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RESPIRATORY PROTECTIVE DEVICES MANUAL

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PREFACE

Respiratory protective devices are perhaps the oldest method of controlling occupational diseases; however, health and safety personnel are generally less informed about the applications and limitations of these devices than about any other particular control device. Many books and technical reports have been written on engineering control measures, but it should be noted that no text exists covering comprehensively the field of respiratory protective devices.

Because of the limited published technical data in this field, the committee has drawn heavily upon the experience of respirator manufacturers, representatives from the U.S. Bureau of Mines, and information made available by the American Standards Association. Throughout the preparation of the manual, close cooperation of all these agencies was achieved.

The manual primarily involves commercial devices; hence, there are specific technical details that cannot be discussed. Obviously, the respirator manufacturers are reluctant to jeopardize their development investment and possible patent rights by disclosing information until such rights are protected. Research and development laboratories are reluctant to give interim progress reports, preferring to make the completed research available in the form of a technical report or of a product. Government classification may also make it necessary to withhold some of the developments.

This book has been prepared primarily to provide the industrial hygienist and other health and safety specialists with technical information pertaining to the principles of operation of the various types of respiratory protective devices and their selection, use, and maintenance. Safety and supervisory personnel will find many of the chapters especially useful.

This committee will gratefully receive comments and suggestions for future consideration. The manual will be revised as needed to present new practices and developments.

Edwin C. Hyatt, Chairman
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INTRODUCTION

In the control of those occupational diseases caused by breathing air contaminated with harmful dusts, fumes, mists, gases, or vapors, the primary objective should be to prevent the air from becoming contaminated. This is accomplished as far as possible by accepted engineering control measures; however, although one may wish to be idealistic in applying these procedures, there will always be circumstances in which, for one reason or another, the procedures will be uneconomical, inapplicable, impractical, or ineffective. Protective respirators will be needed for these situations, either as a primary means or as an adjunct or supplement to other primary control measures.

The terms "respiratory protective devices" and "respirators," as used throughout this Manual, include gas masks, self-contained breathing apparatus, chemical cartridge respirators, hose masks, abrasive blasting respirators, air line respirators, mechanical filter respirators, and combination mechanical filter—chemical cartridge respirators.

I. HISTORY OF RESPIRATORY PROTECTIVE DEVICES

Respiratory protective devices are probably the oldest method of controlling occupational disease, their first use dating back at least as far as the Christian Era. Pliny the elder[1] (23-79 A.D.) describes filter respirators of a sort, for use against vermilion dust, and Agricola[2] mentions the use of such devices in various mining operations in the 16th Century. Katz et al.[3] in 1926, and Drinker and Hatch[4] in 1935, gave a review of the history and development of respirators. Davies[5] in England in 1949 presented a good review of the filters used in combat gas masks and discussed their possible application in industry.

Significant contributions to the design and testing of respirators date from about 1900, with the real development of these devices dating from World War I. Drinker and Hatch note that in the United States apparently no technical papers on respirators or masks appeared until after that war, when the U.S. Bureau of Mines first started investigations of respirators for industrial uses based on their earlier work on military gas masks. Drinker mentions advertisements, dated 1914, illustrating air masks for sand blasters as part of the equipment sold by an American manufacturer, and notes that masks supplied with fresh air were not used industrially for operations like paint spraying until about 1919 or 1920. The Bureau of Mines highlighted the early development of respirators in 1923 when it described approved hose masks sold for protection against irrespirable gases.

II. DEFINITION AND CLASSIFICATION OF RESPIRATORS

Although by definition a "respirator" is any device used for providing respirable air, the use and connotation of the word "respirator" has become both more specialized and quite variable. Some interpret it as a device for protecting against atmospheric contaminants alone; some envisage specifically a device to fit over the nose and mouth to protect against the inhalation of dust and smokes. To others, the word signifies a small face-type device for either gases or dusts, in contradistinction to a larger device, such as a gas mask of the type with a breathing tube and a canister worn on the chest. Frequently, the scope of the meaning includes canister gas masks and even masks supplied with fresh air through hose lines. It appears logical to expand the scope further and include all devices for personal respiratory protection.

In order to promote greater uniformity in the naming of the various devices that appear on the market and to provide a basis for a clearer understanding of the operating principles and uses of the device as implied by the name, the Bureau of Mines and the American Standards Association (ASA) have promulgated standard definitions and classifications for respiratory protective devices. Appendix A lists the ASA definitions, as well as some additional terms that are used in the respirator field and sometimes found in the literature.

Respiratory protective devices are grouped broadly according to their mode of functioning. The basic classifications are:

- Air-purifying respirators
  - Particulate-removing (mechanical filter) type
  - Gas- and vapor-removing (chemical filter) type
  - Combination particulate-removing and gas- and vapor-removing type
- Atmosphere-supplying respirators
  - Hose-type atmosphere-supplying respirators
    - Hose mask
    - Air line respirator
    - Continuous flow type
    - Demand type

Self-contained breathing apparatus
  Recirculating type
  Demand type

Design details and operating principles are discussed in the following chapters: air-purifying respirators, Chapter 6; hose-type supplied air respirators, Chapter 7; and self-contained breathing apparatus, Chapter 8.

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Chapter 1

A RESPIRATOR PROGRAM

This chapter presents the essential information for the intelligent selection and use of respirators, and the fundamentals of a respirator program. The chapter also considers the Bureau of Mines Approval Program, unapproved respirators, and the problems of outdated and surplus gas masks.

I. SELECTION AND USE

A respiratory protective device is used to protect the wearer from the inhalation of harmful atmospheres. The protection required may range from conditions which are mainly a nuisance, as from odor or irritation, to those which are immediately dangerous to life. The hazard may be due to one or more toxic contaminants or to an atmosphere significantly deficient in oxygen. The contaminants may be in the gaseous or particulate state or a combination of both. Protection may be needed for only minutes, as in rescue operations, or for hours, as in routine use.

For adequate protection against the multiplicity of conditions which may be encountered in individual operations, many types of respiratory protective devices have been developed. Each has a particular field of application and limitations from the viewpoint of protection, as well as advantages and disadvantages from the viewpoint of operational procedures and maintenance.

The use of a respiratory protective device is justified only after a consideration of the factors involved indicates that the device selected will provide satisfactory protection when properly used. It is clearly evident, therefore, that the use of a respirator requires a thorough knowledge of such factors as the following:

1. The chemical, physical, and toxicological properties of the substance against which protection is required (Chapter 5, Table 5.3).

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

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

4. 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.

5. The nature of the duties to be performed by the wearer of protective devices, particularly as they relate to restriction of movements (see Chapter 13).

6. An understanding of the principles, design, scope of use, limitations, advantages, and disadvantages of the respiratory protective equipment available (see Chapters 6, 7, and 8).

Virtually all applications of respiratory protective devices are specific and require individual attention. However, a classification of principal kinds of exposures and the type of respiratory device considered effective is given in Fig. 1.1. Since the various types of respirators were outlined in the Introduction and are described in other chapters, they will not be discussed here. The following discussion will be confined mainly to the nature of exposures and conditions affecting the use of respiratory protective devices.

As shown in Fig. 1.1, hazardous atmospheres have been classified into two major groups: (1) oxygen deficient, and (2) those containing significant concentrations of toxic contaminants. The toxic contaminants are classified into three subgroups depending upon physical state, namely, gaseous, particulate, and a combination of gaseous and particulate contaminants. From the viewpoint of hazard, the atmospheres containing toxic contaminants are grouped into two subgroups: (1) those immediately dangerous to life and (2) those not immediately dangerous to life. Under each classification is the type or types of respirator considered satisfactory. This selection chart follows the classification system in this Manual for the various types of devices.

For protection against atmospheres deficient in oxygen, only the self-contained type of respirator or the hose mask with blower is considered satisfactory.

The oxygen content of normal air is about 20.9 percent by volume. Atmospheres in confined spaces such as wells, mines, holds of ships, tanks, and burning buildings may contain a lower percentage of oxygen because of dilution or displacement of the air by other gases or vapors, or because of the loss of oxygen by its reaction with, or absorption by, other substances. When the oxygen content of the air is about 16 percent, the flame of a safety lamp will be extinguished. Below this concentration, a person breathing the air exhibits symptoms ranging from increased volume of

