CHAPTER 36

# PERSONAL PROTECTIVE DEVICES

*Harry F. Schulte*

## GENERAL PHILOSOPHY

It is one of the fundamentals of industrial hygiene that personal protective devices are "last resort" types of controls, to be used only where engineering controls cannot be used or made adequate. It should be noted that this fundamental is stated unequivocally in the standards adopted under the Occupational Safety and Health Act.[1] There are many jobs in industry which are short-term or which must be conducted where exhaust ventilation or other control measures cannot be employed on short notice. Protective devices are also extremely important as a second line of defense against inadvertent or unexpected conditions. Thus, when a man dons a respirator or a face shield before opening a container of toxic material he does not expect to need this equipment, but he is prepared and protected if the toxic material escapes its confinement.

Personal protective devices appear to be very simple to provide and use in contrast to such equipment as exhaust ventilation or sound absorbing barriers. It is the purpose of this chapter to show that this is not necessarily true, and to provide the reader with essential information on the selection and correct manner of use of personal protective devices. In making a selection of equipment to be used the employer is advised to consider the wishes of the workers who must use the equipment, since worker acceptance is the key factor in a successful protective equipment program. For this reason the comfort factor should be given considerable weight at the expense of costs but not of protection. Full discussion of the use of the devices with the employees, training in their use and instructions for care and maintenance are very important. For example, handing a man a respirator and telling him to use it is not only an ineffective technique, but it can be very dangerous.

## PROTECTION AGAINST INHALATION HAZARDS

### Where Used

There will always be a temptation to resort to respirators as a cheap substitute for a ventilation system. If this is done it is clear that management has not carefully considered the alternatives since reliance on, and effective use of, respirators is definitely not cheap. A careful study may be required to determine that no other effective control measures can be used. Respirators are designed to protect only against certain specific types of substances and in certain concentration ranges, depending on the type of equipment used. Many other factors should be considered carefully in making the decision that other engineering controls are not practical. Nevertheless, there are many places where respirators can and should be used with full knowledge of their limitations and requirements.

### Approval Systems and Schedules

The U. S. Bureau of Mines gave its first approvals of oxygen breathing apparatus in 1918 and gradually extended this activity to include all types of respirators. Each approved respirator and each approved filter, canister or cartridge bears an approval stamp or mark. Approvals are issued according to a series of "schedules" which describe the tests to be performed on each type of respirator and the standards it must meet to receive approval. Lists of approved devices are issued periodically by the Bureau and supplements are added to include newly approved devices. The last complete list of approved devices was issued by the Bureau of Mines as Information Circular No. 8436 and included devices approved up to December 31, 1968.[2] Supplements were issued in January 1970 and February 1971.

The approval schedules themselves are subject to occasional reviews and new schedules are developed to meet the needs for protection against new hazards or to reflect the development of new kinds of devices. Where respirators are used regularly, these schedules should be consulted since they set forth the precise information to be obtained in the test procedures as well as the limitations of the tests. Prior to 1971 the U. S. Department of Agriculture performed tests and issued approvals on respirators to be used in working with pesticides. This function has now been taken over by the Bureau of Mines. With the passage of the Occupational Safety and Health Act and the subsequent formation of the National Institute for Occupational Safety and Health (NIOSH), the approval system has been in the process of change. In 1972 NIOSH took over the approval function from the Bureau of Mines for aboveground uses. Considerable research is now underway to expand the scope of the approval tests and to develop more satisfactory procedures to meet the changing and expanding needs.

### Particle-Removing Air Purifying Respirators

*Applications and functions.* These devices are designed to protect the wearer against inhalation of material dispersed in air as distinct particles — as a dust or fume in the case of solid particles or as a mist or fog in the case of liquid droplets. They consist, principally, of a facepiece with some type mechanical filter. The material to be protected against may be a nuisance dust such as sawdust, a pneumoconiosis-producing dust such as silica or coal dust, a toxic dust like lead oxide, a metal fume like cadmium, a highly toxic dust like beryllium oxide or a radioactive dust such as plutonium. These examples range in their degree of protection required from relatively minor to extremely high. Respirators to meet this range of requirements differ chiefly, *but not solely,* in the efficiencies of their filters.

*Limitations.* The user of any air purifying respirator must be certain that the atmosphere contains adequate oxygen and that the only harmful materials present are those which can be removed by the respirator to be worn. There are many ways in which air can leak around the filter, seriously reducing the protective capability of the respirator. Failure of the filter to seat properly in its holder, leaking valves and imperfect sealing of the respirator to the wearer's face are all significant. Some of these factors can be controlled by proper design but all require good and frequent inspection and maintenance.

*Facepieces.* There are two basic types of facepieces used on air purifying respirators — half masks and full face masks. The half masks do not cover the eyes and hence offer no eye protection nor do they interfere as much with vision as do the full face masks. The half mask must contact a rather complex facial surface and the possibility of leaking is greater than in the case of the full face mask. Obviously, faces vary considerably in their dimensions from one individual to another and since a given respirator is usually made in only one size, a successful fit for the respirator cannot be made on all persons. Recently some manufacturers have begun making some respirators in several sizes. Where this choice is not available, it is essential that the employer stock several different models of respirators, usually from several different manufacturers. A fitting program, to be discussed later, is required to provide adequately fitted respirators.

A serious problem with full face respirators is obtaining an adequate seal for the worker who must use corrective glasses. Where the temples of conventional eyeglasses emerge from the facepiece, there is a serious place of leakage. Some masks provide methods of mounting a special set of corrective lenses inside the respirator facepiece. Half masks are usually held on the face by means of a single set or a double set of elastic bands. The double sets of straps are practically a necessity in assuring a reasonable face fit and each set should fasten to separate suspension points on the respirator. Full face masks, being much heavier, are supported by a head harness which should have at least five adjustable straps.

Most respirator facepieces contain valves to direct the flow of air from outside, through the filter, into the nose and then back outside. Valveless respirators are being used, but are not approved for use with hazardous materials. The most important valve is the exhalation valve which opens during expiration allowing expired air to pass directly outside the mask. It closes during inhalation and must close positively and quickly to prevent toxic material being drawn into the facepiece.

The inhalation valve is located close to the point where the filter attaches to the facepiece. It opens during inhalation to allow air to be drawn in through the filter and closes during exhalation to prevent the passage of moisture-laden expired air through the filter. Some approved respirators do not have inhalation valves. Obviously, all valves should offer minimal resistance to air flow, but low resistance is particularly important in the exhalation valve. Resistance to exhalation is much less tolerable than is resistance to inhalation.

