Suction

In a branch duct close to the hood, a static pressure reading is called the hood suction. It is a measure of the pressure required to induce air flow at the required velocity in the branch (velocity pressure) plus the pressure lost in overcoming the resistance to air flow offered by the hood (entrance or acceleration loss).

Hood suction therefore is a function of the velocity of the air in the branch duct and the ease of getting that volume of air into the duct. (Effective dust control however, is a function of the indraft velocity at the hood and not a function of the hood suction except that velocities in the branch must be sufficient to convey the material without settling and obstructing the air flow by such accumulations).

An analogy and some illustrations may help to clarify this fundamental concept of exhaust system design:

An automobile requires more gas to accelerate from rest to 40 miles an hour than it does to travel the same distance at 40 miles per hour. Much of the power has been used to overcome inertia and give the auto a velocity pressure (energy not used in overcoming friction but available to coast after the engine is stopped or to be expended by braking if the car is stopped sooner). Similar energy is required to move air from relative rest in a workroom to the specified velocities in an exhaust duct. An automobile requires less gas to accomplish this acceleration on a smooth hard surfaced road than on a rough gravel or dirt road.

In like manner less energy (entrance loss) is required to move air through a flared hood which gradually changes its shape than through a hood with abrupt changes in shape or direction of air travel.

The actual static pressure reading (the hood suction) can vary widely dependent on the branch pipe velocities and hood entrance loss. However, once the hood design has been established and the branch pipe determined, *any change from the original hood suction can only indicate a change in velocity in the branch and consequently a change in air volume removed from the hood.* This relation will be true unless hood design has been changed which would effect the ease of exhausting the air volume (entrance loss), or obstructions or accumulations in hood or branch ahead of the point of hood suction reading. Restriction of the cross sectional area will reduce the air volume, although hood suction may even increase, dependent on location and degree of accumulation.

Measurement of Hood Suction

At the time of exhaust system installation, a $\frac{1}{16}$" hole should be drilled in each branch connection for static pressure (hood suction) readings. The hole should be perpendicular to the duct, in a straight section (4 to 6 diam-

eters long if possible) at least one diameter from hood or connecting elbow. Such small holes will be in addition to larger pitot tube holes for actual measurement of air flow.

A vertical U-Gage is satisfactory for static pressure readings above 0.8". Use an inclined design for lower values. Both designs are inexpensive. The vertical type can be made with a scale divided into tenths of an inch and a bent glass tube approximately ⅛" inside diameter mounted on a support.

The gage is leveled and zeroed and the length of rubber hose attached to the proper side (either side of the conventional U-Gage).

Reading consists of measuring the distance in inches between the top of the water columns in both legs of the U-Gage. Most manufactured gages use a special gage oil with scales calibrated for the specific gravity and with the reading indicated on only one leg of the gage. Be certain that the end of the rubber tubing is held tightly over the hole in the duct while the reading is taken. Folding over the end of the rubber hose assures a tighter fit. Check tubing for kinks or sharp bends that would close the passage.

The easily obtained static pressure reading not only furnishes an accurate check on performance, but the amount of change can be quickly calculated. It has been previously shown that hood suction is a static pressure equivalent to the velocity pressure in the branch plus the entrance loss which can be stated in terms of percentage of velocity pressure. Velocity pressure, entrance loss and most pressure losses vary as the square of the velocity of air flow.

if CFM_a = cubic feet of air per minute originally exhausted

CFM_b = cubic feet of air per minute exhausted during test.

SP_a = hood suction originally noted.

SP_b = hood suction during test

$$CFM_b = CFM_a \sqrt{\frac{SP_b}{SP_a}}$$

or in terms of conveying velocities in the branches—

FPM_a = feet per minute originally maintained

FPM_b = feet per minute during test.

$$FPM_b = FPM_a \sqrt{\frac{SP_b}{SP_a}}$$

From the above equations, it is possible to approximate the actual volume of air exhausted through a branch duct from the hood suction reading. Such approximations necessitate estimation of the entrance loss of the hood. Unless such estimates are based on considerable experience they are subject to appreciable error. Consequently, a pitot tube should be used for determination of original air volumes and the use of hood suction readings restricted to checking for change in exhaust volumes.

The pitot tube which measures the velocity of air flow in the duct can, of course, be used for routine check purposes instead of the static pressure method described above. In either case an understanding of hood suction is essential. The hood suction method of checking can more readily be delegated to an assistant without technical training than the pitot tube where care must be exercised in reading velocity pressures in the correct location with the tube paralleling the flow of air. U-gages have been standard plant equipment long enough to eliminate any feeling of uncertainty in its use.

As pressure readings vary as the square of the velocity or volume in question, a slight change is magnified by comparison of gage values. Normally, a reduction of volume or velocity of 10 to 15% will not be sufficient to reduce the effectiveness of the exhaust system. This range is the equivalent to a reduction in static pressure readings of 21 to 32%.

Causes for Reduction in Hood Suction

A marked reduction in hood suction can often be traced to one or more of the following items: reduced performance by the exhaust fan caused by reduced speed due to belt slippage, wear on rotor or casing, or accumulation in rotor or casing that would obstruct air flow;

Reduced performance caused by defects in the exhaust piping such as accumulations in branch or main ducts due to insufficient conveying velocities, condensation of oil or water vapors on duct walls, adhesive characteristics

of material exhausted, or leakage losses caused by loose cleanout doors, broken joints, holes worn in duct (most frequent in elbows), poor connection to exhauster inlet.

Losses in suction can also be charged to additional exhaust points added to the system (sometimes systems are designed for future connections and more air than required is handled by present branches until future connections are made), change of setting of blast gates in branch lines (blast gates adjust the air distribution between the various branches. Tampering with blast gates can seriously affect such distribution and therefore gates should be locked in place immediately after system has been installed and its effectiveness checked). Increased pressure loss through dust collector due to lack of maintenance, improper operation, wear, etc. vary with the collector design. Refer to operation and maintenance instructions furnished with the collector or consult the equipment manufacturer.