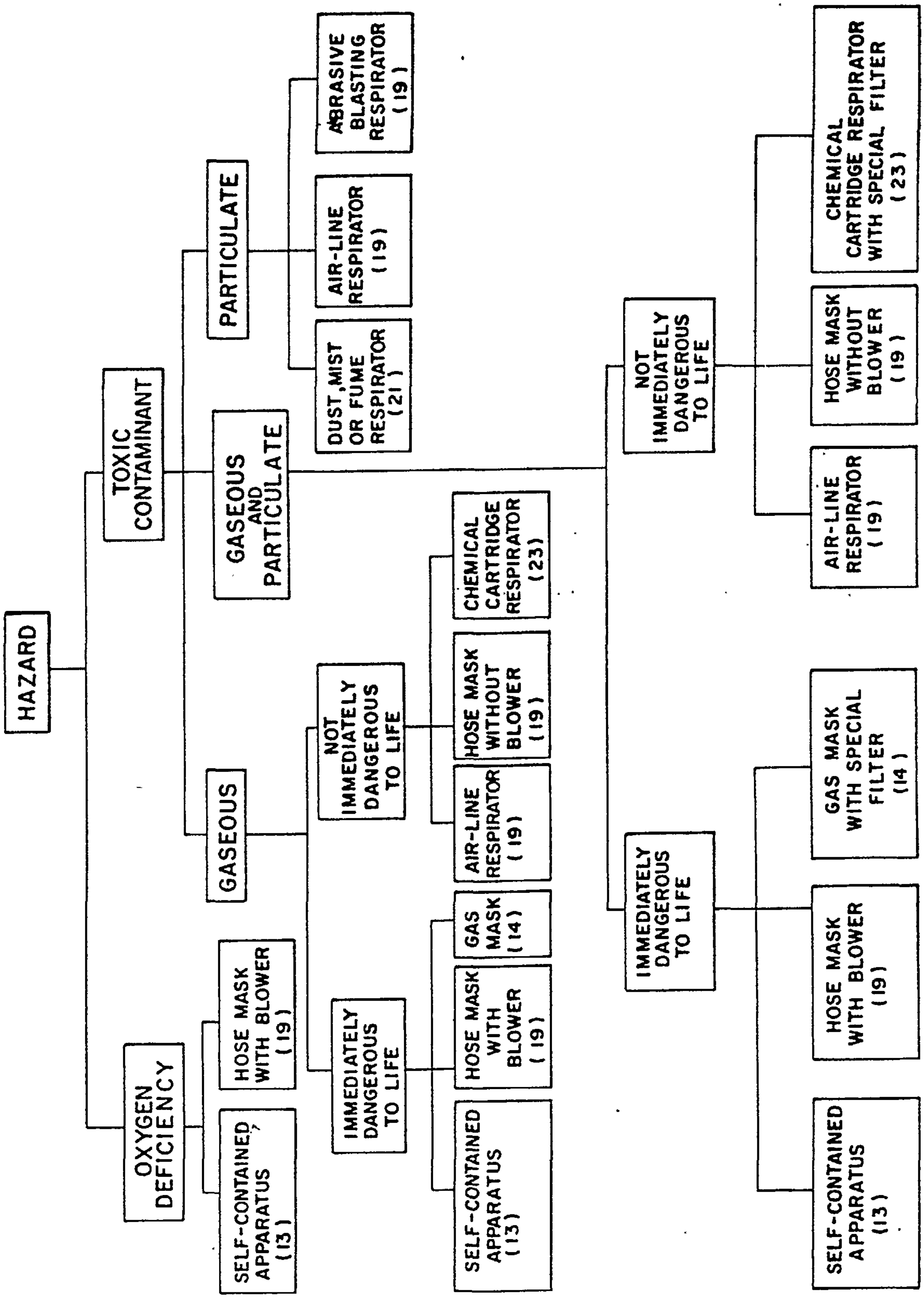

Fig. 1.1. Outline for selecting respiratory protective devices.

(After Bureau of Mines information circular 7792. Numbers in parentheses refer to Bureau of Mines Schedules and Revisions thereof).

breathing and acceleration of pulse rate to unconsciousness and death, depending on the oxygen content of the air and the degree of his physical activity.

For protection against concentrations of gaseous contaminants which are immediately dangerous to life, the self-contained apparatus, hose mask with blower, or gas mask may be used. Gaseous contaminants immediately dangerous to life are gases present in concentrations that would endanger the life of a person breathing them for even a short period of time. For example, 400 to 500 parts of sulfur dioxide per million parts of air (0.04 to 0.05 per cent) by volume is considered to be dangerous for a short exposure. A gas mask should not be used if the concentration of the contaminant is above 3 per cent by volume of ammonia, 1 per cent of chlorine, or 2 per cent of other gases and vapors, as stated on the label of the particular canister. When the gas mask is used, the proper canister should be selected for protection against specific contaminants. It also must be borne in mind that high concentrations of gaseous contaminants may be irritating to the skin and mucous membranes, and also that some substances, such as hydrocyanic acid, can be absorbed through the unbroken skin. In addition, they may be explosive hazards. These factors, as well as respiratory protection, must be considered in using respiratory protective devices.

For protection against concentrations of gaseous contaminants which are not immediately dangerous to life, the air line respirator, hose mask without blower, or chemical cartridge respirator may be used. Gaseous contaminants not immediately dangerous to life are gases present in concentrations that could be breathed for a short period without endangering the life of a person breathing them, but which might produce discomfort and possible injury after a prolonged single exposure or repeated short exposures. For instance, the threshold limit value for sulfur dioxide has been set at 5 ppm, based primarily on the irritating effect of the gas on the nose, eyes, and throat. If the concentration of organic vapors is above 0.1 per cent by volume, the chemical cartridge respirator should not be used.

For protection against concentrations of gaseous and particulate contaminants which are immediately dangerous to life, the devices that were listed for gaseous contaminants may be used, with the addition that the gas mask should be provided with a special filter.

For protection against particulate contaminants, the dust, fume, or mist respirator, air line respirator, or abrasive blasting respirator may be used. The majority of particulate contaminants are not immediately dangerous to life; that is, days, weeks, or even years of exposure may transpire before harmful effects are noted. Notable exceptions are dusts and mists containing the organic phosphorus insecticides which, if present in high concentrations, may incapacitate or even kill a man in a very short time. Other exceptions to this generalization are certain radioactive particulates and beryllium.

For protection against highly toxic contaminants such as radioactive aerosols, beryllium, and pesticides (not shown in Fig. 1.1), see Chapter 11, Sections II through V.

II. INSTRUCTION

The selection of respiratory protective equipment should be the responsibility of a person with adequate training and experience to decide if the respirator is a desirable control measure and to evaluate thoroughly the hazard, the limitations of the various types of devices, and the conditions of usage. Of equal importance to proper selection is proper use and maintenance (see Chapter 12 for maintenance recommendations). The failure of a respirator to give adequate protection may result from improper use and maintenance as well as from improper selection; therefore these factors require particular emphasis.

No one should be permitted to wear a respirator as a control measure unless he has been instructed in its use (see Chapter 13 for training). The purpose for which the respirator is to be worn, its operating principles, its limitations, and the essential parts should be explained to the wearer. There should be both demonstration and practice in how the respirator should be worn, how to adjust it, and how to determine if it fits properly. The extent of instruction varies from a specific and detailed training program for the use of self-contained breathing apparatus to brief instructions for the simpler devices, such as the dust respirator.

In general, the amount of training is directly related to the anticipated hazard. For example, the training should be thorough and complete for devices that will be used in atmospheres immediately dangerous to life. In the use of the gas mask, the wearer not only must be acquainted with all mechanical aspects of the apparatus but also should be trained in the detection of the odor and irritating effects of incipient concentrations so that he can immediately detect when the canister is exhausted. The use of devices in an emergency by unauthorized or untrained persons will only handicap a rescue operation.

III. SUPERVISION

After a wearer is instructed in the use of a selected respirator, he needs adequate supervision, as well as an explanation of the character and magnitude of the hazard. The respirator should be inspected to assure that it is in proper operating condition. The device should then be carefully adjusted in fresh air, paying particular attention to obtaining a gas-tight fit with the facepiece. The wearer should enter the contaminated air cautiously, and if there is any evidence of improper functioning of the device, he should return to fresh air to determine the cause. If the atmosphere is immediately dangerous to life, the wearer should know the approximate length of time that the respirator will allow him to remain in the contaminated area, and he should know his distance from fresh air. If the wearer is to enter a confined space, such as a tank, he should use a life line, and attendants with similar apparatus should stand by in fresh air in case of an emergency. The use of respirators under such dangerous conditions should always be under strict supervision, and the wearer should never be permitted to operate alone.

When respirators are used for routine protection in atmospheres not immediately dangerous to life, supervision can be much less and the individual wearer can be responsible for proper use of the device if he is adequately trained. Closer supervision is required if a respirator is worn for protection against toxic particulates which could produce chronic poisoning, or against dusts producing fibrosis or other significant pulmonary impairment, than is needed with so-called nuisance dusts whose effects are negligible. <u>In general, however, some degree of supervision should be in effect at all times.</u>

IV. PROGRAM ESSENTIALS

The effective use of respirators in industry requires a planned program with responsibility specifically assigned to an adequately trained, experienced person. The following are essential parts of the program:

A. Selection

Select a respirator that will protect adequately, and one that can be worn with reasonable comfort under the conditions of use.

B. Instruction

Instruct the wearer in the need for using the device and the means by which protection is afforded. Demonstrate and have the wearer practice obtaining proper facepiece fit and adjusting for comfort and effective protection.

C. Supervision

Supervise to assure that the proper device is being used for each exposure condition and that the device is complete and in proper operating condition. Provide such supplemental safety precautions as a life line and stand by rescue personnel where needed.

D. Centralized Cleaning Station

Use a centralized cleaning station to clean respirators after each use when they are used routinely; see Chapter 12 for cleaning methods. Assign each worker two respirators marked with his initials or number so that he retains the same respirators and has a clean one always available.

E. Inspection and Maintenance

Devices used routinely can be inspected during cleaning, and worn or deteriorated parts replaced with parts specifically designed for the particular respirator. Filters or cartridges may be changed after each use or according to schedule.

Emergency equipment should be thoroughly inspected at scheduled periodic intervals to assure first-class condition at all times.

F. Storage

Store equipment in dustproof containers (original cartons, cases, or plastic bags are suitable) away from sunlight, heat, extreme cold, and excessive moisture.

G. Medical Surveillance

Since respirators are a control measure, persons using them should have the same medical supervision as persons protected by ventilation or other control measures.

V. U.S. BUREAU OF MINES RESPIRATOR TESTING AND APPROVAL

The U.S. Bureau of Mines, through its central experiment station in Pittsburgh, in 1919 began issuing schedules for testing respiratory protective equipment of specific types. Under the current Bureau of Mines approval schedules and tests the manufacturer of respiratory protective devices can for a reasonable fee have his products tested and approved by the Bureau, a now widely accepted procedure throughout the United States.

The Bureau of Mines currently has five approval schedules (see Chapter 9) under which it tests and approves the following types of respiratory protective devices: (1) self-contained breathing apparatus, (2) gas masks, (3) supplied air respirators, (4) nonemergency gas respirators (chemical cartridge respirators), and (5) dust, fume, and mist respirators.

Several types of respirators that are currently available are not covered by existing Bureau of Mines approval schedules. These are (1) filter type respirators for protection against materials significantly more toxic than lead, such as radioactive aerosols, beryllium, and pesticides; (2) chemical cartridge respirators for protection against gases and vapors other than organic vapors; (3) escape type self-contained breathing apparatus; (4) combination air line and self-contained breathing apparatus; (5) supplied air suits; and (6) combination air supplying-purifying device using a facepiece, helmet or suit.

The Bureau of Mines[1] is considering the feasibility of establishing performance requirements for types (2), (3), and (4) above, and work is in progress on a revision of the performance requirements for supplied air respirators. The Bureau of Mines is currently engaged in establishing test procedures and assembling information on which to base performance requirements for filter type respirators noted above in (1).

The Bureau of Mines, at present, approves devices to be used only for protection against contaminants not significantly more toxic than lead. Since the end of World War II many highly toxic materials, including radioactive aerosols, beryllium, and organic phosphates (insecticides and nerve gases), have been marketed. Before the introduction of these extremely toxic contaminants, many users assumed that respirators approved for lead fume would protect adequately against other toxic fumes. Following World War II, however, the Bureau of Mines decided to limit the approval of dust and fume respirators to dusts and fumes that are not significantly more toxic than lead.