*Filters.* Filtration by fibrous filters is the method universally used in respirators for removing particles from the air. The filter material may be a loosely or tightly packed mass of fibers of cotton, wool, synthetic fibers, glass or mineral fibers, or it may be a paper made of these materials. The filter efficiency is influenced by the particle size, shape and density of the aerosol and by a number of other factors determined by the filter and the respirator.

The diameter of the fibers used in the filter is important since higher collection efficiencies are obtained with finer fibers. The tightness with which the fibers are compressed is another factor leading to higher efficiency. As a filter is used in a dusty atmosphere its efficiency usually increases with time since the layer of collected dust becomes an additional filter. It should be noted that all of these factors leading to increased filter efficiency also lead to increased resistance to breathing. This limits the extent to which these factors can be used to obtain higher particle removal efficiency. The only way to compensate for high filter resistance is by providing large filter surface areas. Thus, many filters are folded in various ingenious ways to achieve large surface areas in small spaces. Filters may be incased in "cans" or holders to protect the folded filter.

There are approval schedules for respirators for protection against (1) pneumoconiosis-producing and nuisance dusts, (2) toxic dusts (not significantly more toxic than lead), (3) metal fumes (not significantly more toxic than lead), (4) chromic acid mist, (5) dusts significantly more toxic than lead and (6) various combinations of these. A summary of some of the requirements for approval are given in Table 1 taken from the AIHA-ACGIH Respirator Manual.[8]

*Special Purpose Respirators.* Because of recognition of the necessity of maintenance and regular servicing and cleaning of respirators, there has been increased interest in the possibility of single-use respirators. These could be discarded when breathing resistance became excessive or the respirator became dirty or damaged. Some simple respirators of this type have been used in the past — a surgeon's mask is an example — but they have never been approved because of their low efficiencies and lack of exhalation valves. Recently several manufacturers have begun making single-use masks, and one has been approved under a new

TABLE 36-1

U.S. BUREAU OF MINES APPROVAL SCHEDULES AND TESTS
TEST CONDITIONS AND PERFORMANCE REQUIREMENTS
FOR DISPERSOID RESPIRATORS

| Dispersoids Covered by Respirator for Protection against | Test Dispersoid | Concentration of Dispersoid, $mg/m^3$ | Duration of test, hr | Maximum Allowable Leakage, mg | Maximum Final Resistance to Air Flow, mm of $H_2O$ |
|---|---|---|---|---|---|
| Pneumoconiosis-producing and nuisance dusts | Silica dust; geometric mean not more than 0.6 $\mu$; $\sigma_g = 1.9$ | 50 ± 10 | 1.5 | 3.0 | 50 |
| Toxic dusts (not significantly more toxic than lead) | Litharge, ~75%; free metallic lead, ~25%; geometric mean not more than 0.6 $\mu$; $\sigma_g = 1.9$ | 15 ± 5 | 1.5 | 0.43 (Pb) | 50 |
| Metal fumes (not significantly more toxic than lead) | Freshly generated lead fume | 15 ± 5 | 5.2 | 1.50 (Pb) | 50 |
| Chromic acid mist | Electrolytically generated chromic acid mist | 15 ± 5 | 5.2 | 1.0 | 50 |
| Pneumoconiosis-producing and nuisance mists | Mist formed by atomizing a silica dust-water suspension | 10 ± 5 | 5.2 | 5.0 | 50 |
| Various combinations of above types of dispersoids | Respirator must meet requirements for each type.[a] | | | | |

[a]For example, the protection against dusts not significantly more toxic than lead, the respirator must meet the requirements for the first two items in this table, that is, for pneumoconiosis-producing and nuisance dusts and for toxic dusts not significantly more toxic than lead.

From RESPIRATORY PROTECTIVE DEVICES MANUAL published by American Intustrial Hygiene Association and American Conference of Governmental Industrial Hygienists, 1966.

Bureau of Mines approval schedule recently adopted for such masks. Replacement (and disposal) costs must be balanced against cleaning and maintenance costs.

Nuisance dust masks, including some not carrying Bureau of Mines approvals, may still have some use in industry. These may be useful in woodworking shops, on workers operating machines on dusty roads and farms, and for workers sensitive to pollens in certain seasons. Their costs are likely to be lower than those for approved masks and the reasons for their lack of approval should be given careful consideration. Thus a mask may fail to meet approval standards because of high breathing resistance, and this is likely to make it unacceptable for long wearing by workers. On the other hand, a mask may be a simple device for which no approval schedule exists, and it may be adequate, highly acceptable and useful to the librarian required to clean dust from stacks of books. Such masks must be kept strictly separate from masks used for genuine protection against hazardous materials.

A new type of respirator which is being employed where high efficiency must be combined with low breathing resistance is the powered filter respirator. In this device a battery-powered pump forces air through the filter, and by way of a hose, into the facepiece. The rechargeable battery, pump and filter are carried in a compact unit worn on the belt or other harness. For heavy work requiring large air volumes and low resistance to breathing in atmospheres containing highly toxic materials, this powered filter device is proving both useful and popular. Workmen cleaning coke ovens and uranium miners are among those who are using this respirator.

### Gas and Vapor-Removing Air Purifying Respirators

*Applications.* These respirators are designed to protect the wearer against the inhalation of materials in the air that are present in the form of gases or vapors. Respirators for protection against such materials are equipped with a container or canister filled with a sorbent which absorbs, adsorbs or reacts with the hazardous gas in the atmosphere. Some sorbents are highly specific for a particular compound and so the respirator containing only this sorbent gives no protection against any other material. Other sorbents take out whole classes of compounds such as acid gases or organic vapors.

*Limitations.* Like the particulate removing respirator, the gas removing device is useless unless adequate oxygen is present. Unless the device is specifically equipped with a filter in addition to the sorbent, it will not offer adequate protection against any hazardous particulate substances. Leakage around canisters can also occur as around filters but this is less likely. Leakage around the facepiece is also possible but, since these respirators usually offer less resistance to breathing than filter types do, there is a slightly smaller chance of this type of leakage. Once a sorbent canister is opened and used, the sorbent may absorb moisture or other deleterious materials from the air and deteriorate even without further usage.