Testing Toxic Atmospheres

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In manufacturing, many operations and processes of one industry are common to those of another, although the two industries may be engaged in the production of entirely different types of goods. For example, welding is used very extensively throughout the aviation, shipbuilding, automobile and steel industries; this applies also to spray painting, electroplating, buffing, grinding, and many other operations. Similarly with raw materials, various kinds of acids, organic solvents, etc., are found in almost any type of plant. For this reason there are certain industrial poisons which appear much more frequently than others and which may be found throughout the entire defense industry. Some of these are:

Dusts	Toluene
Carbon Monoxide	Xylene
Hydrogen Sulfide	Trichloroethylene
Hydrogen Cyanide	Carbontetrachloride
Sulfur Dioxide	Carbon Disulfide
Oxides of Nitrogen	Nitric Acid
Ammonia	Chromic Acid
Phosgen	Hydrofluoric Acid
Lead	Hydrochloric Acid
Cadmium	Sulfuric Acid
Benzene	

Others which are more directly associated with specific industries are:

Trinitrotoluene (dust and vapors)
Ammonium Picrate (dust)
Mercury (vapors)
Aniline
Radon
Thoron

As will be seen by examination of the above list, some of these substances are present as raw materials; others are final products, while a third group occurs as by-products generated in the various operations. Typical of the first group are the various acids, organic solvents, chlorinated hydrocarbons, ammonia, and carbon disulfide. In the second class we have TNT and ammonium picrate, while the remainder are commonly occurring dusts, fumes, gases and vapors of a toxic nature generated in various industrial processes. While the theoretical possibilities for exposure to toxic substances in the above industries are far too numerous for tabulation, this list represents those most commonly encountered.

Dusts

Silica-bearing inorganic dusts are probably found in all of the above industries. For example, mining of the iron ore in the steel industry presents exposures to free silica dust in considerable quantities. Buffing, polishing, and grinding operations done very

extensively in a great many industries, generate inorganic dusts, which for the most part consist of aluminum oxide and silicon carbide, but also include free silica in amorphous and crystaline forms.

For the purpose of quantitative determination, dusts may be divided roughly into three classes, as follows:

1. The inorganic type such as free silica and asbestos, which is collected and the number of particles per unit volume of air determined microscopically.

2. Organic dusts of natural origin, the amount of which is usually determined by weight. Typical of these are tobacco and flour dusts.

3. Synthetically manufactured organic compounds which may occur in the form of dusts, such as TNT and ammonium picrate. These substances when present as air contaminants in low concentrations are generally evaluated quantitatively by chemical means.

Besides above types, there are also metallic dusts such as lead, zinc, cadmium, manganese, etc., some of which will be discussed under another heading.

Inorganic Dusts

The most common method for evaluation of this type of dust is to collect air samples in liquid solutions by means of an impinger (1) and to make the quantitative determination microscopically. When calculating the dust concentration, usually expressed in number of particles per cubic foot of air, the microscopic calibration factor, the volume of the sampling liquid, and the size of the air sample are taken into consideration.

The sampling procedure, microscopic arrangement, and calculations are extremely simple, but the actual counting is a tedious job associated with severe eye strain and requires considerable experience before dust counts can be relied upon. In recent years the microprojection method (2) has been used for counting of impinger samples. With this method in which the microscopic field is projected on a translucent screen, the eye strain experienced in direct microscopic work, is eliminated.

Other methods for evaluation of this type of dust are by means of electrostatic precipitators (3) and various types of "grab" samplers. With the electrostatic precipitator, the dust is collected in a dry state and either weighed as is, or suspended in water and counted in a manner similar to that employed with the impinger method. Several of the grab samplers have microscopes incorporated with the sampling device and these are calibrated in such a manner that the number of particles per cubic foot of air can readily be obtained by almost instantaneous readings (4).

Organic Dusts (Natural)

This group as a rule is not classified by medical authorities as fibrosis producing dusts, and hardly warrants any discussion in this paper. While claims do exist to the effect that some dusts in this class have produced respiratory irritation, bronchitis, asthma, etc., these dusts are generally looked upon as nuisances rather than occupational disease producers. No official physiological threshold limits have been established and sampling of this type of dust for the purpose of evaluating an occupational disease hazard has little or no meaning.

Most of these dusts, however, are explosive when dispersed in certain proportions in the air and require control from this point of view. Considerable work to establish explosive limits for this type of dust has been done by the United States Department of Agriculture.

Synthetic Dusts

In the manufacture of TNT and ammonium picrate, both of which represent basic war industries, we are confronted with toxic raw materials as well as hygienically injurious final products. In this industry great quantities of toluene, anhydrous ammonia, sulfuric and nitric acids are used, all of which are classified as industrial poisons. TNT and ammonium picrate are themselves systemic poisons as well as skin irritants known to have produced fatalities and severe cases of dermatitis.

A method for sampling and determination of TNT was described recently by Pinto and Fahy. (5) This procedure calls for the use of 10 c.c. of isopropyl alcohol in the midget

impinger. The chemical determination is based on the reduction of TNT to triaminotoluene, and finally, a colorimetric comparison with known standards.

Ammonium picrate is highly soluble in water which therefore can be used as the collection medium in an impinger when sampling for this material in industrial atmospheres. The deep color which results upon solution of ammonium picrate in water is also evident in extremely low concentrations and for this reason a direct colorimetric comparison of the sample with known standards can be made. With this method there is a possibility of interference from dinitrophenol, the extent of which has not been determined (6).

Carbon Monoxide

This is a very toxic gas encountered in various industrial activities. The toxic limit for this gas is generally accepted as 100 p.p.m. for prolonged exposure. To the public in general its presence is most commonly associated with automobile exhaust and gas burning appliances utilizing manufactured gas with a high percentage of carbon monoxide. As a result of incomplete combustion it may also be present when burning natural gas or other fuels. In industrial operations involving baking ovens, drying kilns, coke ovens, blast furnaces, etc. carbon monoxide is frequently encountered. In industrial processes in general, and particularly where chemical reactions are involved, carbon monoxide may be generated as a dangerous by-product. In prism grinding, which is closely allied with the defense industry, a high quality iron oxide rouge is required. Occasionally this material is manufactured on the premises as an adjunct to the prism grinding work. This involves the use of oxalic acid for production of iron oxalate which is later decomposed by heat to yield iron oxide rouge. In this process carbon monoxide as well as other gases are generated.