Before selecting any respirator one must be aware of the limitations imposed by face fit and the limits of the Bureau of Mines schedules, as described in Chapter 9. Ignorance of these limitations and improper use have resulted in overexposure to the workmen.

Tentative approval requirements for materials significantly more toxic than lead have been prepared. Obviously many respiratory protective devices must be selected and used for such contaminants. Chapter 11 (Sections II through V) deals specifically with this subject, and Appendix B contains interim recommendations for respiratory protective devices for protection against aerosols that are significantly more toxic than lead. These interim recommendations differ from those first published[2] in that limitations of the half mask respirator are given.

VI. USDA RESPIRATOR EVALUATION PROGRAM

The U.S. Department of Agriculture (USDA) in 1949 initiated an investigation of respiratory protective devices for operators handling pesticides. Respirator manufacturers were invited to submit devices that might provide suitable protection against pesticides.

Since 1950, the USDA has issued several lists of devices tested and found satisfactory against specific pesticides. Two types of devices are listed in the 1962 report (see Appendix D)—chemical cartridge respirators and gas masks. This report includes other precautionary measures to be observed. The methods of testing these devices are described in Chapter 11, Section V.

VII. UNAPPROVED RESPIRATORS

Two main groups of unapproved respirators are of great concern: the "nuisance dust respirators" sold by many of the respirator manufacturers, and the respiratory protective devices for protection against special materials significantly more toxic than lead. Unfortunately, if a device lacks approval, it is not readily apparent whether this is due to the lack of a suitable schedule, to failure of the device to meet approval under an existing schedule, or to not having been submitted to the Bureau of Mines for approval.

If a qualified individual selects the respiratory protective devices for a particular situation (see Section I), some of the unapproved devices may be used safely.

Since the inhalation and exhalation resistance is a large factor in U.S. Bureau of Mines approvals, anyone selecting unapproved devices should give these facts full consideration. High resistances will increase the leakage due to poor fit as well as at connections of cartridges, canisters, valves, and other parts. Low resistances may indicate open valves, very inefficient filters or even worn|punctured parts. An employee selecting a device will generally select one having a low resistance, regardless of other important factors that must be considered.

Many respirators are selected and bought by a purchasing department, which may be attracted by the cheapest price. Often the purchaser gives little thought to the type of problem and the degree of protection afforded. Obviously, an inexpensive respirator with a frame holding a piece of gauze or a sponge is ineffective against toxic dusts and should never be used for such a purpose. Unquestionably there are nuisance dust problems, and some of the nuisance respirator filter media on the market may be 50 to 95 per cent efficient against 1 to 5 micron (μ) in diameter dusts. Nuisance respirators may be effective for certain limited applications, as when 20μ pollen particles must be filtered to protect hay fever sufferers. Nuisance respirators should only be used for dusts positively known to be nontoxic.

VIII. SURPLUS MILITARY AND CIVILIAN MASKS

Following World War I, thousands of surplus masks were thrown on the market and used for protection against substances for which they were never intended. There were many nonfatal poisonings of workers[3] in ammonia plants and of firemen who used these devices when they were exposed to carbon monoxide. These poisonings resulted in widespread newspaper publicity which emphasized the hazards of using such devices. After World War II the U.S. Army Chemical Corps policy[4,5] was very conservative, as indicated in the following instructions issued to all military personnel in September 1948:

"Surplus masks must be rendered useless for further use as gas masks in the interest of military security and public health and safety by the removal of the canister. The canister may be demilitarized by smashing it, punching several holes completely through it, or by disassembling it if recovery and sale of the components is considered economically feasible. However, disassembly must be done so that the canister cannot be reassembled."

To eliminate further the possible disposition by sale of Chemical Corps controlled surplus gas masks, the following additional instructions were furnished to all military personnel: "Surplus military type protective masks will be demilitarized as follows: the facepieces of surplus protective field masks will either be chopped or cut up so that they cannot be repaired, or destroyed entirely by burning, depending upon the method of disposal. . . . Canisters for military type protective masks will be destroyed by burning. Under no circumstances will canisters be declared or sold as scrap."

The above instructions notwithstanding, a limited quantity of assorted gas masks periodically are offered to the public, from stocks evidently purchased many years ago by surplus dealers, before the disposition instructions were issued. These sales cannot be legally restrained; however, warnings to the public (for example, the warning bulletin issued by the State of Kansas, as shown in Fig. 11.5) are encouraged by the military authorities to eliminate the misuse of these masks.

The following three factors are involved in the use of surplus military masks. First, the canisters will not protect against carbon monoxide or ammonia and are not designed for industrially-occurring concentrations of other gases and vapors. Second, the rubber in the facepieces, valves, and head harness may have deteriorated. Third, an employer may be subject to legal action if one of his employees should be injured while wearing a surplus military mask issued by the employer.

Surplus respiratory protective devices also originate from the U.S. government agencies using them for the protection of civilian personnel. Civilian government agencies have no uniform instructions regarding the disposition of surplus respirators. Surplus devices are not available from manufacturers of respiratory devices, since the industry polices itself through the Industrial Safety Equipment Association.

It is strongly recommended that individuals responsible for the disposal of surplus equipment follow this guide:

1. If a respiratory protective device is judged inadequate for the protection of your personnel, it should be completely destroyed and not placed on a government surplus list to endanger the health of anyone buying such a device through a surplus dealer.

2. If an agency has large quantities of new but unneeded respiratory protective devices which currently are on the market and approved by the Bureau of Mines, and if these respirators are of the simple dust type (in new condition) they may be safely surplused. If they are of the air-purifying type, with chemical cartridges or canisters, and have been stored three years or longer, they should be destroyed. If the canister is attached to the facepiece (with bottom seal intact), the canister should be discarded after one year (see Chapter 12).

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Chapter 2

PHYSIOLOGICAL FACTORS IN RESPIRATORY PROTECTION

I. INTRODUCTION

The purposes of this chapter are to describe the physiological factors which must be considered in respiratory protection and to discuss those physical factors in the protective respiratory equipment that must be considered in the design, testing, and use of respiratory devices. The types and applications for protective respiratory devices are discussed in detail in subsequent chapters. However, it should be mentioned that, in terms of physiological requirements, the distinction between the devices must be based primarily upon their inherent design characteristics.

Physiological demands are the greatest for the widely used filter or canister respirator, in which the wearer breathes through the protective filter or sorbent, or combination thereof, and then exhales through a relief valve of some type.

In supplied air units of the type utilizing demand or diaphragm valves or utilizing a self-generating canister, the respiratory resistance requirements are not severe since a forced draft or positive air supply exists, or there is supply which can be triggered by a slight negative pressure. Exhalation from these devices would be comparable to that in the induced flow type of equipment, except for the self-generating unit, in which exhaled flow is through a canister and then into a bag or bellows under a slight positive pressure.

Supplied air respirators of the continuous flow type differ completely in that a continuous flow of air is provided to the wearer, and the only physiological requirement is that total flow supplied should be greater than the peak instantaneous value. Details of peak flows created during inhalation are covered in this chapter so that the essential physiological requirements for all types will be included.

This chapter does not describe respiratory physiology in detail nor cover the mechanism of oxygen transport through the pulmonary membrane. It is essential that the wearer of a particular respiratory device understand its purpose. Some devices provide flows of particulate- or gas-free air or air with minimal contamination by removing contaminants from the existing atmosphere. In other cases, they may provide an independent source of oxygen or air. In certain industrial exposures, oxygen-deficient atmospheres can exist. Naturally they should never be entered without a device that will supply oxygen.

For purposes of this chapter the lungs may be considered to be inflatable bags in which the inflation is created by the downward movement of the diaphragm. Flow of air into the lungs must enter through the nose or mouth into the oral nasal cavity and thence through the trachea into its subdivisions, the large bronchi. Flow then proceeds into the small bronchi and into the smallest receptacles of the lungs, the alveoli. The important point to emphasize here is that inhalation or inspiration is an active movement created by a nervous impulse to the phrenic nerve which innervates the diaphragm and causes it to contract downward, which inflates the lungs. The motivation for this, which is both nervous and chemical in nature, is not of primary concern here and can be reviewed in detail by reference to a number of texts[1-3] on human physiology.

During inhalation, oxygen transport takes place through the epithelial membrane to the blood circulating through the lungs; while this is being achieved, there is simultaneous passage of carbon dioxide into the lungs. During exhalation, which is passive except under forced movement, the diaphragm relaxes. By means of this relaxation the lungs are deflated through elastic collapse, expelling the air through the same airway system.

It should be pointed out that exhalation can be forced by a contracting action of accessory muscles known as the external and internal intercostals. These muscles which surround the lungs and rib cage can, by their action, induce forced exhalation. However, the important distinction to bear in mind in regard to breathing through respiratory impedance, such as filters and sorbent canisters, is that inhalation is an active action while exhalation is passive. For this reason it is possible for a subject or wearer of respiratory devices to inhale through a higher inspiratory resistance than that through which he can exhale. This is the primary reason that inhalation resistance values that can be tolerated by subjects are greater than those on exhalation.

It should be mentioned, however, that subjects can be trained to exhale against resistance. Once muscle conditioning for this purpose has been achieved, performance of the individual is not impaired and wearing such a respirator is not considered an abnormal physiological task. This is true for the wearers of self-contained underwater breathing apparatus (SCUBA). It is especially so in the case of pressure demand oxygen equipment used by pilots at elevations about 40,000 feet (ft), where a small positive exhalation resistance increases the altitude capabilities of the wearer.

Since the lungs are a device designed primarily for gaseous exchange and involve a two phase system, namely, a gas phase on one side of the membranes and a liquid or blood phase on the other, it is necessary to consider the influence of the respiratory resistance and physical work of breathing on other factors. It should be remembered that, anatomically speaking, the cardiac system—that is, the heart—is also in the lung cage. Thus, if severe positive pressures are created within the cage because of forced breathing in either phase, stress will be placed upon the thin walls of certain heart vessels. Most of the disturbing effects will occur, fortunately, at resistance values far higher than those which can be tolerated by a subject without almost immediate subjective complaints.