For respirators designed for use under highly dangerous conditions some canisters are equipped with devices which change color when sorbent depletion approaches. For respirators designed for use under less hazardous conditions the odor of the gas penetrating the canister is the only warning. For these reasons simple gas removing respirators are most frequently designed for a single usage in dealing with a specific situation.

*Facepieces.* Essentially the same information relating to facepieces on particulate removing respirators applies also to gas and vapor removing respirators. Because many gases and vapors are also irritating or damaging to the eyes, full face respirators are much more frequently required than half masks. Half mask respirators usually carry relatively small sorbent canisters which can be used only for short periods in relatively low concentrations of gas. Even with the full facepiece and its head harness, the sorbent canister for heavy duty usage may be too heavy to be supported on the facepiece. It may be worn on a chest harness or strapped to the belt. The canister is then connected by a hose to the facepiece.

*Sorbents.* As previously noted, some sorbents may be used only in dealing with specific chemical compounds or with classes of compounds. Thus manufacturers have specific sorbents for ammonia or chlorine. Many canisters contain combinations of materials to assure absorption of a specific compound. It is important to note whether protection against the substance required is claimed on the canister of the device to be used. Obviously, it is not always possible to include the complete list of all such compounds on each canister, and the canister may effectively remove some materials not listed. A list of sorbents for a large number of materials is given in the Respirator Manual.[4] The Bureau of Mines makes approval tests on only a limited number of common industrial toxic chemicals.

Since there is usually little warning of impending canister failure, the instructions of the manufacturer must be carefully followed regarding the length of time the device can be worn and the circumstances of its use. The effectiveness of a canister depends on the presence of a reactive chemical and canisters usually deteriorate with time. Here again, the manufacturer's instructions regarding shelf life should be followed and outdated canisters should be discarded.

*Types.* Gas masks are full facepiece units with large canisters. The names of the substances against which the mask gives protection are written on the canister and, in addition, the canisters are given specific colors for identification purposes.[6]

Chemical cartridge respirators are half mask respirators with small cartridges and are used for protection against the inhalation of atmospheres that are not immediately dangerous to life. Those used for protection against organic vapors are limited to use in concentrations not exceeding 0.1% by volume of such vapors; they are not satisfactory for all organic compounds. Mouthpiece respirators are small, compact devices for self-rescue in short term emergency situations (Figure 36-1). Instead of a facepiece this device fits in the mouth with a clip to put on the nose to force breathing through the mouth and the respirator.

Various combinations of filter and vapor removing respirators are available. A widely used device of this type is the universal gas mask which contains a filter plus sorbents for organic vapors, acid gases, ammonia and for the oxidation of carbon monoxide. This mask is used where the nature of the contaminants cannot be completely identified or where it is known that the atmosphere

Supplied by and used with permission of
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico

Figure 36-1. Mouthpiece Respirator — Self Rescue Device.

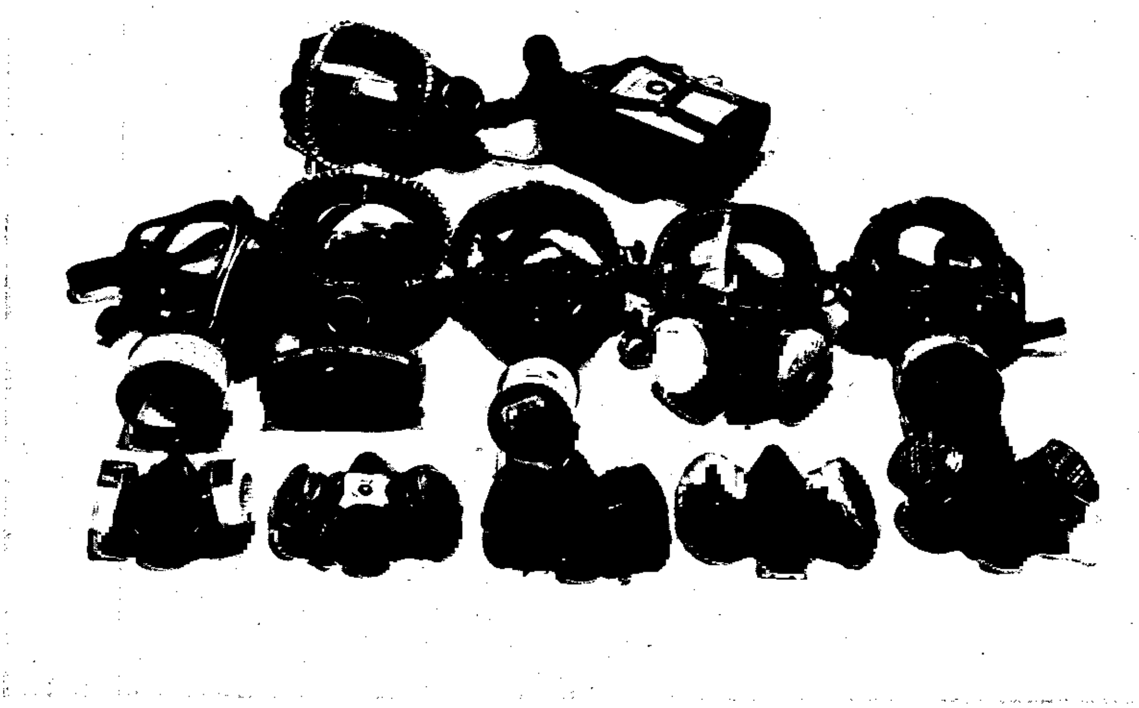
contains several of the above materials. It is the best respirator for protection against oxides of nitrogen in moderate concentrations. It must be remembered that it offers no protection when there is little or no oxygen present. Some manufacturers use the same basic facepiece for a variety of applications and various filters and canisters can be used on the same unit. Figure 36-2 illustrates air purifying respirators.

**Atmosphere Supplying Respirators**

*Applications.* When a lack of oxygen is known or suspected or when a very high degree of protection is required the only suitable device is the atmosphere supplying respirator. This consists of a source of air or oxygen which is fed through a hose to a mask or a helmet. Intermediate mixing and regulating equipment may be required. Supplied air devices offer essentially no resistance to breathing, and the atmosphere supplied may be cool and more acceptable than that from other types of respirators.