Several methods have been developed for the quantitative determination of carbon monoxide, but only the two most expedient procedures employed in industrial hygiene work will be discussed here. One of these is the carbon monoxide indicator based on the catalytic reaction of hopcalite which oxidizes carbon monoxide to carbon dioxide. The small electric current produced by the heat of the reaction through a thermocouple is calibrated in terms of carbon monoxide concentration which is read directly on the dial of a milliammeter. The source of suction in this instrument is a small centrifugal blower, the motor of which is operated either from a built-in 6 volt battery or from a 110 volt lighting circuit through a transformer.

Another convenient method for estimation of carbon monoxide though less sensitive and not so accurate is the use of palladium chloride ampoules. In this reaction the palladium chloride is reduced to metallic palladium thereby producing a stain, the intensity of which is in direct proportion to the amount of carbon monoxide in the atmosphere under observation. The stain produced is compared to known color standards for evaluation of the carbon monoxide present. This method is not specific for carbon monoxide, however; three are other reducing gases which also will produce a stain in the presence of palladium chloride. Incidentally, the standard method for carbon monoxide evaluation, adopted by the British Department of Industrial Research (7) consists of a palladium chloride test paper through which the air to be sampled is drawn by means of a handpump. The stain thus produced is compared with a standard color chart.

Hydrogen Sulfide

Hydrogen sulfide is a very toxic gas with a disagreeable odor. It is found in many industrial operations where sulfur or sulfur compounds are used, but primarily it is encountered in the artificial silk, chemical and petroleum industries. Safe limits varying between 20 and 50 p.p.m. by volume have been suggested by various State authorities in this country.

The most rapid method for determination of hydrogen sulfide is undoubtedly the use of a hand operated instrument consisting essentially of an aspirator bulb and a detector tube through which the air sample is drawn. The detector tube contains a chemical substance which when in contact with hydrogen sulfide produces a discoloration the length of which is in proportion to the amount of hydrogen sulfide present and can be measured on an attached scale. It can also be determined iodometrically, either by bubbling

through a sodium hydroxide solution and titrating with iodine, or by bubbling through potassium iodide starch solution and a measured amount of standard iodine in which reaction the disappearance of the color indicates the end point (8).

Hydrogen Cyanide

This gas for which the industrial hygiene bureaus of California, Connecticut and Massachusetts have established a safe limit of 20 p.p.m. by volume, is found in electroplating operations, heat treating, etc.

A portable instrument of the type discussed in connection with hydrogen sulfide, has been developed for hydrogen cyanide also. I have been informed, however, that the hydrogen cyanide detector in its original form proved less satisfactory and that it has been withdrawn from the market temporarily pending further research.

Chemical tests are available for detection of hydrogen cyanide, such as the prussian blue and thiocyanate reactions, both of which are specific for this gas but allegedly not sensitive enough for concentrations encountered in industrial hygiene work. Other methods suitable for determination of this gas in small concentrations are the Congo red-silver nitrate and the benzidine–copper acetate test papers. These methods, which have been adopted as standard tests by the British Department of Industrial Research, are non-specific, however, so that the possible interference of other gases such as HCL, H_2N, SO_2 and H_2S should be taken into consideration.

In a method suggested by the Air Hygiene Foundation (A.H.F.) the air sample is bubbled through 0.5 per cent potassium hydroxide after which the determination is made by titrating with silver nitrate (9).

Sulfur Dioxide

Exposures to sulfur dioxide gas are common in the petroleum industry, rubber works, and sulfuric acid manufacturing. Sulfur dioxide is also encountered in bone and glue works, magnesium foundries, and other industries where sulfur compounds are used. It is an extremely irritating gas for which a threshold limit of 10 p.p.m. has been suggested.

For the testing of sulfur dioxide, the American Public Health Association (A.P.H.A.) (10) refers to an iodometric method (11) by means of which the air sample is passed through a gas wash bottle containing a measured amount of standard iodine in potassium iodide-starch solution. The disappearance of the color indicates the end of the test, after which the amount of sulfur dioxide present can be calculated.

The British Department of Industrial Research employs a starch-potassium iodate test paper through which the air sample is drawn by means of a handpump. The sulfur dioxide reduces the iodate to iodine with the production of a stain the degree of which is compared to known color standards.

Oxides of Nitrogen

This is a group of gases, some of which are extremely toxic. They are produced when nitric acid comes in contact with organic materials and certain metals; during chemical nitration processes and burning of nitrated materials; they are also present in small quantities during electrical discharges in the air. Above gases may, therefore, be found in such industries and operations as ammunition works, photographic film manufacturing, nitric acid plants, electroplating (bright dipping), detonation of explosives, electric welding, etc.

During the chemical reactions that accompany above operations, a mixture of oxides are formed. The hazardous nature of this group, also called "nitrous fumes" is due primarily to the nitrogen dioxide, a reddish brown gas which reacts with water and upon respiration forms nitric acid in the lungs. The result is often pulmonary edema which frequently proves fatal. The fact that the respiration of these gases does not produce any immediate discomfort in spit of their toxicity, makes them doubly dangerous. A person may be exposed to these fumes and experience only a slight respiratory irritation immediately following the exposure, while the case may develop into a fatal condition by next day.

For example, I know of a case in a nitric acid plant where a man was engaged in filling nitric acid into carboys in a department with a wooden floor. One of the carboys accidentally broke causing the acid to

flow over the wooden floor producing the brown nitrogen dioxide gas in great volumes. The operator not being familiar with the toxicity of this gas and experiencing no immediate physiological warning, remained on the job attempting to clean the floor by mopping up the acid, instead of leaving the work place for fresh air. As a result a considerable portion of this gas was probably inhaled. He became seriously ill a few hours later and died within 48 hours. Cases of men becoming sick while doing electric welding inside tanks or in other confined spaces are often referred to in the literature. Many of these cases are undoubtedly due to oxides of nitrogen generated in the electric arc.

While there are several methods known for the quantitative determination of oxides of nitrogen, testing for these air contaminants is not so simple as that for some of the others discussed in this paper. Incidentally, in view of the cumbersome procedures involved in testing for these gases, the amount of ventilation required for their control after blasting in mining and tunnel work is sometimes based on the amount of carbon monoxide present, which can readily be determined. With explosives designed for a low oxygen balance resulting in a relatively high carbon monoxide concentration and correspondingly low volumes of oxides of nitrogen, this is a safe and expedient procedure.