The manner in which air enters and leaves the airways of the lung during breathing with different amounts of inspiratory and expiratory resistance can be represented by the shape of the air flow curves developed by measuring instantaneous flow on a time scale. There are certain factors to be considered when the lung is represented as a set of inflatable bags which are not of a completely collapsible structure. One, of course, is the so-called anatomical dead space beyond which volume the lung cannot contract. The other is the maximum volume which the lung can occupy in full expansion. This is considered the vital capacity, which can be determined by complete inhalation from a volume-measuring device or by complete exhalation from full distention of the lungs into a similar device. Actually, the vital capacity and anatomical dead space of the lungs are not of primary concern in evaluating ability of the wearer to tolerate the influence of resistance or respiratory impediments on breathing.

However, the dead space and the tidal volume (the volume of air per breath) have a relation to the volume of the air included within the respirator cavity, which is known as respirator dead space. This volume does become contaminated with various amounts of carbon dioxide from the previous exhalation, which is thus inspired on each subsequent inhalation. Carbon dioxide in significant amounts can stimulate the respiratory center. It has been determined that the dead space of the respirator cavity is not of consequence if it does not exceed 150 to 200 milliliters (ml). It obviously is of greater significance at rest with minimal air flow requirements. It should be borne in mind, however, that dead space of breathing apparatus is an important consideration in their design and that minimal volumes should exist in respirators. In positive supply equipment this consideration is unnecessary.

II. PHYSIOLOGICAL FACTORS OF IMPORTANCE IN RESPIRATION THROUGH PROTECTIVE DEVICES

Physiological factors which are important in respiration under sedentary and working conditions are the following: minute volume, mean inspiratory flow, instantaneous air flow, expiratory air flow, tidal volume, mean inspiratory and expiratory air flows, inspiratory and expiratory resistance to air flow, work rate, and respiratory work rate. They are discussed in detail below.

A. Minute Volume

The minute volume is the volume of air breathed per minute by the subject. This may be measured during inhalation or exhalation. There is very little difference between these two values because the depletion of oxygen during inhalation is compensated for by a volume of carbon dioxide and water vapor from the metabolism of the body.

Minute volumes for adults vary from a minimum of 5 liters, corresponding to subjects under basal conditions or complete rest, to above 100 liters at heavy work. Table 2.1 indicates average values measured at 20°C for a number of conditions. Minute volumes significantly higher than the 100 liters shown for maximum exertion will be required by certain individuals at maximum effort. However, the values presented in Table 2.1 are primarily for purposes of general consideration and are of concern to those interested in designing masks or estimating and evaluating flows encountered in their use.

B. Mean Inspiratory Flow

Since inspiration may be approximately 40 per cent of the total cycle during resting conditions and 50 per cent during work, the average inspiratory flow rate is thus usually considered as twice the numerical value of the minute volume for working conditions. This concept has been used as the basis for resistance and penetration measurements and for testing purposes. However, it should be pointed out that the maximum flow may attain values ranging to almost four times the minute volume.

Early studies led to the assumption that 85 liters per minute (l/min) represented the maximum average flow rate for air into or out of the lungs during sustained work. This value was based on measurements which corresponded to the

TABLE 2.1

MEAN AIR FLOW MEASUREMENTS AND GAS ANALYSES FOR NINE LEVELS OF ACTIVITY[a]

Measurement	Sedentary	Work Rate, Kg-M/min							
		0	208	415	622	830	1,107	1,384	1,660
Subjects	29	12	12	14	12	59	46	8	6
Pulse rate per minute	73	93	105	116	128	158	166	177	178
Respiration rate per minute	14.6	19.6	21.2	22.7	23.0	30.4	34.8	40.7	47.6
Minute volume, liters	10.3	14.2	20.8	29.9	37.3	54.7	75.3	104.0	113.8
Maximum inspiratory flow, l/min	40	49	63	84	100	149	194	254	286
Maximum expiratory flow, l/min	32	43	58	85	107	154	211	314	322
(Maximum inspiratory flow)/(minute volume)	3.9	3.4	3.1	2.8	2.7	2.7	2.6	2.4	2.5
(Maximum expiratory flow)/(minute volume)	3.1	3.0	2.8	2.9	2.9	2.8	2.8	3.0	2.8
(Maximum inspiratory flow)/(maximum expiratory flow)	1.3	1.1	1.1	1.0	1.0	1.0	0.9	0.8	0.9
(Inspiratory cycle)/(total cycle), %	39.2	41.4	44.1	46.8	48.2	48.3	49.4	51.3	50.2
(Expiratory cycle)/(total cycle), %	57.6	58.2	55.8	53.2	51.7	51.6	50.6	48.7	49.8
(Rise)/(inspiratory cycle), %	17.7	20.7	16.3	13.3	13.8	11.2	14.3	16.9	18.2
(Sustained flow)/(inspiratory cycle), %	58.7	59.0	65.3	69.4	65.9	71.1	69.8	68.1	68.0
(Maximum flow occurrence)/(expiratory cycle), %	27.7	37.5	47.9	46.8	46.7	45.1	44.0	44.4	50.4
(Rise)/(expiratory cycle), %	11.8	20.3	23.5	21.6	22.3	18.8	19.0	21.1	21.8
(Sustained flow)/(expiratory cycle), %	49.3	37.4	51.0	52.3	53.1	57.7	59.7	57.1	61.3
Oxygen deficit, %	3.56[b]	3.89	4.30	4.41	4.63	4.31	4.12	3.39	3.44
Oxygen consumption, ml/min	306	496	800	1176	1545	2075	2723	3114	3413
Carbon dioxide production, ml/min	261	425	695	1068	1432	2017	2723	3399	3598
Respiratory quotient	0.85	0.86	0.87	0.91	0.93	0.97	1.00	1.09	1.06

a. Resistances were 6 mm of water inspiratory and 3 mm expiratory.
b. Values from 11 subjects are included in the mean values for gas analyses.

minute volume of air respired during a slow run, which was about 42.5 liters. Since for this condition inhalation represents one-half the cycle, the actual average inspiratory flow would be twice this value or 85 l/min. Use of this value or of any average inspiratory flow rate as a maximum air flow through a filter or sorbent cartridge during inhalation assumes a rectangular wave shape for flow rates versus time. Actual measurements made at the Harvard School of Public Health, which are described by Silverman et al.,[4] show that the shape of the curve is far from rectangular although it does approach an approximate rectangular shape if a large respiratory resistance is present. Typical curves are presented later to indicate the relation between minute volume and maximum flow conditions.

C. Instantaneous Air Flow

Instantaneous air flows are important in the design of respiratory protective equipment because they determine the velocity of air through the filter or sorbent material which occurs at the peak flow rate. It is on the basis of this streaming velocity that the effectiveness of the filter or sorbent must be assessed. Consequently, evaluations or testing done at average flow rates will not necessarily correspond to the peak values encountered in use.

Pulsation is also important and steady flow tests such as those specified by the Bureau of Mines Approval Schedules, at the present time, do not allow any relaxation period for sorbents. The Army Chemical Corps, prior to World War II, used constant flow tests. During World War II, on the basis of data developed at Harvard University, at the Chemical Warfare Service Development Laboratory at Massachusetts Institute of Technology, and at an Office of Scientific Research and Development project at Northwestern University, it was determined that for testing purposes a breather pump which simulated respiration was essential.

It is of interest to point out here that the Chemical Corps breather pump values now used represent a minute volume of 50 liters with a peak flow rate of 150 l/min. The mean inspiratory flow at steady state would be 100 l/min, but the peak flow is based on the respiratory curve shape, which in the case of the bell-crank type of Chemical Warfare Service pump is a sine wave. A flow of 150 l/min represents a ratio of 3 to 1 for peak flow to minute volume, or 1.5 to 1 for peak flow to average mean inspiratory flow.

D. Expiratory Air Flow

Instantaneous air flows during exhalation are not of much concern except for exhalation valve design. It has been determined that the effect of high inhalation resistances is to increase exhalation flows because the subject tends to inhale over a longer period of time to ease the work of breathing and thus exhales more rapidly. This indicates that the effect of inspiratory resistance is to increase the peak velocity during exhalation. This is especially true should the value of inspiratory resistance reach objectionable levels.

Instantaneous inspiratory air flows under sedentary conditions attain values as high as 40 l/min, depending upon the minute volume and resistance to breathing. At maximum effort, however, peak flows over 300 l/min have been obtained in individual subjects with a mean value without resistance of 286 l/min for a group of three subjects. When air flow resistances correspond to a respirator inhalation equivalent of 64 millimeters (mm) of water at 85 l/min, an exhalation resistance of 41 mm of water for peak values slightly less than 300 l/min is achieved.

E. Tidal Volume

A value of some importance in physiological response to resistance is the tidal volume. This is the volume of air per breath. It can readily be determined from minute volume and respiration rate. Minute volumes have already been indicated in Table 2.1, and respiration rates range from a mean of 15 respirations per minute under sedentary conditions to a value of 48 respirations per minute for maximum effort. Tidal volumes which correspond to these are obtained by dividing the minute volume by the respiration rate.

F. Mean Inspiratory and Expiratory Air Flows

Mean inspiratory and expiratory flows have already been mentioned. These are obtained by taking the shape of the breathing pattern on a cycle ratio basis, determining the percentage of the total cycle represented by inhalation or exhalation, and dividing the minute volume by this value. These values are useful only for determining an integrated value of the respiratory curve shape.

G. Effects of Resistance versus Air Flow

The effect of adding external resistance to air flow to an individual's respiratory tract is to produce a compensatory adaptation response. In order to reduce the effect of resistance, the subject's response is to reduce his peak flows. This is clearly shown by comparing the data of Table 2.2 with Table 2.1. The data of Table 2.1 were obtained with minimal resistance to inhalation and exhalation. These values correspond to 6 and 3 mm of water at 85 l/min air flow. It should be noted that these low values are less than the difference between nose and mouth breathing as far as pulmonary effort is concerned. Data given in Table 2.2 correspond to measurements at 64 and 41 mm (at 85 l/min), respectively, comparable to typical Army or universal mask values. These values also correspond to Bureau of Mines limits (89 and 38 mm) for this type of mask although the exhalation resistance is somewhat high for exhalation valves now widely in use.

The comparison of the data in these two tables shows that essentially the effect of resistance is to reduce minute volume, maximum inspiratory and expiratory flow, and respiration rate. The air flow curve shape becomes more rectangular and the subject makes his breathing more effective by increasing the oxygen deficit. That is, a greater percentage of oxygen is removed per breath than when the resistance is at minimal values. From the negligible changes in pulse rate, it can be seen that the amounts of resistance imposed are not of serious concern as to well-being of the individual.