*Facepieces.* A variety of facepieces are used with atmosphere supplying respirators. Half masks and full face masks are similar to those previously described although the valves are somewhat different. In addition to these, helmets may be used which cover the entire head and a cover may extend down to the waist as in the abrasive blasting hood. Another type of facepiece is the air supplied face shield. In this, the air is supplied by a hose to a perforated or slotted tube at the top of the face shield and the jets of air are directed downward past the eyes, nose and mouth. It is difficult to adjust this device to avoid entraining contaminated air and blowing it into the breathing zone. There are other combinations of atmosphere supplying equipment with hoods, blouses and complete clothing

*Hose types.* There are several varieties of the hose types including the hose mask with blower, hose mask without blower and the air-line respirator. The hose mask with blower can be used in any



Supplied by and used with permission of
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico

Figure 36-2. Air Purifying Respirators.
Front Row — Half Masks
Second Row — Full Face Masks
Rear — Universal Gas Mask.

atmosphere provided that enough respirable air is supplied to the wearer by means of the blower. The blower must be hand operated and the blower operator serves as an observer capable of rescuing the wearer in case of accident. The hose mask without blower is used under conditions not immediately dangerous to life and from which the wearer can escape without the aid of the respirator.

The air-line respirator (see Figure 36-3) consists of a source of compressed air to which the facepiece is connected by means of a small diameter hose. In the line is a pressure reduction valve and some type of flow regulating device. This equipment is used for protection in atmospheres that are not immediately dangerous to life or health or from which the wearer can escape without the aid of the respirator.

There are two basic types or modes of operation of air-line respirators — continuous flow and demand. In the first, the air is fed to the facepiece continuously and a positive pressure is maintained inside the mask at all times and any leakage will be outward. Considerably more air is used than is consumed in breathing. In the demand type a valve which regulates the flow of air opens only when a slight negative pressure is produced inside the mask as a result of inhalation. Thus, only air used in breathing is drawn from the source. Since a negative pressure is produced inside the facepiece it must fit tightly to the face or contaminated air will be drawn in. Usually the demand type has a by-pass valve so the wearer can switch to continuous flow if he desires. A newer variation is the pressure-demand type of flow regulation. In this, a small positive pressure is always maintained in the facepiece even on inhalation. The demand valve opens to supply air when the positive pressure decreases to a certain level as a result of inhalation. Thus leakage is always outward if a poor fit of facepiece to face is obtained.

*Self-contained breathing apparatus.* In this apparatus the wearer carries his own supply of air or oxygen and so he is able to move about without attaching hoses which limit his travel distance and maneuverability. Since the wearer is limited to the supply of air which he can carry, several methods are used to conserve this supply. Demand and pressure-demand valves may be used in the same manner as in the air-line respirator. A bypass for continuous flow is also provided, but can be used only for very short periods or the supply will be quickly exhausted. Either air or oxygen may be used in this type of apparatus.

Another type of device uses recirculation to conserve the oxygen supply. In this unit the exhaled air is not expelled but passes through an absorber which removes carbon dioxide and then enters a breathing bag. Here it mixes with fresh oxygen from the gas cylinder and then passes back to the facepiece for rebreathing. Oxygen only enters the breathing bag when the pressure in the bag drops below a fixed value. Since the oxygen content of exhaled air is still about two-thirds of that of inhaled air, it is only necessary to make up this difference from the tank and thus the recirculating type can be used for much longer periods for the same quantity of oxygen carried. Both demand and recirculating equipment are marked for use only for a specified period of time ranging from thirty minutes to three hours.

A third type of self-contained breathing apparatus uses a chemical source of oxygen which is liberated when carbon dioxide and moisture are absorbed from the exhaled air. A breathing bag is provided to mix the incoming oxygen with the purified exhaled air. This apparatus can be used for thirty minutes only and includes a timer to warn of the approaching limit (see Figure 36-4) Once the canister is opened it cannot be resealed for further use even if it has been used for only a few minutes. Like all chemical cartridges it has a limited shelf life even if unopened.

*Combination types.* One variety of air-line respirator utilizes a small cylinder of compressed air worn on the user as an emergency device. If anything happens to the regular air supply the wearer simply disconnects his air line, automatically switching to the small cylinder supply and unhurriedly leaves the hazardous area. In place of a compressed gas supply, a filter or a sorbent canister may also be used for emergency conditions. Even with these devices air-line respirators are not approved for use in atmospheres immediately dangerous to life.

*Sources of air or oxygen.* The hose mask simply

Supplied by and used with permission of
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico

Figure 36-3. Airline Respirator.

Supplied by and used with permission of
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico

Figure 36-4. Self-Contained Breathing Apparatus.

uses air drawn from a source outside the contaminated atmosphere. The air-line respirator may use a compressed gas cylinder of air or oxygen or a compressor which picks up outside air. If the compressor is driven by a gasoline or diesel engine extreme care must be taken to see that the engine exhausts away from the pump intake and no exhaust gases enter the breathing air system. Water-lubricated compressors, or those not requiring internal lubrication, are the best sources of compressed air for these devices since heating may cause breakdown of lubricating oil forming carbon monoxide. Oil-lubricated compressors, if used, should be equipped with thermal overload switches to turn them off if overheating occurs. In any case, the compressor should be followed by a trap and filter to remove dirt, oil and water from the air line. If a regular building supply is to be used for an air-line respirator the system must be checked repeatedly to be certain that it does not contain even small concentrations of carbon monoxide.[6]

A new alternative source of oxygen for the self-contained breathing apparatus is liquid air or liquid oxygen. Several devices using this oxygen source have been approved by the Bureau of Mines. Air from this source is cooler and may have a "fresher" odor than compressed air.

*Maintenance.* All types of respirators require maintenance and cleaning. The highly complex atmosphere supplying devices must be inspected for signs of wear and deterioration and to make certain that all of the parts are functioning properly. Other types of respirators are simpler but still require regular inspection. Rubber parts deteriorate with time and exposure to ozone and other gases. Hence, hoses, facepieces and valves must be inspected regularly and parts or whole respirators replaced when necessary. All respirators should be brought in for cleaning occasionally and emergency devices cleaned after every use when cylinders of gas or canisters are replaced. Emergency devices and self-contained breathing apparatus should be inspected monthly since they are usually to be used under very hazardous conditions.

When respirators are used routinely they should be brought in regularly to be dismantled, washed and dried, inspected and parts replaced as necessary, new filters or canisters put in and the whole reassembled and stored in a clean place.