For actual detection of nitrogen dioxide, the method employing starch-potassium iodide test paper is probably the best known. This paper when damp is colored blue in the presence of nitrogen dioxide. The method is non-specific, however. Other, specific methods for evaluation of nitrogen dioxide, and sensitive at low concentrations are the Griess-Ilosvay and the Bismarck Brown tests. With both methods, the air sample is bubbled through chemical solutions after which the quantitative determinations are made in the laboratory by colorimetric analysis. Although physiological safe limits up to 40 p.p.m. have been proposed for these gases, atmospheres which by odor or color indicate the presence of nitrous fumes should always be viewed with suspicion.

Ammonia

As stated elsewhere, ammonia is an important raw material throughout the chemical industry. It is a strong respiratory irritant for which safe limits ranging between 50 and 85 p.p.m. have been recommended (Russian investigators 13-39 p.p.m.; State of Massachusetts 50 p.p.m.; Flury and Zernik 85 p.p.m.).

Ammonia vapors can be evaluated directly in the field by bubbling the air sample through a measured volume of 0.1 N hydrochloric acid in water solution using phenolphthalein as an indicator; the appearance of a pink color indicates the end point. From the amount of acid used and the size of the air sample, the concentration of ammonia vapors can be calculated (8).

Sulfuric acid can also be used with above method. In another method, recommended by the A.P.H.A., the air sample is collected in sulfuric acid, but the final evaluation is made in the laboratory by standard analytical means.

Lead

Exposure to this metal occurs very extensively in nearly all types of manufacturing. The most frequently encountered forms of lead are fumes, dust and dispersed pigments. These occur around lead melting operations, soldering, welding of metals covered with lead-bearing paints, and in spray painting work.

Sampling of lead-contaminated atmospheres is usually done either by means of the impinger or by the electrostatic precipitator. When the impinger is used, as is frequently the case when investigating spray painting and many other types of work involving lead dispersion, the sampling liquid may be either distilled water or dilute nitric acid.

Regardless of the collection method used, the final evaluation of the amount of lead present is done in the laboratory by various analytical methods, the description of which is beyond the scope of this paper. It probably should be emphasized, however, that although some of these methods are highly sensitive and the experienced analysts usually well-trained to handle minute quantities of lead in their work, it is preferable to take large air samples wherever possible to facilitate the laboratory work. With the large impinger and the electro-static precipitator

with sampling rates of 1 and 3 cubic feet of air per minute respectively, this is not a problem. With the midget impinger, on the other hand, with a sampling rate of only 0.1 cubic foot per minute, this becomes a tiresome task, especially if the handcranked instrument is used. Let us take, for example, a case in which the atmospheric lead dispersion is just about on the border line of the safe limit, i. e. 1.5 mg. per 10 cubic meters of air. For a 30 minute sample with the midget impinger, only 3 cubic feet of air have been handled. This represents only 0.013 mg. of lead in the air sample, which evidently requires a fairly sensitive analytical method and careful handling for a successful completion of the test.

Cadmium

The United States Public Health Service (U.S.P.H.S.) (16) suggests as a safe limit with respect to toxicity of cadmium fumes a concentration of 1 mg. per 10 cubic meters of air.

The metal is used extensively as a coating of iron and steel for rust prevention, as well as in structural steel to impart certain properties. Exposures to cadmium and cadmium fumes may, therefore, be encountered in such operations as electroplating, welding of cadmium-bearing iron and steel as well as many other processes where work involves cadmium-plated articles. Some of you are probably familiar with the cases of cadmium intoxication in a plant in Ontario, Canada, a few years ago, when 14 persons were poisoned—two fatally—during annealing of cadmium plated rivets (17).

As in the case of lead, sampling for cadmium fumes or dust may be done either with the impinger (with water as collection medium—A.P.H.A.) or by the electrostatic precipitator and the samples evaluated in the laboratory by gravimetric or colorimetric analytical methods.

At this point it probably should be brought out that for sampling of metal fumes, the impinger has a lower collecting efficiency than the electrostatic precipitator, which should be taken into consideration when comparing results obtained on samples collected with the two instruments (18).

Mercury

The present emergency has greatly accelerated the use of mercury, not only in our ammunition works, but also in many other plants directly or indirectly connected with the defense industry. In some cases entirely new uses have been introduced for this metal. For example, a recent development is an anti-fouling paint containing mercury, now used in our shipyards. Application of this mercury-bearing paint by means of spraying naturally introduces a serious exposure to mercury poisoning and calls for careful control; this applies also to the manufacture of the paint. Due to the great demand for mercury and the shutting off of foreign supplies, many old mercury mines are now being reopened so that refining of this metal with accompanying occupational disease hazards has expanded considerably during the past year.

The toxic properties of mercury as a respiratory hazard when present in the form of vapors or in a finely divided metallic state are probably fairly well-known to most men concerned with industrial health. A safe limit, toxicologically, of about 2 mg. per 10 cubic meters of air appears to be generally accepted for inhalation exposures. Although the metal has a relatively low vapor pressure at ordinary temperatures, investigations have shown that sufficient vapors are emitted to produce a mercury hazard in rooms where this material is used in metallic form.

A number of methods are available for the evaluation of mercury vapors in air. One of the most expedient procedures is probably by means of the Nordlander apparatus utilizing a selenium sulfide test paper, the color of which darkens in the presence of mercury. The amount of mercury present is estimated by comparing the degree of darkening with a standard color chart.

Another more recently developed method involves an optical instrument based on the opacity of mercury vapors to ultra violet light of a certain wave length. In this instrument, therefore, when ultra violet light of a specific wave-length is directed towards a phototube, interfering mercury vapor will reduce the light received by the phototube and consequently also its current flow, which in turn is calibrated in terms of mercury concentration. This instrument is not specific as it is

subject to other light intercepting media such as smoke and fog.

There are also other methods for determinations of mercury, entailing condensation of the vapors and subsequent electrolytic deposition of the metal, chemical reaction methods, etc. The first two mentioned above, however, are the most expedient and yield immediate results during the field investigations.