An over-all comparison of the effects of several changes in resistance on all of the respiratory air flow values can be obtained from the data of several experiments performed at Harvard by Silverman and his co-workers.[4,5] These data are shown in Figs. 2.1 and 2.2 for a number of experimental series. Resistances ranged from the minimal values of 6 and 3 mm expressed above to 106 mm of water on inhalation and 76 mm on exhalation. Even these greater limits had no serious effect on the capability of the wearer to perform hard work.

A subjective resistance comparison was made to determine values which would not be considered objectionable. For this purpose, a simple arbitrary scale was adopted in which subjective response to air flow resistance to inhalation and exhalation was placed in four discrete categories which called for some judgement on the part of the subject. By limiting the number to a small group, less arbitrary decisions could be made. These categories are as follows:

1. Not perceptible
2. Noticeable
3. Uncomfortable
4. Objectionable

TABLE 2.2

MEAN AIR FLOW MEASUREMENTS AND GAS ANALYSES WITH EXTERNAL RESISTANCE[a]

Measurement	Sedentary	Work Rate, Kg-M/min 0	208	415[b]	415	622	830	1,107	1,384	1,660
Subjects	13	12	12	14	12	12	48	22	6	3
Pulse rate per minute	75[c]	91	103	118	115	131	155	169	176	184
Respiration rate per minute	14.8	17.5	18.7	22.0	20.7	22.5	27.4	32.5	34.2	42.0
Minute volume, liters	9.1[c]	13.2	19.8	28.2	27.0	36.2	48.9	64.4	81.3	90.3
Maximum inspiratory flow, l/min	37	44	60	79	78	101	128	160	192	240
Maximum expiratory flow, l/min	29	37	56	85[c]	77	105	144	195	252	274
(Maximum inspiratory flow)/(minute volume)	3.9	3.4	3.1	2.8	2.9	2.8	2.6	2.5	2.4	2.7
(Maximum expiratory flow)/(minute volume)	3.1	2.8	2.8	3.0[c]	2.9	2.9	2.9	3.0	3.1	3.0
(Maximum inspiratory flow)/(maximum expiratory flow)	1.3	1.2	1.1	0.9[c]	1.0	1.0	0.9	0.9	0.8	0.9
(Inspiratory cycle)/(total cycle), %	38.2	43.1	46.4	48.7	47.9	49.0	51.2	51.9	53.9	51.4
(Expiratory cycle)/(total cycle), %	57.5	56.1	53.3	50.9	52.0	50.9	48.6	47.8	46.2	47.1
(Rise)/(inspiratory cycle), %	19.1	17.7	15.1	13.3	14.5	12.6	11.6	11.5	10.2	11.8
(Sustained flow)/(inspiratory cycle), %	62.6	60.1	62.2	66.5	65.2	66.6	71.7	73.0	74.3	71.9
(Maximum flow occurrence)/(expiratory cycle), %	27.5	37.6	44.7	39.9	45.0	45.8	45.1	46.9	43.6	45.6
(Rise)/(expiratory cycle), %	14.1	18.4	20.3	15.7	19.1	20.3	17.7	19.4	18.7	19.5
(Sustained flow)/(expiratory cycle), %	42.3	49.2	54.9	57.2	57.8	60.1	61.4	62.1	65.8	62.8
Inspiratory work rate, Kg	0.4	0.6	1.3	2.5	2.3	4.1	7.2	12.7	19.3	27.8
Expiratory work rate, Kg	0.1	0.3	0.7	1.1	1.3	2.5	5.2	9.5	16.5	19.2
Total respiratory work rate, Kg	0.2	0.4	0.9	1.8	1.8	3.3	6.1	11.1	18.0	23.3
Oxygen deficit, %	3.79	4.15	4.60	4.75	4.85	4.98	4.70	4.54	4.14	3.98
Oxygen consumption, ml/min	304	489	812	1190	1159	1606	2052	2591	3033	3245
Carbon dioxide production, ml/min	259	416	709	1052	1039	1482	1976	2621	3231	3450
Respiratory quotient	0.85	0.85	0.87	0.89	0.90	0.92	0.96	1.01	1.07	1.07

a. Resistances were 64 mm inspiratory and 41 mm expiratory.
b. Resistances were 64 mm inspiratory and 27 mm expiratory.
c. One less subject is included in mean.

A fifth category, intolerable, which represents the situation where the subject will not wear the mask, could be included.

This scale is simple and covers a wide enough range of reactions for the subject to interpret. One other condition necessary in using such a scale is to be sure the subject is concentrating on some task or work effort; otherwise his response will be oriented to the fact that his attention was focused on his respiratory efforts. In the Harvard study mentioned above, the resistances were changed without the subject's knowledge.

The effect of increased inhalation resistance is to reduce peak inspiratory flows and to cause increased peak expiration flows. This effect takes place because the subject usually extends the period of inhalation and then must expel the same air volume over a shorter exhalation period. This can be seen in Fig. 2.1, when one examines the curve corresponding to expiratory flow. For minimal exhalation resistance, the peak flows are greatest. This points out the fact that it is desirable that there should be a balance between the two resistances; otherwise a conscious effort becomes apparent on the part of the wearer. In practice, exhalation resistance has been half or less than half of inspiratory resistance, although changes of ±25 per cent from this ratio are not significant from a comfort consideration.

H. Effect of Work Rate on Physiological Response in Respirators

It has been mentioned in the preceding section that the effect of concentrating on the task minimizes subjective complaints, unless excessive resistances are added to the airway path. Under these circumstances it is essential that the actual resistance to breathing should not interfere with normal oxygen transport to the lungs and

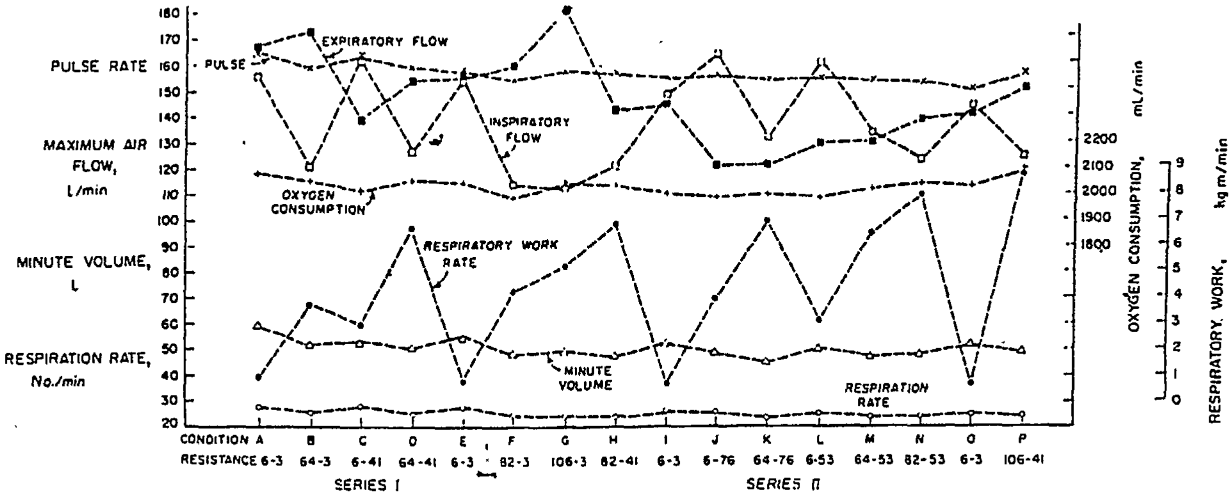

Fig. 2.1. Effect of various amounts of resistance on several mean values of physiological and subjective measurements for 12 subjects performing series I and II. Series I and II were a sequence of resistance changes produced by simulated canisters in which values conformed to existing respiratory protective devices. Work rate was 830 Kg-M/min.

circulatory system. The data in Tables 2.1 and 2.2 and Fig. 2.1 confirm this fact. The work rates which have been studied using a bicycle ergometer and in some instances a treadmill, correspond to sedentary no load, 1,500, 3,000, 4,500, 6,000, and 8,000 foot-pounds per minute (ft-lb/min) or, in the metric system, 208, 415, 622, 830, and 1,107 kilogram-meters per minute (Kg-M/min). The 4,500 ft-lb/min value represents medium work which can be continued for long periods (hours) by average individuals. The 6,000 and 8,000 ft-lb/min load cannot be sustained except for short periods of about fifteen minutes. A period of training is required to achieve the upper value for this time period.

The condition of working while wearing a respirator that involves breathing through some respiratory impediment does not present the wearer with a serious problem unless a great pulmonary effort must be made to obtain enough air exchange to satisfy his oxygen demand for a given task or work rate. In some cases it has been found that if the resistance is intolerable, the subject will be forced to terminate or suspend his work effort. The intolerable situation can also be related to the subject's physical condition and degree of training. Well-trained individuals or athletes with well-developed respiratory musculature and physiological tone have presented far less difficulty in this regard. Athletes when compared to non-athletes show a lower respiration rate, minute volume, and peak flow rates for the same amount of external work. This is shown clearly in Table 2.3 for these values and others.

Studies at Harvard[5] and in England by Cooper[6] have confirmed the fact that there must be some relation between the output work rate or the task performed and the effort resulting from respiratory resistance that can be tolerated by the respiratory musculature and diaphragm. This relation is discussed in the following section. The external effort of breathing through a resistance must be distinguished from the internal work of the lungs in breathing through the existing respiratory system (normal airway resistance).

I. Respiratory Work Rate and Its Significance

The respiratory work rate is defined as the actual work done by the lungs in drawing air through the resistances of the valves, filter, and canister. It can be divided into inspiratory and expiratory values, but the total effort must be the sum of the two components. The values are obtained by multiplying the mean inspiratory or expiratory air flow by the total air flow resistance of the respirator or exhalation valve corresponding to that flow. The time of inspiration or expiration as a percentage of the total cycle must be considered in making respiratory work calculations. These values can be related to the output of work achieved by the subject.