**Special Topics**

*Worker Acceptance Factors.* Good equipment is ineffective if the equipment is not accepted and used by the workers. Hence, factors leading to such acceptance must be carefully considered by management. All respirators are uncomfortable and irksome to wear but consideration of the comfort factor in respirator selection can do much to gain worker acceptance in using respirators when they are needed. Low breathing resistance is important, and while the Bureau of Mines specifies maximum values of permissible resistance, there are still differences among approved respirators. If face fit can be obtained only by very tight strap tension, the respirator cannot be worn long and its use will be avoided. A particularly important point is management's interest in the program. If every effort is made to provide conditions where respirators are not necessary then they will be better accepted when they are necessary. Regular cleaning and maintenance is evidence of management's interest. An educational program in respirator use is essential.

*Training.* Respirators are complex devices and cannot simply be handed to the worker with the assumption that they will be used properly. When the worker is told to use a respirator he should see the various devices available to him and have their method of operation explained including all essential parts. He should then try on the device and test the fit of the facepiece. This may be done by covering the exhalation valve, if possible, and then exhaling sharply or by closing the intake ports and inhaling. Most manufacturers include instructions for leak testing with the respirators and these directions should be followed. The worker should be taught to inspect the respirator before each use. The subject of training is discussed at considerable length in the Respirator Manual[7] and is an extremely important topic. Where considerable numbers of respirators are worn, it is advisable to designate a specific individual to be responsible for fitting and training.

*Heat problems.* All respiratory equipment is very uncomfortable and fatiguing to use under hot conditions. Supplied air equipment such as air-line respirators may be most satisfactory under such conditions and complete supplied air suits may be necessary. A small compact vortex cooler is available which can be worn on the belt or harness to supply cool air.

*Communications.* Some voice communication is possible while wearing a respirator but sounds are muffled and attempts to talk loudly may loosen the face fit. With most full face masks it is possible to replace the exhalation valve with a combination valve and speaking diaphragm which permits much better voice transmission. When good communication over considerable distance is necessary, it is possible to equip the full facepiece with a battery operated microphone transmitter which transmits to an outside speaker or to receivers or earphones worn by others.

*Codes and sources of information.* As noted, the Bureau of Mines issues approvals for all types of respiratory protective devices and the approval schedules which can be obtained from the Bureau contain full information on how the respirators are tested and the standards they must meet. The Bureau has also issued a list of dust respirators approved for use in coal mines.[8] The American National Standards Institute has issued its American National Standard Z88.2-1969 entitled *Practices for Respiratory Protection* which contains much useful information.[9] The most complete publication in this field is the *Respiratory Protective Devices Manual* published by the American Industrial Hygiene Association and the American Conference of Governmental Industrial Hygienists. The National Safety Council has recently published a series of articles on respiratory protection in National Safety News.[10]

**A Respirator Program for Industry**

The important elements of the successful plant respirator program have been discussed in previous sections of this chapter. Here they will be summarized to provide a means for checking to be certain that all factors are covered in a particular situation.

*Determination of need.* This will require knowledge of the hazards anticipated in carrying out a particular job. An estimate will be required of the possible concentrations of toxic material that could be produced; whether existing engineering controls, such as ventilation, can adequately meet the needs; the anticipated duration of the required protection and any limitations imposed by the job. The latter includes the intensity of the physical activity required and whether or not the worker must be able to move about without encumbering hoses. Obviously, the determination of the need for respiratory protection is a technical decision and can best be made by an industrial hygienist.

*Selection of equipment.* Much of the same information required in establishing the need for respiratory protection is required here also. In addition, one must have a knowledge of the types of devices available for the particular circumstances encountered. Since it is impossible to expect each plant to have on hand every type of device manufactured, equipment kept on hand must be purchased in advance on a basis of surveys and studies of anticipated needs. Here, there is a requirement for close cooperation between the person in charge of the respirator program and the plant's purchasing and stores department. Preliminary education of appropriate persons in this department may be necessary since their tendency will be to stock items on a basis of price without regard to important distinctions between different pieces of equipment.

*Training.* This is very important and requires continuous study and updating of knowledge by the person giving the training. The latter should be the person responsible for selection of respirators to be carried in stores, or at least he should be in very close touch with this aspect, since his direct contact with workers using protective devices makes him aware of their needs.

*Supervision and enforcement.* The support and encouragement of supervisors, such as foremen, are essential to the program. The foremen, particularly, should be asked to participate in fitting and training even though they may have little occasion to use respiratory protective devices. This provides an opportunity to demonstrate the importance of the activity and gains their support for the program. Without this support many workers will not use the equipment correctly nor care for it adequately.

*Inspection.* Industrial hygienists and safety engineers in the plant must include regular inspection of the condition of respirators as one of their routine duties. It is particularly important that emergency devices such as those mounted on walls or in cabinets be checked regularly. The most important inspections, particularly of smaller devices, are those given by the worker himself. His training must include information on the importance of this and how to do it adequately.

*Maintenance.* In most plants there should be a central cleaning station where respirators are brought in regularly for cleaning and replacement of worn or damaged parts. In very small plants this may be done by the worker himself with the aid of the safety engineer, industrial hygienist or plant nurse.

*Storage.* New respirators should be stored in their original container in a clean, cool dry place before being issued. Cleaned respirators if not immediately reissued should be placed in a dust-tight container, such as a plastic bag. The worker also should be instructed to store his respirator properly after it is issued to him. A respirator crammed into a tool kit can be permanently distorted in shape so that it cannot fit. Dust accumulated on the interior of the mask is readily breathed in and wearing such a mask may be a cause of more exposure than failing to wear it.

*Management interest.* Top management should give some evidence of support of the program. This may be done, in part, through the plant paper or magazine or through shop bulletins or other means of indicating interest or concern. It is the responsibility of the person in charge of the pro gram to keep management informed about the program if he is to obtain their interest and support.

## PROTECTION AGAINST NOISE

The previous section of this chapter has dealt at considerable length with the subject of respiratory protection. Much of this is also applicable to devices used to protect against noise and other hazards. With hearing protective devices, both ear plugs and ear muffs, there is a need for experimentation in trying different types of devices to meet specific needs. Since the noise hazard is not as acute as the respiratory hazard more experimentation is justified. Both plugs and muffs attempt to prevent the penetration of sound through the outer ear to the inner ear; however, some sound also reaches the inner ear by conduction through bone and tissue. Thus, any protective device is limited in the degree of protection which can be achieved. In sound fields in excess of 120 decibels no protective device will give adequate protection for continuous exposure.