Benzene (Benzol), Toluene and Xylene

These three aromatic hydrocarbons are widely used as industrial solvents and ingredients in a number of chemical reactions. Toluene, for example, is an important raw material in our ammunition manufacturing, especially in the production of trinitrotoluene. With the increased demand for toluene and the corresponding scarcity of this material, benzene is rapidly taking its place as a solvent in many industries. Xylene, which besides being an important solvent, also does enter as a raw material in certain chemical processes, at present associated with the defense industry and therefore used in great quantities. For instance, in a plant I visited recently xylene is used in the production of a certain type of resin, which in turn is employed in an article manufactured for the United States Army.

All these three materials are classified as industrial poisons, although there appears to be some confusion as to the relative toxicity of each. Benzene is generally considered as the worst offender, although this may not be due to a greater toxicity of the material *per se* but to the fact that it has a higher vapor pressure than the other two so that for a given temperature more of it will be found in the air. However that may be, the toxic effect of all of them, once dispersed in the air, is generally recognized and therefore indicates the need for strict control wherever they are used.

For the evaluation of these materials some chemical as well as physical methods are available. Most of these, however, are complicated and cumbersome, involving such operations as nitration by bubbling the air through nitric acid with subsequent colorimetric determination, or condensation of the vapors followed up by laboratory analytical procedures for the final evaluation. While methods of this type may be satisfactory for scientific purposes, for routine sampling in control work in industrial plants, a combustible gas indicator is far more expedient. Most of these devices, used primarily for fire prevention work, are designed to read to within 1% of the lower explosive limit of the gas or vapor under test. For above substances with lower explosive limits around 1% by volume, this means that concentrations down to 100 p.p.m. can be detected, which is approximately the accepted toxic limit for these solvents. For benzene with a safe limit of 75 p.p.m. (19) a modified combustible gas indicator has been placed on the market, which measures concentrations ranging between 0 and 1000 p.p.m. A spectroscopic method for determination of benzene and toluene in air has been described by Cole (20).

Chlorinated Hydrocarbons

Of these, trichloroethylene and carbon tetrachloride are probably most frequently found. They are used extensively as metal cleaning agents; the former in regular degreasing machines on a production basis and the latter for work of a more occasional nature. These materials with their grease dissolving properties are regarded by medical authorities as very injurious to the fatty tissues of the human body.

As in the case of other substances referred to above, there are chemical methods for quantitative determination of vapors from these materials, but they are mostly too cumbersome for routine sampling. Optical instruments are available, however, for rapid evaluation of such vapors dispersed in the air. The best known of these is probably the portable interferometer in which the difference between the refraction of air (the comparison substance) and that of the gas mixture to be examined is measured. This difference is calibrated in terms of concentration of the gas or gases under observation. Naturally the same readings will be obtained for all gas mixtures resulting in the same refractive index, so the instrument is therefore not specific. With information, however, as to the type of air contaminant concerned in a particular problem it is an exceedingly useful instrument applicable to the investigation of a great variety of gases and vapors.

Carbon Disulfide

This substance which at ordinary temperatures occurs as a liquid with a high vapor pressure, generates toxic vapors for which

relatively low safe limits have been suggested by various authorities. Russian investigators have recommended a threshold limit of only 3 p.p.m. for prolonged exposures, while the British Department of Scientific and Industrial Research has suggested a value of 10 p.p.m. and our own State of Massachusetts, 20 p.p.m. While there is a wide divergence between these values, they all tend to indicate the potential dangers connected with exposures to vapors of carbon disulfide.

Although this solvent may be encountered in a great many industrial operations, it is found primarily in the viscose—and rubber industries where it constitutes an important raw material.

For evaluation of these vapors, the Air Hygiene Foundation recommends drawing the air through an alcoholic potassium hydroxide solution to form potassium ethyl xanthate which is determined iodometrically. The British Department of Scientific and Industrial Research uses a colorimetric method consisting of bubbling the air through diethylamine and copper acetate forming a colored compound the intensity of which is compared with standards. In view of the inflammability of these vapors, a rapid method of their evaluation in high concentrations would be by means of a combustible gas indicator. Unfortunately, however, the sensitivities of these instruments as built at present, are not low enough to get within the physiological safety range of this material.

Acids

In this group probably nitric, chromic, hydrofluoric, hydrochloric and sulfuric acids are those most commonly encountered. Of these, nitric acid has been discussed under another heading. Exposures to chromic acid resulting in chrome ulcers and the perforated nasal septum are frequently found around chromium plating tanks. A safe limit of 1 mg. per 10 cubic meters of air has been established for chromic acid which in electroplating work occurs as a mist over the plating baths. Hydrofluoric and hydrochloric acids also exist in gaseous form as hydrogen fluoride and hydrogen chloride respectively. A safe limit of 3 p.p.m. has been suggested for the former, while it has been set at 10 p.p.m. for the latter.

Sampling for nitric, chromic, and sulfuric acids is usually done by bubbling through a sodium hydroxide solution; hydrofluoric acid through potassium hydroxide; and hydrochloric acid through glycerol-potassium carbonate-water solution. For the final laboratory evaluation I refer to standard methods of the A.P.H.A.

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Leaflet No. 5—Nitrous Fumes
Leaflet No. 6—Carbon Disulfide
Leaflet No. 7—Carbon Monoxide
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Selection, Use and Maintenance of Respiratory Protective Devices*

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There are several well-recognized procedures for controlling exposure to hazardous atmospheres in industry. They include (a) substitution of less toxic material, (b) enclosure of processes, (c) wet methods, (d) local exhaust, (e) general ventilation, and (f) use of respiratory protective devices. In addition to their employment as a control measure in occupational exposures, respiratory protective devices also are essential in emergencies that may arise from failure or improper use of other control equipment.

Respiratory protective devices usually are employed to supplement other methods of control, as a temporary expedient, or when other methods are not readily applicable or practicable. It seems reasonable to assume, however, that where respirators are used, consideration has been given to the factors involved, and that the devices can provide satisfactory protection if used properly. Their use should not be arrived at simply by a process of elimination of other methods that are more difficult to apply.