Based on a large number of subjects and a wide range of respiratory resistances which were

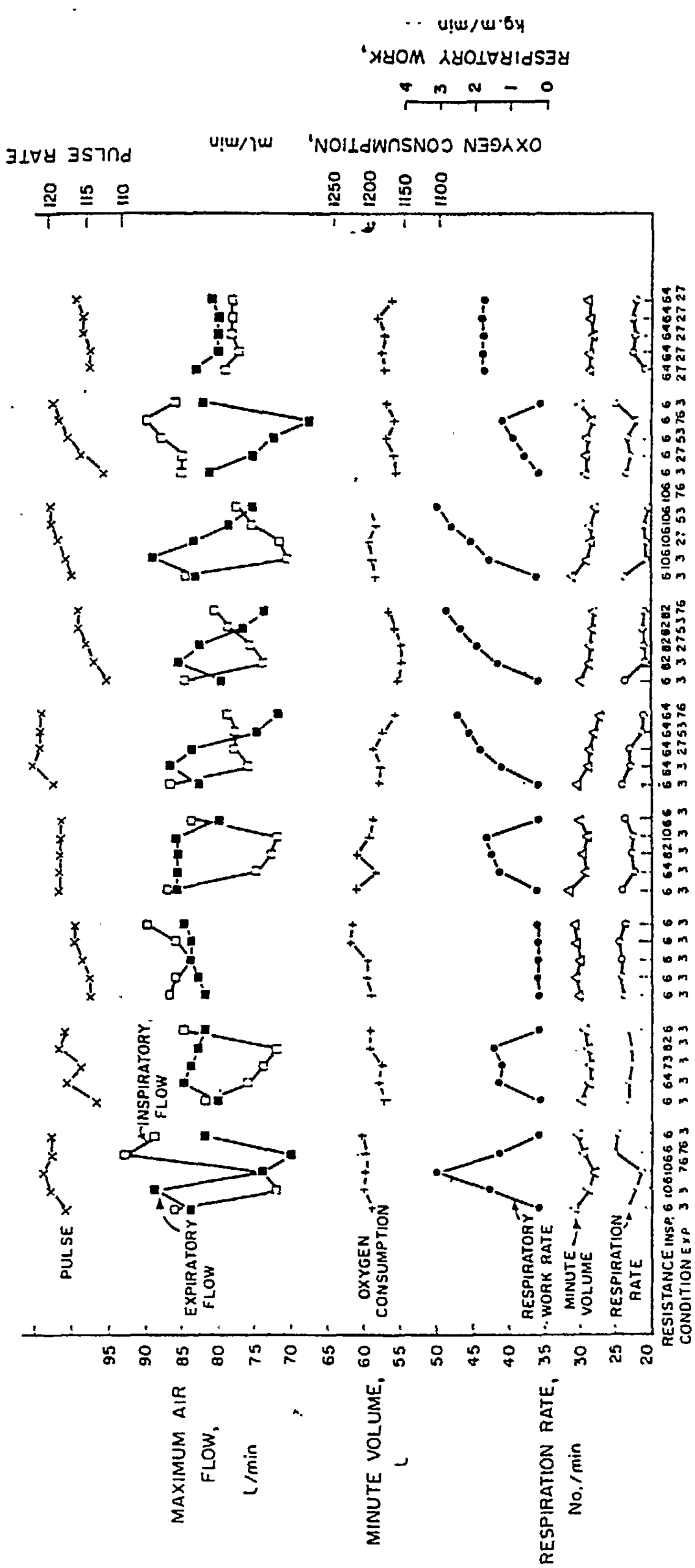

Fig. 2.2 Mean respiratory changes, airflow measurements, gas exchange, pulse, and subjective reactions for 10 subjects performing series III, conditions AA through AI. These conditions were a series of simulated inspiratory and expiratory resistance values corresponding to values shown above the condition denoted. Resistance changes were made while the subject was continuing at a constant work rate of 415 Kg-M/min.

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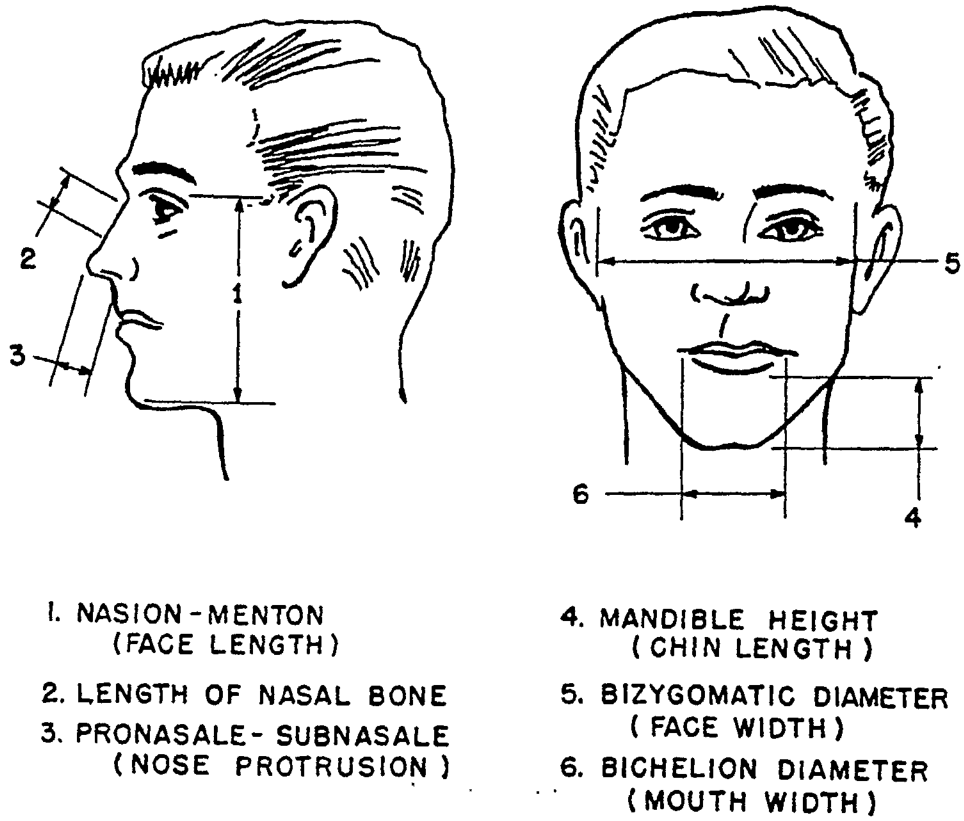

Fig. 3.2. Facial measurements of importance in fitting facepieces.

of the measurements of importance for fitting respiratory protective devices.

Although other facial characteristics must be considered in designing and fitting a facepiece, by far the most important single measurement is the face length. Faces have been classified according to the general appearance of the full face as round, square, or triangular and then subclassified within this system, e.g., variations of the round include vertical oval and horizontal oval. Attempts have also been made to identify faces according to profile as concave, convex, or straight. However, to date no study has been reported in which either of these classification systems was used in the fitting or design of respirator facepieces. Facepieces manufactured in the United States reportedly are triangular, round, or long and narrow. However, the configurations of the masks are not intended for any particular face type, but represent instead the manufacturer's concept of the facepiece which will best fit the largest number of people.

Whatever the configuration of the facepiece, the wearer's face length must be within its range to obtain a proper fit. Due to variations in other measurements, some individuals may be fitted with one facepiece and not with another with the same face length range. It is often desirable, therefore, to have respirators from different manufacturers available for issue. However, even if a respirator is available in various sizes, or is exceptionally versatile, a few people still will be unable to obtain a leakproof fit. For example, the Army expects the three sizes of its assault mask to fit only about 98 per cent of its personnel.

It is difficult to fit women who must wear personal respiratory protective equipment because no commercially available full face masks, and few half masks, are sized to fit them. Although the Bureau of Mines' approval does not specifically exclude women, they are not required to be fitted in the Bureau's evaluation of a respirator.

A. Half Masks Fitting under Chin (Type A)

During World War II the Aero Medical Laboratory[4] of the Army Air Force collected the facial measurements of 1,454 flying personnel (men and women), subsequently measured an additional 1,500 as a check on the original findings, and then

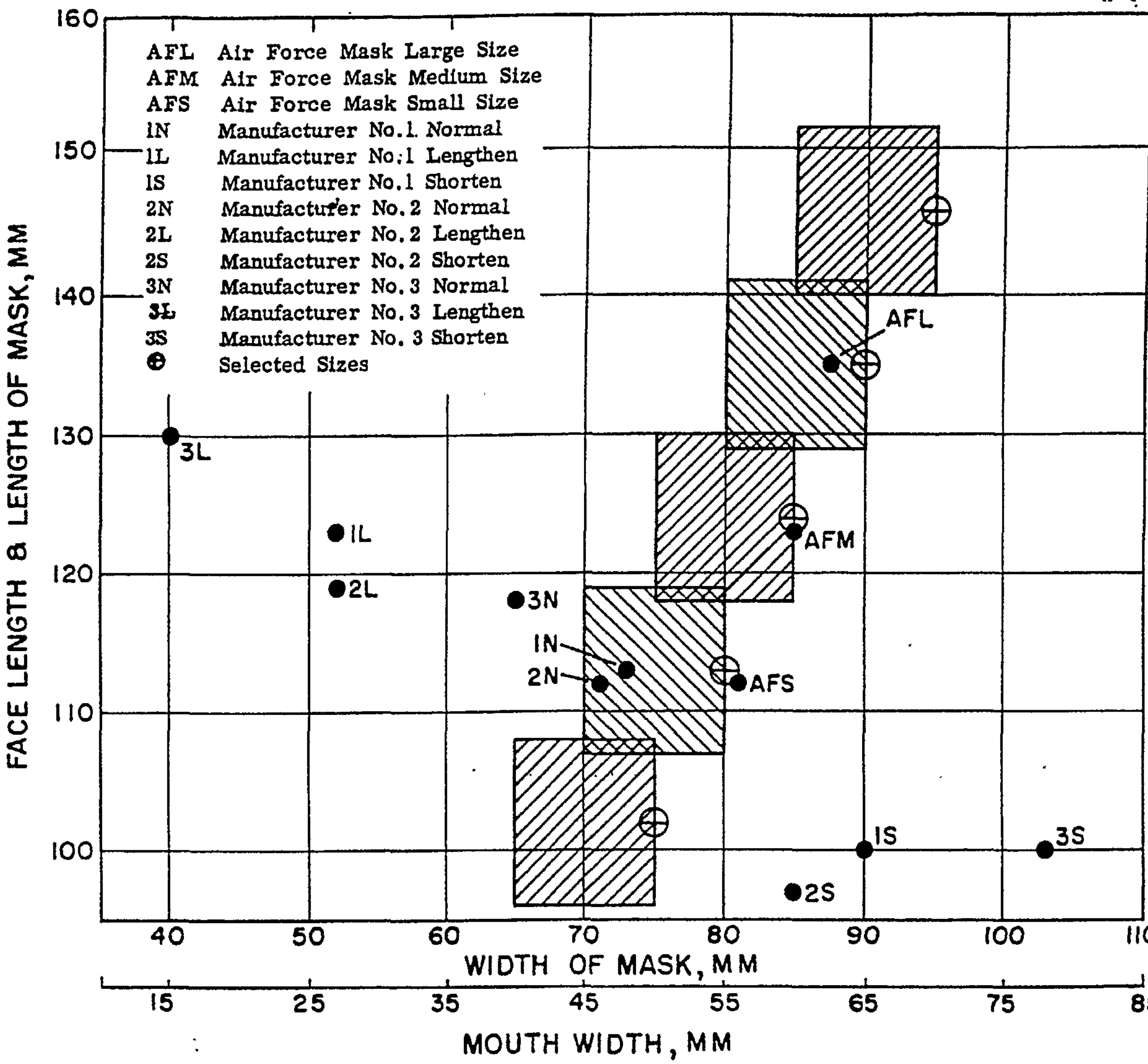

Fig. 3.3. Length and width of Type A half masks, actual size and five selected sizes.