When ear protectors are first used by a worker, he experiences a sensation that his own voice is very loud since outside noises are reduced. As a result, he tends to speak softer making it more difficult to communicate with others especially if they are wearing protectors also. Noises signaling dangers around the worker may be muffled and their warnings not heeded.

### Ear Plugs or Insert Devices

Ear plugs are small conical or cylindrical devices made to fit into and seal the ear canal against the entrance of sound. The more closely the plug approximates the shape of the ear canal the more positively it will seal. Plugs are usually made of a soft pliable material like soft rubber or plastic so they can be inserted into the ear canal with positive force without being uncomfortable. Many models have soft flanges which can seal the canal even if contact with the body of the device is incomplete. Attempts have been made to improve the usefulness and acceptability of ear plugs by introducing models with "valves" or perforations which were to allow passage of sound of certain frequencies or to block loud but not soft sounds. None of these has been successful and the plain plug remains the best. Since fitting to the ear canal is important some manufacturers make plugs for individual ears by making casts or impressions of the ears and then moulding and curing a plastic material in the shape of the impression. While such devices would appear to have a great advantage in effectiveness and comfort, this is not always the case.

Malleable wax material is available which can be moulded into the ear and discarded after use. Wadded cotton has often been used, but actually is comparatively ineffective. Cotton impregnated with wax or vaseline is much more effective. A very fine glass wool material has been introduced in recent years, often called Swedish Wool after its country of origin. This material can be rolled into plugs and gives almost as good protection, if properly used, as a good commercial plug. Dispensers for this material can be installed and the material is more acceptable to many workers than regular ear plugs.

The degree of sound attenuation provided by ear plugs varies in different frequency bands or octaves. For good, well-fitted plugs this varies from 25 decibels in the low frequency or low pitched sounds to 40 decibels at frequencies over 1000 Hertz. Fitting of the plugs is very important in achieving good results. Most plugs come in several sizes and the correct size must be chosen to fit the individual's ear canal. Frequently different sizes are needed for the two ears. Fitting by the Medical Department is a good way of achieving this part of the program's purpose. The physician can examine the ear canal carefully for size and at the same time detect any ear infections or canal irregularities which may rule out the use of ear plugs. Some persons simply cannot wear ear plugs.

### Ear Muffs

Ear muffs are much like communications type earphones in appearance although the ear cup is usually deeper. They are equipped with a headband which may go over the head or around the back of the neck. The latter type permits the wearing of a hat but usually offers slightly less hearing protection. They may also be mounted on a helmet or hard hat. The degree of attenuation obtained varies with the sound frequency and may range from 20 decibels at low frequency to 45 decibels at high frequency. There is a standard method of measuring attenuation by muffs, but it is complex and requires special equipment. Most users will have to rely on the attenuation data supplied by the manufacturer.

To attain good protection the muff should seal over the ear and the seal may be made of foam rubber or liquid-filled or grease-filled cushions. The latter two are somewhat more effective and comfortable. Large cup volumes and small cup openings lead to greater attenuation.

Proper fitting is important with muffs, but is not quite so individual a matter as with plugs. The worker should be offered a choice of several models to achieve the best fit and to gain his acceptance of the device. Where communication is necessary in a high noise level environment, ear muffs can be equipped with earphones and battery operated radios. The microphone can be muffled and mounted directly in front of the mouth.

### Plugs or Muffs?

Good ear plugs may give slightly higher attenuation in the very low frequency range while muffs give better attenuation in the middle ranges. Above 1000 Hertz there is little from which to choose on a basis of the degree of protection afforded. Plugs are more acceptable to some workers while muffs are preferred by others. Where exposure to noise is intermittent, muffs are somewhat more easily removed and replaced when needed. Plugs are easier to carry than muffs, but for the same reason are more easily lost. They are also less expensive. Muffs are more comfortable for use in cold weather. Both plugs and muffs deteriorate with time and should be inspected frequently.

### Evaluation

If ear protection is required, there should also be a medical program which includes audiometric testing of exposed workers. Results of such testing will determine whether continued exposure is advisable even if protective devices are used. Obviously, every attempt should be made to control the noise by engineering methods and eliminate the need for personal protective devices. One author puts the case as follows — "When the only possible control method is ear protection, it is important — rather it is essential — that the ear protection program be continually monitored by knowledgeable and enthusiastic people who are dedicated to the task of protecting the hearing of noise-exposed employees."[11]

## PROTECTION OF SKIN AND BODY

This section deals with the subject of what is usually called protective clothing and includes protection of the various parts of the whole body either completely or partially as may be required. The term, protective clothing, is a correct one although much protective clothing offers no more direct bodily shielding than would be offered by ordinary street dress. Since street clothing might be ruined or rendered unsuitable for street use if worn in the shop, the shop clothing provided is "protective" of one's ordinary clothing. Chemicals, dirt, heat and cold are the chief hazards against which protective clothing are used. Certain rather specialized occupations require unusual types of protection including firemen, aircraft crews, missile fuel handlers, astronauts and divers. In general, this section is not directed to these specialized vocations but much of what we have learned about protective clothing comes from experience in providing protection for workers in such unusual environments.

There is a wide variety of materials available today to meet the requirements of many types of conditions. Fabrics such as cotton, glass fibers, Orlon, Nylon, Dynel and even Teflon are available for jackets and coveralls. These can be made impervious by coating with various plastics, rubber or Neoprene. Plastics are also available in sheet form and can be made into clothing with glued or heat-sealed seams. Respiratory protective devices often are worn with protective clothing and, in many cases, become an integral part of such clothing (see Figure 36-5).

While some protective clothing is supplied and cleaned by the worker it is more commonly done by the employer, especially if the wearing of such clothing is a requirement of the job. In many cases, work clothing cannot and should not be taken home since such clothing could become a hazard to persons handling it there. This is particularly true of workers handling radioactive materials, pesticides, beryllium and other highly toxic materials. If the employer is responsible for cleaning the clothing he, too, must decide whether to send it to a commercial laundry or to set up his own cleaning facility. For clothing contaminated with ordinary dirt, soil, grease and perspiration, a commercial laundry may be an acceptable method of handling the problem. In many cases, one or more plant laundries will have to be provided depending on the variety of exposures encountered.

Supplied by and used with permission of
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico

Figure 36-5. An Air Ventilated Blouse with Integral Respirator.