Atmospheric contaminants include gases, vapors, dusts, fumes, mists, and fogs. Respiratory protection against these contaminants may be required for concentrations that are immediately dangerous to health or life

after comparatively short exposures, or that may produce injury only after prolonged or repeated exposures. Also, it may be necessary to use such devices against a single type of contaminant, against a combination of various types, or in atmospheres deficient in oxygen.

To meet the conditions mentioned, various types of respirators have been developed. Two basic principles have been utilized in their development—purification of the inhaled air by removal of the contaminant (air-purifying respirators) and supplying a respirable atmosphere to the wearer from an uncontaminated source (atmosphere—air or oxygen-supplying respirators).

Air-Purifying Respirators

Air-purifying respirators include canister gas masks and chemical cartridge respirators for removing gaseous contaminants and mechanical-filter respirators for removing particulate matter or dispersoids. Canister gas masks and chemical cartridge respirators may be equipped with filters for removing dispersoids, thereby giving protection against both gaseous and particulate contaminants. As these devices provide protection only by removing contaminants, it is obvious that sufficient oxygen must be present in the atmosphere to support life.

A canister gas mask usually consists of a full facepiece connected by a flexible breathing tube to a canister that may be carried in a harness on the chest, under the arm, or on the back. The canister contains the materials for removing the contaminants and purifying the air. These materials remove the contaminants either by chemical reaction or by physical absorption, as on activated charcoal. As no single substance has been discovered that will remove all types of gaseous contaminants, the canister fill depends on the type of contaminant against which it is designed to protect. Fortunately, materials are available that will protect against groups of compounds; therefore, a multiplicity of materials is not required.

For example, activated charcoal will absorb organic vapors, and alkaline materials such as soda lime and caustite will remove acid gases. Ammonia may be removed by silica gel or by various materials impregnated with such substances as copper or cobalt salts. Carbon monoxide is removed by catalytic oxidation to carbon dioxide by Hopcalite, a special preparation of manganese and copper oxides. The protection that a canister affords depends on the material with which it is filled. For example, a canister may be filled with activated charcoal alone and give protection only against organic vapors, or it may be filled with all types of the materials mentioned and give protection against all gaseous contaminants. For protection against a single contaminant the use of a single absorbent is desirable, as the life of the canister is longer, thus providing more economical protection.

It is therefore extremely important to know the contaminants against which a canister will protect. To assist users in easy identification, a classification of gas-mask canisters has been developed in conjunction with a color code. This code, which is an American standard used by all manufacturers of gas masks in the United States, is as follows:

Canister, type letter	Contaminants proctected against—	Colors
A	Acid gases	White.[a]
B	Organic vapors	Black.[a]
C	Ammonia	Green.
D	Carbon monoxide	Blue.
AE, etc.	Dusts, fumes, mists, fogs, and smokes in combination with any of the above gases or vapors	One-half inch contrasting black or white stripe around the canister near the top.
AB	Acid gases and organic vapors	Yellow.
ABC	Acid gases, organic vapors, and ammonia	Brown.
N	All of the above atmospheric contaminants	Red. Filters are included in this canister, but stripes to indicate them are unnecessary.

[a]Canisters for a single gas or vapor other than ammonia or carbon monoxide shall have a ½-inch colored stripe around the canister near the bottom. The color of the stripe will be assigned.

Canister gas masks have been developed primarily for protection against atmospheres immediately dangerous to life and are used mainly in emergencies. Therefore, first consideration has been given to complete respiratory protection to prevent even momentary failure that might result fatally. These masks, however, are not designed for protection against extremely high concentrations, and in Bureau of Mines Approval Schedule 14E concentrations are limited to two per cent by volume, with the exception of ammonia, for which the limit is three per cent. The service life of the canister depends on the individual characteristics and the amount of absorptive material used. Although these masks are designed primarily for emergency use, they will, of course, give good protection for non-emergency situations, and filters may be incorporated to remove particulate matter.

Chemical cartridge respirators usually consist of a small cartridge or canister attached directly to a half-mask facepiece. The materials for removing the contaminants are the same or similar to those used in canister gas masks, and filters may be incorporated to remove particulate matter. These devices may be considered small gas masks and are designed for protection in atmospheres that could be breathed by workmen without protection, but that might be irritating or disagreeable or produce injury to health after prolonged or repeated daily exposures; hence, primary consideration has been given to lightness, compactness, and comfort.

Mechanical-filter respirators usually consist of a filter arrangement of some fibrous material such as felt or paper, in a holder connected directly to a half-mask facepiece. The filter consists of fine fibers criss-crossed to form a maze or intricate network of tortuous passages. The dust, fume, mist, and fog are removed by physical trapping when the air is drawn through this material. The filtering efficiency increases as the dust load on the filter increases. The service life of the filter, therefore, does not depend on recognizable leakage, as does that of the gas masks, but on increase in resistance of the filter to a point where resistance to inhalation becomes excessive or uncomfortable. Although the filters will remove all types of particulate matter, the extent to which the material is removed depends on the characteristics of the particles, such as size and state. Also, the amount of permissible leakage depends on the toxicological significance of the material. Therefore, various types of filters are used; that is, a filter may be satisfactory for silica dust and not satisfactory for a toxic dust such as lead or cadmium, owing to the greater toxicity of the latter. A filter that is satisfactory for dust (mechanically generated, as by grinding) may not be satisfactory for fume produced by heating or burning, as in lead burning, owing to particle-size differences. On the other hand, a filter satisfactory for silica dust is considered satisfactory for all other fibrosis-producing dusts and nuisance dusts; and a filter considered satisfactory for lead dust is considered satisfactory for other toxic dusts, the toxicity of which does not exceed significantly that of lead.

Mechanical-filter respirators have been designed for protection against atmospheres that are not immediately harmful; therefore, primary consideration has been given to lightness, compactness, and comfort.

Atmosphere-Supplying Respirators

Respiratory protective equipment that supplies a respirable atmosphere from a source independent of the wearer's immediate atmospheric environment is of two basic types—a hose type, in which air from an uncontaminated source is conveyed to the wearer through a hose or tube, and a self-contained type, in which a supply of oxygen is carried by the wearer.

The air-supplying respirators commercially available may be divided into three types: Hose masks, air-line respirators, and abrasive blasting helmets, hoods, or masks.