lengths and mouth widths, with the 12.5 mm clearance on each side, which each size of facepiece should fit. Also plotted on Fig. 3.3 are the measurements of three commercial respirators and the sizes of the Army Air Force oxygen mask. It is obvious that for practical reasons the Army Air Force decided not to manufacture and stock the extremely large or extremely small size mask required to fit the one per cent at the extremes of the surveyed population. It must be borne in mind that the Army Air Force could and would eliminate from flight duty individuals who could not be accommodated by standard equipment.

Three configurations—normal, maximum elongation, and maximum shortening—are plotted for each commercial respirator in Fig. 3.3. Since elongation of the facepiece decreases the width and shortening increases the width, this flexibility of the half mask obviously is contrary to actual needs in fitting an adult population.

Ideally, the length and width should be increased or decreased independently. Figure 3.3 implies that it would be impossible for a single size of half mask to fit a high percentage of the adult population. This is supported by data in Table 3.2, summarizing tests at the Los Alamos Scientific Laboratory[7] on 500 adult males, using three different commercially available half masks fitting under the chin.

The following points should be noted in

TABLE 3.3

SELECTED SIZES OF TYPE B HALF MASKS

Facepiece	Observed Population in Size Range, %	Length of Facepiece, mm	Width of Facepiece, mm	Face Length of Individuals Fitted, mm	Mouth Width of Individuals Fitted, mm
1	22	97	80	96-118	40-55
2	92	114	90	113-135	50-65
3	28	131	100	130-152	60-75

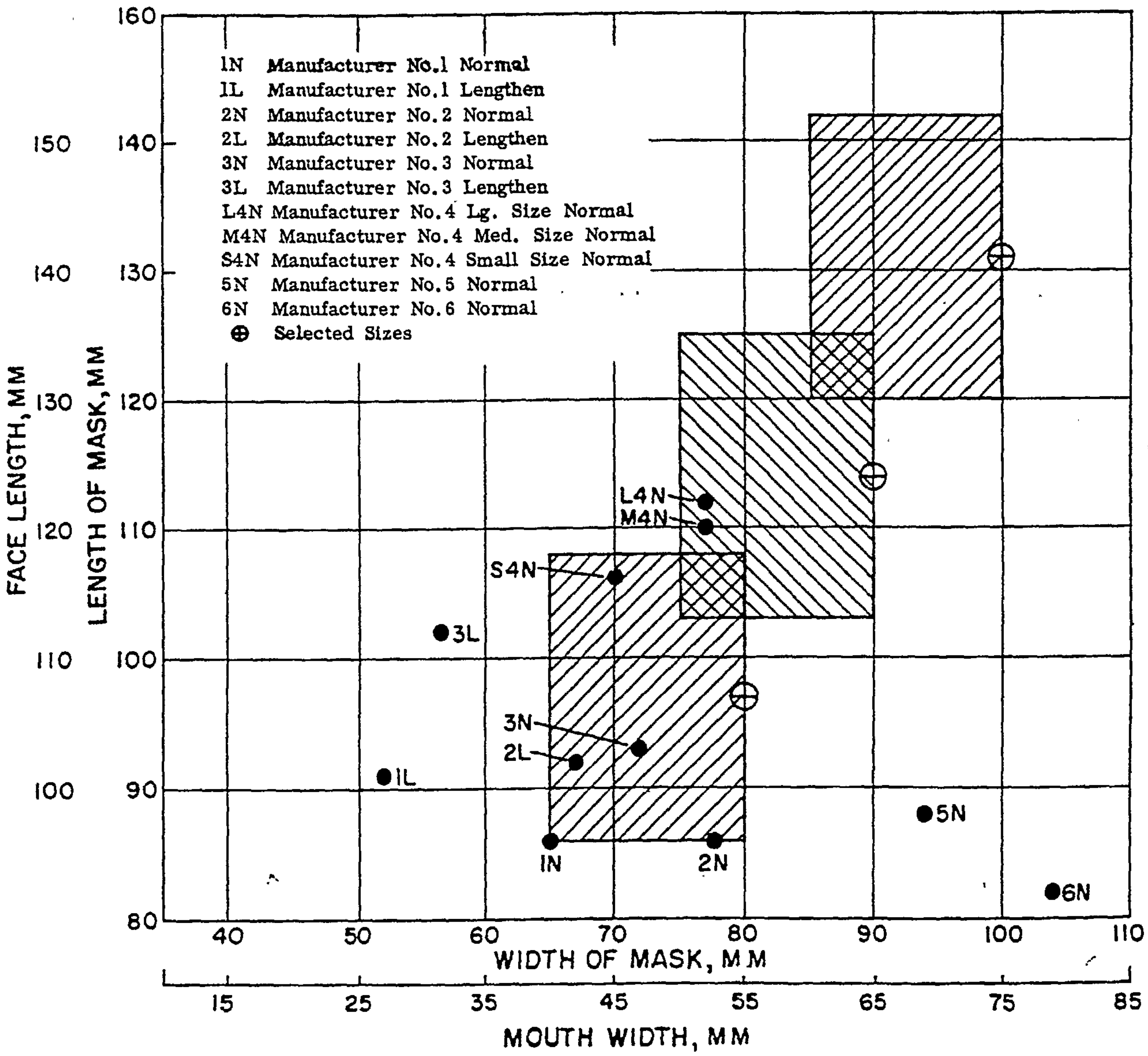

Fig. 3.4. Length and width of Type B half masks, actual size and three selected sizes.

which the wearer's chin must fit nor the positioning of the eyes is fixed. In these cases the term "facepiece length" is meaningless; however, for those facepieces in which the face position is fixed by a molded chin cup and small viewing apertures, the facepiece length can be established with reasonable accuracy and can be related to face length for prediction of fit.

Obviously, a greater range of face length could be fitted with a given respirator if the wearer's chin and eye positions were not fixed by the features of the respirator. The U.S. Navy, with a single size of the Mark V full face mask, has fitted successfully an exceedingly high percentage of males. This mask has one large viewing aperture and no fixed chin position. In addition, the sealing periphery of the facepiece is a pneumatic tube which the Navy believes is responsible for the high percentage of fittings among the male population. The mask, however, fits only a small percentage of the Navy's female personnel.

Two factors in the design of facepieces with a single large viewing port should be mentioned here, although they have no bearing on face fit. First, fogging of the large eyepiece must not become a problem and, second, the shape of the facepiece accommodating the larger lens should not have a dead air space exceeding a volume of about 150 to 200 milliliters (ml) (see Chapter 2, Section I).

III. RELATION OF MECHANICAL FEATURES TO RESPIRATOR EFFECTIVENESS

Any respiratory protective device must have a number of mechanical features to maintain the separation between ambient and respirable atmospheres, yet permit proper respiration and adequate vision. Because most of these features require openings in the facepiece, they are, potentially, points of penetration for the ambient atmosphere. The seal at these points should be effective for the life of the device and should withstand rough handling of the respirator without developing a leak.

A. Peripheries of Facepieces

Figure 3.7 shows cross sections of the peripheries of several facepieces in current use. There is no general agreement on the superiority of any sealing edge. The U.S. Navy, after considerable research, concludes that the pneumatic type of periphery achieves a superior seal with maximum comfort. The combat mask developed by the British also has a pneumatic tube periphery. The British[8] believe it is important to provide such a periphery with a valve for re-inflating the tube, but the Navy has experienced little or no trouble

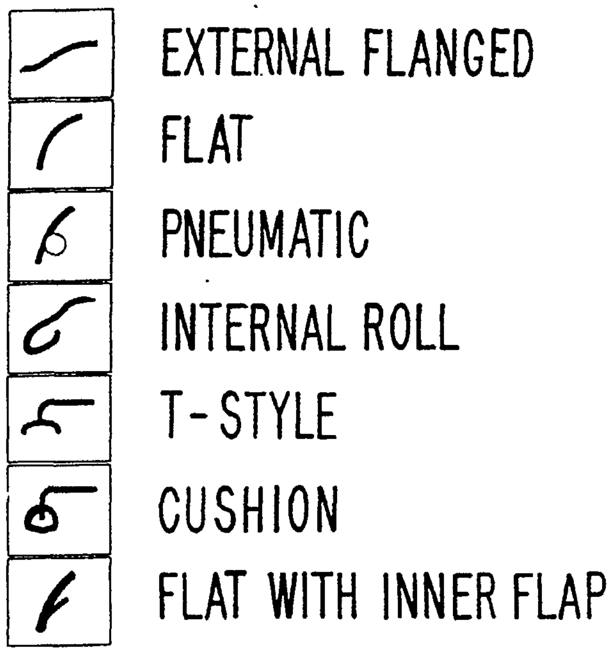

Fig. 3.7. Gas mask peripheries.

with sealed tubes collapsing. The Army M-9 assault mask has a flat peripheral surface because Army tests showed that such surfaces provide leaktight face seals. It is apparent that either approach can be used to achieve essentially a leakproof seal. Most commercial full face masks use a smooth, flat peripheral surface, although some of the newer facepieces have a flat surface with an inner flap as the sealing surface. All types of peripheral surfaces are used for half masks except the pneumatic and the flat surface with inner flap; the internal roll and the cushioned types are the most usual.