There is also the problem of maintenance and of replacement. Garments must be inspected before or after cleaning and worn garments discarded. Those not meeting standards of cleanliness required may have to be recycled. For radioactive materials, this may mean monitoring of each garment with a special instrument. Where the exposure is to certain chemicals, it may mean periodic tests on occasional selected garments after cleaning.

Training in the use of protective clothing is important, especially with complex gear. Even with simple laboratory coats and coveralls, workers should be given some instructions in how to care for such garments and how and when to turn them in for cleaning and replacement. For complex garments, especially those including respiratory protective equipment, regular training and refresher courses should be given. Here again, some *one* person should be in charge of selection, storage, maintenance and training in the use of such equipment. An important element in this training is that dealing with the methods of putting on and taking off this clothing. Special standardized techniques may be necessary where clothing has or could have become heavily contaminated. If care is not exercised, contaminating materials can be brought into contact with the worker's skin or transferred to his street clothing. Separate lockers for work clothing and street clothing are necessary when hazardous materials are handled. These lockers may be on opposite sides of the shower room.

**Protection Against Contamination**

Situations included in this category are those where there is no immediate danger to the skin from contact with the contaminating material, but where it is undesirable to have the worker expose himself in his street clothing. This includes the mechanic or machinist exposed to dirt and grease, the operator handling toxic dusts, the laboratory employee handling various chemicals that could damage his clothing and the person working with radioactive materials or bacteriological agents. The emphasis in all of these cases is on limiting the spread of the contamination. When the worker leaves his job, he should not transfer the hazardous or undesirable material to clean parts of the plant or to places outside the plant. Clothing for these applications is often called anti-contamination or anti-C clothing. It should be noted that also within this category of jobs are those where extreme cleanliness is required for the protection of the product being made. In that case, the aim is to prevent the spread of contamination from street clothing or the worker to the product. The same requirements and procedures also prevail here.

Garments worn in these situations are principally of cotton or synthetic fibers and usually are not impervious to liquids or dusts. The mechanic and the chemical plant operator usually wear coveralls. If the material is difficult to remove he may also wear gloves and some type of cap. Footwear may consist of a pair of shoes which are left in the plant. In working with more dangerous material like toxic dusts or radioactive materials more strict regulations are necessary. Here a complete change of clothing including socks and underwear is needed and showering is essential. For heavily contaminated work special attention must be given to sealing all openings in the clothing. For dirty jobs which are not done routinely, openings may be sealed with masking tape and two suits of coveralls may be worn. If possible, the clothing should be designed to minimize the number of openings, decorative buttons and folds as these items collect contamination and make it difficult to remove.

Many workers wear full coverage clothing all day in doing their routine jobs. They may also wear surgeon's gloves or similar types to give the required sensitivity in handling objects, but these are not satisfactory if the work subjects the gloves to abrasion. Head covering in this case is usually a simple cloth cap although a hard hat may also be required on certain jobs. In addition to shoes worn only in the plant, special shoe covers may also be required. These may be of heavy cloth, plastic coated cloth, plastic or rubber. These are particularly important to the worker who must move from one department or operation to another. By changing shoe covers he prevents the spread of the particular type of hazardous material in one department to another where a different material may be handled.

Rooms where workers remove heavily contaminated clothing must be well ventilated since removing contaminated clothing can cause suspension of the contaminant in the air where it becomes hazardous to everyone in the room. For the same reason, chutes and bins where contaminated clothing is deposited should have exhaust ventilation. For limiting contamination, consideration should be given to the possibility of using disposable clothing made of paper or plastic, particularly on very dirty jobs. Cleaning costs should be balanced against the costs of replacement and disposal. In making this evaluation careful consideration should be given to the disposal cost as this is often neglected.

**Protection Against Corrosive Chemicals**

Included in this category are situations where the contaminant can have an immediately damaging effect on the skin. These include exposures to strong acids and acid gases, alkalis, some organic chemicals and strong oxidizing agents. Also included are those requiring protection against very heavy contamination where ordinary anti-C clothing would permit skin contamination to levels where complete removal would be difficult. Clothing in this category is usually impervious to liquids, gases and vapors and may be made of fabrics impregnated with rubber or plastic. Rubber "frog suits" have been used for work in heavy concentrations of dangerous radioactive materials. The worker may be required to shower with the suit on and then shower to clean himself after carefully removing the suit using standardized procedures. Respiratory protective equipment is almost always required in conjunction with this clothing. It may be worn under the clothing or it may be an integral part of the clothing. An air line may be attached directly to the clothing for ventilation or it may go directly to a respirator. The head cover is usually part of the clothing in the form of a hood. Gloves must be impervious and may also be an integral part of the clothing.

Wearing impervious clothing imposes serious limitations on the amount of time the worker can wear the clothing and the strenuousness of his activity. Unless the clothing is ventilated with an air line, perspiration will rapidly accumulate inside the clothing and the body temperature may increase except in cold environments. These conditions impose a serious stress on the worker. Air-ventilated clothing is much more comfortable and permits wearing the clothing a longer period of time although it may limit the movements of the worker. Air-ventilated clothing must be studied and evaluated carefully because improper design can result in only parts of the clothing being ventilated. The air line must discharge through several openings to supply the various parts of the suit. Where workers must work in impervious clothing for long periods close medical surveillance is required.

**Protection Against Skin Penetration**

Certain materials will pass through the intact skin and produce systemic toxic effects without necessarily doing any damage to the skin or causing pain. Situations involving these materials include exposure to hydrogen cyanide, missile or rocket propellant and the radioactive form of hydrogen known as tritium, either in elemental form or as water vapor. The clothing requirements for these exposures are practically the same as those discussed in the previous category. They are grouped separately because the effects produced can be very serious and there is little or no warning of failure of the protection. Thus, there is more need for frequent inspection and testing of the clothing worn in this type of exposure situation. Respiratory protection is always required.

**Protection Against Heat and Cold**

For mild exposure to heat the clothing should be light and well ventilated. At higher temperatures most clothing restricts the body's ability to remove body heat by evaporation of perspiration and forced ventilation of the clothing is necessary for prolonged work at elevated temperatures. Obviously, the design of clothing for protection against heat and cold emphasizes thermal insulation and the principles on which such design is based are well known. If there is a great deal of radiant heat, as around a furnace or flames, aluminized plastic, cloth or asbestos may be used to provide a reflective surface.