Hose masks consist of a tight-fitting, full facepiece, breathing tube or tubes, a harness, a comparatively large-diameter, noncollapsible hose line, and a hand-operated blower. The harness and hose are strong enough for retrieving the wearer in an emergency, and the hose must not collapse under heavy weight and must not kink. The maximum length of hose approved by the Bureau of Mines is 150 feet. The use of a hand-operated blower assures that a second person will be present in the event of difficulty. Also, the attachment of the hose to the blower and the large diameter of the hose permit breathing without undue resistance, even though the blower is not operated. The

intake to the blower must be in uncontaminated air.

Hose masks are sturdily constructed, as they are designed to be worn in atmospheres immediately dangerous to life and to afford protection against all types of atmospheric contaminants and atmospheres deficient in oxygen.

Special-type hose masks without blower and generally used with about 25 feet of hose also are available. Although the hose, breathing tubes, and facepieces are essentially the same as those for hose masks with a blower, the harness is much lighter and the device is designed for lightness, compactness, economy, and simplicity of operation. Such masks are designed for non-emergency use or for use in atmospheres not immediately dangerous to life.

Air-line respirators usually consist of a high-pressure air-supply system, a hose of relatively small internal diameter, a detachable coupling, and either a full or half-mask facepiece, or even a helmet or a hood. As the air for this type of respirator usually is supplied from a high-pressure compressed-air system, it must be checked to see that it does not contain objectionable or harmful contaminants. Dust from dust, oil mists, odors; and even carbon monoxide may be present if the compressor becomes too hot; therefore, critical attention should be given to the air supplied to these devices.

Although this respirator will give respiratory protection against all types of contaminants, it is designed for routine protection against concentrations of contaminants that are not immediately dangerous to life or health. It is thus limited, owing to the possibility of leakage around the half-mask facepiece and also to the fact that no provision is made so that the wearer can breathe respirable air, should the air supply fail.

Abrasive blasting respirators are essentially air-supplying respirators that have been modified by the addition of a suitable covering to protect the head and shoulders against impact and abrasion by rebounding material. They are designed primarily for use in abrasive blasting operations and not for use in atmospheres that are immediately dangerous to life.

The most common devices for supplying oxygen to the wearer are self-contained oxygen breathing apparatus. These apparatus consist of a cylinder of compressed oxygen, a reducing valve, an admission valve, a breathing bag, breathing tubes and mouthpiece with valves for direction of inspired and exhaled air, a regenerator for removing carbon dioxide, and a cooler. They operate on a closed-circuit principle, and the entire device is worn by the user. When the cylinder valve is opened the oxygen flows through the reducing valve, thence through the admission valve, into the breathing bag, until the bag is expanded to a point at which the admission valve automatically cuts off the supply of oxygen. Oxygen is breathed from the bag, and the exhaled air passes through the regenerator to permit removal of carbon dioxide, thence through a cooler, and back to the bag. As oxygen is consumed, the bag tends to collapse, and the admission valve automatically admits additional oxygen.

Self-contained oxygen breathing apparatus give respiratory protection against all types of atmospheric contaminants in any concentration that can be endured by the skin but require gas-tight goggles in atmospheres irritating to the eyes. They also protect against atmospheres deficient in oxygen and are designed for protection against atmospheres that are immediately dangerous to life.

Selection of Respirators

The use of respiratory protective devices as a control procedure requires as much consideration as any other control method. In the selection of a respirator, thorough consideration should be given to various factors involved, such as:

a. the chemical, physical, and toxicological properties of the substances against which protection is required

b. the effect of the processes and conditions of use of the substances as they relate to the possible formation of significant secondary products

c. the processes and conditions of their use as they relate to the dissemination of contaminants

d. an evaluation of actual and potential hazards to determine whether conditions immediately dangerous to life or health might arise or whether injurious effects would be produced only after prolonged or repeated exposures

e. the nature of the duties to be performed by the wearer of protective devices as they relate particularly to restriction of movements

f. an understanding of the principles, design, scope of use, limitations, advantages, and disadvantages of the respiratory protective equipment available.

Virtually all applications of respiratory protective devices are specific and require individual attention. Examples of typical conditions with indication of choice of appropriate respiratory protection are given.

Atmospheres deficient in oxygen may be extremely hazardous and immediately dangerous to life. Only oxygen breathing apparatus or a hose mask with blower should be chosen for protection under such conditions. Final choice between these two devices will depend on working conditions.

For example, for rescue work in mines, the men must proceed for considerable distances from a source of fresh air. Obviously, hose masks would not be satisfactory, as wearers are limited to a distance of 150 feet; therefore, oxygen breathing apparatus must be used. However, for use in entering confined spaces, such as tanks and manholes, hose masks are generally preferred because they are easier to maintain and relatively little training is required to use them. Air-purifying devices should never be worn in atmospheres deficient in oxygen.

By very high concentrations is meant those exceeding two or three per cent. Either oxygen breathing apparatus or hose masks with blowers are the logical choice, and again final selection will depend on working conditions. Although gas masks might afford some protection, they would not be a good choice, because very high concentrations indicate a confined space with possibility of low oxygen; moreover, the absorbents would be used up rapidly. The marked discomfort produced by such irritating gases as ammonia and sulfur dioxide and the danger of poisoning through the skin by absorption of hydrogen cyanide limit the concentrations that can be entered.

Concentrations referred to here are those not exceeding approximately two per cent but nevertheless immediately dangerous to life. Oxygen breathing apparatus would, of course, be applicable, as would hose masks with blowers and gas masks. Owing to their weight and maintenance and training requirements, oxygen breathing apparatus probably would not be used. The hose mask would be satisfactory and might be chosen if the encumbrance of the hose line were not too great. The most probable choice would be a gas mask, because of its light weight, ease of maintenance, and the small amount of training required by the wearer. The appropriate canister should, of course, be chosen.

Low concentrations are atmospheres that can be breathed without protection but that will produce discomfort and possible chronic injury after repeated exposure to them. Hose masks and oxygen breathing apparatus would give satisfactory protection, but they would be given little consideration for such a situation for the reasons already outlined. Gas masks, chemical cartridge respirators, or air-line respirators would be satisfactory. Final choice would depend on actual conditions and freedom of movement required by the worker.

For pneumoconiosis-producing and nuisance dust, air-line respirators and pneumoconiosis-producing- and nuisance-dust respirators or all-dust respirators could be chosen. If the dust concentration is exceedingly high, air-line respirators would be preferable. If the conditions of work are such as to interfere with the use of an air-line, mechanical-filter respirators will serve satisfactorily, even though they are awkward to wear for many kinds of work.

For toxic dust, air-line respirators, toxic-dust respirators, or all-dust respirators would be a logical choice. The final decision will depend on local conditions of work and the materials being used. Knowledge of the concentrations likely to be encountered and of the safe or permissible concentration is necessary in evaluating the protection afforded.

Fume is particulate matter formed by volatilization and condensation, as in lead burning. Fume is defined because it is a term used loosely to refer to gases, vapors, and particulate matter. Such usage is confusing and may lead to serious injury if a mechanical-filter fume respirator is used for protection against some toxic gas or vapor against which it affords no protection. For fume as defined above, air-line respirators or mechanical-filter fume respirators would be the logical choice, and final decision would depend on local working conditions.

Frequently protection must be afforded against a combination of gases and particulate matter (dust, fume, mist, and fog). If the atmosphere is not immediately dangerous to life, air-line respirators are generally recommended. However, gas masks equipped with a suitable filter or cartridge-type respirators equipped with a suitable filter may be used. Final decision not only would depend on the local conditions of work as they relate to freedom of movement but also on thorough consideration to ascertain whether gas masks or cartridge respirators would give the desired protection.

Use of Respirators

Although choice of a suitable respirator is important, other considerations are equally so. Obviously, if a respirator is to do the job for which it is chosen, it must be worn properly and be kept in good condition. Frequently persons do not know how to wear a respirator, and if it is not clean it is unpleasant to wear. Better protection and fuller cooperation doubtless would be obtained if the respiratory protective devices were kept under the supervision of a responsible person who would see to it that the wearer is properly instructed in the use of the device, that the device is cleaned and disinfected regularly, and that it is maintained in first-class condition.

No instructions are necessary when hard hats or hard-toed shoes are given to workmen, as they are used to wearing such articles. Too frequently respirators are handed out in a similar manner. Even the simplest respirator is comparatively much more complicated than protective hats or shoes and is a device that most workers are not accustomed to wearing. The principles on which each device is based, its field of use, and its limitations, as well as the essential parts, should be explained to the wearer in terms he can understand. Detailed instructions with practice should be given to all persons who are expected to wear such devices. Further, an explanation of the importance of wearing the respirator should be helpful in obtaining more complete cooperation.

For example, in the use of mechanical-filter respirators attention should be called to the importance of a good facepiece fit and proper but comfortable adjustment of the headband, and also to the fact that increased resistance to inhalation indicates that the filter should be cleaned or renewed.

In the use of gas masks good facepiece fit is also necessary, and the proper canister must be chosen. As the wearer depends on odor or irritation to warn when the canister is exhausted, he must be acquainted with the warning properties of contaminants for which protection is worn so that leakage will be detected readily. Persons using gas masks in toxic atmospheres should have had preliminary training in the use and limitations of the equipment.

All respirators approved by the Bureau of Mines are furnished with an approval label that gives concise information on use and limitations. Also, more detailed instructions that have been reviewed by the Bureau accompany all approved devices. Both approval label and instructions should be consulted by the user.

Cleaning and Disinfecting Respirators

Respirators, particularly the facepieces, should be scrubbed daily after use with lukewarm water and soap. This not only is good hygienic practice but also prolongs the life of the rubber, as otherwise the dirt, oil, and perspiration from the face may cause rapid deterioration. Respirators should also be disinfected at regular intervals. If a respirator is worn by the same person, disinfection once a week probably should be satisfactory in most instances, depending on conditions of use and thoroughness of cleansing with soap and water. A respirator that has been worn once should be disinfected before it is given to another person to wear.

There are several procedures for disinfecting respirators; however, as certain respirator parts may be damaged by the disinfecting agent, the manufacturer should be consulted as to the best procedure for his device. This warning is particularly pertinent at present, when the use of substitute materials is so common.

Common disinfecting procedures include scrubbing or immersing the respirator for 10 minutes in 70 per cent alcohol, two per cent cresol, or a solution of formalin made by mixing one part of 40 per cent formaldehyde in nine parts of water. When such agents as cresols are employed as disinfectants, the parts that come in contact with the

skin should be rinsed thoroughly with water, as some persons are highly sensitive to such materials.

Cleaning and disinfecting afford an opportunity for cleaning or replacing filters, inspecting valves, headbands, facepieces, and metal parts that might be distorted.

Maintenance and Storage

A most important phase of any control procedure is maintenance. Choice of proper equipment and adequate instruction are completed projects, but maintenance is a continuous problem requiring constant attention. As such it should be supervised by someone thoroughly familiar with the apparatus being used.

Washing and disinfecting the device affords an opportunity to inspect it for minor repairs. In addition, it should be inspected thoroughly at monthly or longer intervals, depending on the apparatus, conditions of use, and storage. Devices for emergency purposes should be inspected after each use to assure that they will be in good condition and immediately available if an emergency arises. After the equipment has been cleaned and inspected and any necessary repairs made, it should be stored properly.

A good procedure is to have a central place of storage, possibly with sub-stations at strategic points if the plant is large. Storage should be in essentially dustproof containers away from sunlight and in a cool place (not near radiators or steam pipes). Small devices, such as dust or chemical cartridge respirators, can be kept in paper or cellophane bags. These devices may be numbered and assigned to some one person, who returns them at the end of the shift to the central station for cleaning and replacement of filter elements, and for repairs if necessary. Thus, wearers are assured clean devices in good working order for each day's use. This program may be facilitated by assigning two respirators to each person, one being used while the other is being serviced.

Larger devices, such as gas masks and hose masks, usually come equipped with a sturdy case or trunk that can serve as a storage place. If they are stored at strategic points for emergency use, they might be placed in a case with a glass window that requires breaking of a seal to assure that they have not been used or tampered with. The seal should bear the date of the last inspection.