Air supplied clothing is particularly useful since the supplied air may be heated or cooled to maintain thermal equilibrium. Air for breathing may also be heated or cooled and very cold air may be tempered if taken in through a hose wrapped around the worker's body under the insulating clothing. For work at very low temperatures, particular attention must be paid to protection of the fingers, toes, ears and nose since they are the parts most difficult to keep at an adequate temperature and frostbite may result from exposure. Thick gloves which are necessary greatly limit manual dexterity and electrically heated gloves may be required under some conditions.

There are special pieces of protective gear used to protect parts of the body against heat, flame and sparks. The welder's leather apron and his face mask are examples. Foundry workers wear leather leggings to protect their legs against spilled molten metal. They also wear special foundrymen's shoes called Congress shoes which can be pulled off quickly if hot metal is spilled into the shoes.

There are many other devices used for the protection of the individual worker against falls, falling objects, flying particles, burns and injuries, such as safety hats, shoes, gloves, goggles, etc. They are not covered in this chapter since they are considered to be strictly "safety" items. See Chapter 47 for a general discussion of these items.

## EMERGENCIES

By its very nature, personal protective equipment is important in dealing with emergencies. Mine explosions and cave-ins, industrial fires, natural disasters and gas leaks all present occasions when men must receive protection against severe and unusual conditions while saving life and property. Engineering controls such as ventilation are completely inadequate and usually inapplicable in such situations; therefore complete reliance must be placed on protective clothing and respiratory protective devices. Some of the same devices used in the daily plant activities may be applicable but in most cases it will be necessary to use more specialized devices such as self-contained breathing apparatus or fire-resistant clothing.

Equipment for dealing with emergency situations must be stored where it is readily available and yet not be placed where it can be damaged by the accident causing the emergency. This requires careful analysis to anticipate the possible emergencies and accidents which can arise. An important characteristic of emergency protective devices is that they are *stored* which means that they are actually used very rarely. Since much equipment suffers deterioration even during storage, it is necessary to set a regular schedule of inspection and testing of each device.

Most such devices are fairly complex and require trained persons for their use. An untrained person attempting to rescue an injured man in a building filled with toxic vapors is very likely to become a casualty himself. Men must be trained in how to function in an emergency and in the use of all emergency equipment. Retraining exercises must be given at regular intervals since instructions are easily forgotten, equipment is changed, and personnel may be transferred. The essential beginning of any emergency planning is a thorough analysis of the possibilities of accidents. This analysis, in itself, may lead to the correction of unsafe conditions.

## STANDARDS AND INFORMATION

The approval schedules of the Bureau of Mines for respiratory protective equipment are standards in a sense as has already been noted. The American National Standards Institute has prepared consensus standards on many items of protective equipment and these are listed in the bibliography of the chapter. There are needs for additional standards for some equipment and for the revision and updating of many existing standards. The process of producing standards is a lengthy one, and changes and improvements in the various devices are being introduced continuously. There must be a willingness to experiment and test new and nonstandard devices under non-hazardous conditions in order to secure improvements in protection and acceptability.

In addition to the written standards there are various guidebooks to the selection, use and maintenance of personal protective devices prepared by organizations concerned with health and safety. These are listed at the end of the chapter and the appropriate guide should be consulted by anyone responsible for supervising the use of these devices. Such guides have been prepared by the National Safety Council, the American Conference of Governmental Industrial Hygienists, the American Industrial Hygiene Association, the International Atomic Energy Agency and others. Most manufacturers of protective equipment furnish information on the degree of protection which can be achieved by their devices and on their proper use, care and maintenance.

### References


1. *Occupational Safety and Health Administration Standards, Personal Protective Equipment,* Federal Register, 36:10590 (No. 106, May 29, 1971).
2. SCHUTZ, R. H. and E. J. KLOOS. *Respiratory Protective Devices Approved by the Bureau of Mines as of Dec. 31, 1968,* Information Circular #8436, Bureau of Mines, Pittsburgh, Pa.
3. *Respiratory Protective Devices Manual,* AIHA-ACGIH, p. 91, 1963.
4. Ibid., pp. 56-58.
5. *American Standard Safety Code for Identification of Gas Mask Canisters,* K13.1-1961, American National Standards Institute, 1430 Broadway, New York, 10018.
6. VENABLE, F. S. and E. D. POLICK. "Your Compressed Air: Fit to Breathe?," National Safety News, 89:28-32, 1964.
7. *Respiratory Protective Devices Manual,* AIHA-ACGIH, Chapter 13.
8. SCHUTZ, R. H. *Approved Dust Respirators for Coal Mines,* Information Circular #8509, Bureau of Mines, Pittsburgh, Pa.
9. *American National Standard Practices for Respiratory Protection,* Z88.2-1968, American National Standards Institute, 1430 Broadway, New York, 10018.
10. "Series on Respiratory Protection," National Safety News, April-December 1971.
11. BONNEY, T. B. *Industrial Hygiene Highlights,* p. 208, Industrial Hygiene Foundation, Pittsburgh, Pa., 1968.


### Preferred Reading


American Industrial Hygiene Association Journal
Health Physics
National Safety News
Industrial Hygiene Highlights
Annals of Occupational Hygiene (British)
Staub (German)


### Additional Reading


Additional Standards from the American National Standards Institute:

American National Standard for Occupational and Educational Eye and Face Protection, Z87.1-1968.

American National Standard Safety Requirement for Industrial Head Protection, Z89.1-1969.

American National Standard for Men's Safety-Toe Footwear, Z41.1-1967.

*Respirators and Protective Clothing,* International Atomic Energy Agency, Safety Series #22, Vienna, 1967.

HYATT, E. C. "Current Problems and New Developments in Respiratory Protection," *Am. Ind. Hyg. Assoc. J.* 24:295-304, 1963.

HYATT, E. C. Evaluation of Respirator Performance by DOP Man Tests, Paper given at the Am. Ind. Hyg. Conf., Toronto, Ontario, May 1971 (To be published).

*Industrial Noise Manual,* American Industrial Hygiene Association, Chapter 10, 1966.

PLUMB, E. E., E. L. MENDENHALL and M. C. ROBBINS. "Evaluation of Protective Clothing and Equipment for Operations in Oxygen-Rich or Deficient Atmospheres Approaching −100°F," *Am. Ind. Hyg. Assoc. J.* 27:29, 1966.

CROLEY, J. J. "Protective Clothing — Responsibilities of the Industrial Hygienist," *Am. Ind. Hyg.* Assoc. J. 27:140, 1966.