Lack of flexibility in the facepiece and periphery makes it difficult for the facepiece to contact facial contours. Quite often, therefore, the tension needed to seal all points on the periphery results in excess pressure at certain spots, causing "pain spots." This is of major importance for, contrary to the belief of many individuals, a half mask must be adjusted firmly to the face to be effective—usually more tightly than the individual prefers for comfort. In the Bureau of Mines' testing procedures half masks are fitted very tightly to most of the wearers, and the Bureau stressed that half masks must be secured firmly for proper protection of the user.

B. Face Fit and Respirator Suspension

Ideally, a respirator would be held against the face by an infinite number of adjustable supports, to direct tension where needed. Practically, a proper seal can be achieved with only a minimum number of supports. The Army's full face mask is supported by a head harness with six adjustable straps attached at six symmetrical points around the periphery of the facepiece. Adjustment of this number of straps is not too complicated, and the seal is tight if the facepiece is of the proper size. Five adjustable straps on a full face mask appears to be the minimum number to ensure a seal.

The buckles on head harnesses should be easily adjustable by pulling on the individual straps and should retain that adjustment without slippage. Ideally, they should be attached without penetrating the facepiece, although commonly the buckle straps are fastened to the facepiece with metal rivets. The rivet head must be recessed to avoid touching the wearer's face which, of course, considerably reduces the thickness of the material around the rivet available for clamping. Tension on the buckle strap may distort the rivet hole and, to offset this, rivet heads are made quite large and then, in turn, must be recessed still further. A compromise, in which the possibility of leakage is minimized, involves hard facial pressure from the metal rivet heads. When full face masks are worn for extended periods, pressure from the hard metal on a restricted area of the face or head creates "pain spots" and makes continued use of the respirator intolerable. The pain spots, or sensitized areas, recover slowly and may remain sensitive for several days. A respirator that is improperly sized for an individual increases the number and the severity of any consequent pain spots.

Half masks generally are supported by one or two straps without a harness. The preferred two straps may be attached to the facepiece at four points or only at two points, with the four-point attachment approximating more nearly the ideal mechanism. Often the straps are attached to the canister or the filter holder. Tension on the straps so attached may fold the facepiece inward, as well as press it against the face, and in some instances the folding action may disrupt the seal at the bridge of the nose. Since half masks usually are available in only one size, the range of facial sizes and characteristics which a respirator with one strap can accommodate is severely limited. Also, the resultant of an ideal number of forces holding a half mask on the face probably would cross the ears; to avoid a strap across the ears, the strap must pass either above or below, with further adjustment generally required because a strap will remain anchored on the back of a worker's head only at certain points. It has been pointed out by Tait[9] that the use of a head harness with a half mask provides for an improved fit and increased stability. Several foreign half masks also utilize the head harness.

C. Valves

Both expiratory and inspiratory valves are used on respiratory protective equipment.

Generally, a valve for such equipment consists of two elements, an orifice for passage of air, which also provides a valve seat, and a moveable diaphragm (cover) for controlling the direction of air flow. The materials of construction can be hard rubber, soft rubber, plastic, mica, or metal, but in any case the material and construction specifications must be such as to ensure trouble-free operation in a pulsating flow of moisture-saturated air.

The operation of an expiratory valve for air-purifying respirators is more crucial than that of an inspiratory valve, which is merely a check valve to prevent the back flow of expired air through the air-purifying system. It is generally agreed,[10] however, that respirators should be provided with inspiratory valves, although they are not required by the Bureau of Mines for all types of respirators.

An inspiratory valve should have a low resistance to air flow and a low opening pressure, and should be well designed and protected to ensure proper operation. It is not necessary for the inspiratory valve to be extremely efficient, although from a leakage standpoint, a poorly designed inspiratory valve or the lack of such a valve will permit passage of moisture-laden expired air back through the filter or chemical cartridge. Condensation on certain types of filter media quickly causes an uncomfortable increase in the resistance to breathing; it also affects adversely the performance and the resistance to breathing of certain chemical sorbents. In addition, an inefficient inspiratory valve allows rebreathing of expired air, with the possible buildup of carbon dioxide in the facepiece cavity and, in the case of full face masks, can be responsible for additional fogging of eyepieces.

Silverman,[11] in what is probably the most complete study of expiratory valves made to date, listed the following factors in the performance of the valves in order of their physiological importance:

1. Resistance to air flow.
2. Leakage.
   a. Dynamic.
   b. Static.
3. Opening pressure.
4. Location or orientation of valve in mask.

5. Protective mechanisms.
   a. Protection against damage.
   b. Effect of atmospheric conditions, such as Temperature and Wind.

The study by Silverman indicates that, for the usual dimensional range of valve orifices and for the physiologically possible flow rate, the air flow may be under streamline, transitional, or turbulent conditions, and that the valve resistance to air flow will depend largely upon the conditions of flow. The location of the valve in the mask also has a considerable effect on the resistance. Experimental data indicate that from the standpoint of resistance the most advantageous position for the valve is midway between the nose and mouth. It is important that the orientation of the valve allows for proper drainage. The protective shield or housing, generally provided for protection, leakage control, and temperature control of the valve, will also be a factor in the over-all resistance. Usually the addition of a shield will increase the resistance, but in some cases it will actually decrease the total resistance.

An important point made by Silverman and also by Smith[12] is that the resistance of a valve should be established for a complete range of physiologically possible flow rates. Tests conducted at a fixed flow rate are suitable for production control, but they are not satisfactory for a complete evaluation of a valve. The tabulation in Table 3.4 was arbitrarily chosen by Silverman[11] for rating the resistance of expiratory valves.

The amount of leakage or back flow through an expiratory valve—an important consideration—depends upon the nature of the sealing surfaces. Surface irregularities or distortions will prevent a proper sealing action of the valve.

The actual leakage from a given source, however, will not obey the laws of air flow—for an increase in negative pressure may increase the sealing action or may create additional sources of leakage. An important factor in valve leakage is the wetting of the valve from condensation of the moisture in expired air, which may actually improve the seal of the valve. However, this moisture is a detriment if it freezes or is responsible for distorting the valve diaphragm or seat.

TABLE 3.4

ARBITRARY TABULATION FOR RATING RESISTANCE OF EXHALATION VALVES

Air Flow	Air Flow Rate, l/min	Resistance, mm H_2O Low	Medium	High
Low	50	< 7	<12	>12
Medium	150	<21	<36	>36
High	250	<35	<60	>60

By conserving the heat of the expired air and by protecting the valve from the effects of high velocity winds, a protective shield of proper design will allow the valve to operate satisfactorily at lower temperatures than would otherwise be possible. The protective shield or housing will also be instrumental in preventing leakage by preventing distortion of the soft, light valve covers from wind and by providing a dead air space on the exit side of the valve. This protected volume of air is swept clean and remains filled with expired air. Any leakage past the valve during the initial phase of the inspiratory process will consist of previously expired air and the very small amount of ambient air that could diffuse into the dead air space between breathing cycles.

In testing valves for leakage, it is important to determine the leakage under dynamic conditions, that is, under conditions that simulate actual breathing patterns for various work loads. A leakage test under a single set of static conditions is not indicative of the reliability of a valve. The cold weather performance of the valve should also be evaluated in any comprehensive study. An arbitrary classification of dynamic leakage established by Silverman[11] is shown in Table 3.5. Opening pressures of expiratory valves were also classified by Silverman on the arbitrary scale in Table 3.5.

TABLE 3.5

CLASSIFICATION OF DYNAMIC LEAKAGE AND OPENING PRESSURES FOR EXHALATION VALVES

Classification	Leakage per Respiration,[a] cm^3	Opening Pressure,[b] mm H_2O
Low	< 2	< 4
Medium	2 to 4	4 to 10
High	> 4	> 10

a. Test conditions were 600 ml per respiration and 50 mm water resistance at 85 l/min.
b. With wet valve.

A high opening pressure is undesirable for several reasons, of which comfort considerations are most apparent. A high opening pressure can cause a snapping or popping of the valve on each expiration that can become extremely annoying. Probably the most serious consequences of an excessively high opening pressure are the diffusion of moist expired air into the facepiece cavity, with resulting eyepiece fogging, and the breaking of the seal between the face and respirator periphery. It has been found by Glidden[13] that an expiratory valve with high opening pressure will freeze sooner than one with a lower opening pressure. Experience has shown that the higher the opening pressure of expiratory valves, the poorer the acceptance of the respirator by wearers.

The main protective feature provided for an expiratory valve is the protective shield or housing previously discussed in connection with resistance and leakage. Physical protection of the generally fragile valve cover is provided by the shield when the respirator is in use or in storage. A reduction in possible leakage is provided by the valve shield in two ways; first, by creation of the dead air space and, second, by reducing aspiration of the ambient atmosphere into the mask by decreasing turbulence at the valve.

The shield also provides climatic protection for the valve in that it prevents distortion of the valve cover in high velocity winds and retards freezing of the valve.

In addition to the main factors of an expiratory valve noted in the above discussion, Smith[12] in his report listed the following characteristics of a good expiratory valve:

1. Ease of cleaning.
2. Dimensional and material stability.
3. Ease of production in large quantities.
4. Lightness in weight.
5. Minimum obtrusiveness.
6. Good voice transmission, if practicable.

D. Air-purifying Elements

The seal of the filter or cartridge to the facepiece usually is leakproof if the manufacturer's directions are followed, although users tend to fasten these elements carelessly, so that in practice loose connections are common. In some devices the filter material itself serves as a gasket, and a tight seal without wrinkling or tearing the filter requires considerable care; leakage because of this difficulty has been reported.[9] Research by the U.S. Navy[14] indicates that a leakproof connection between the facepiece and a canister can best be accomplished by covering the joint with a rubber apron.

When the canister or cartridge is connected to the mask by means of a hose, the outside diameter of the nipple and the inside diameter of the hose must be nearly equal. Stretching the hose unduly to go over a large nipple will cause the hose to deteriorate rapidly, and too small a nipple will make the hose wrinkle when the clamping band is applied.

Obviously, the proper filter media or chemical sorbents must be selected for suitable processing of the contaminated ambient air.

E. Eyepieces (Lenses)

Three important considerations attend the attachment of eyepieces to a full face mask. First, the eyepieces must be secured so as to ensure a leakproof connection which will withstand not only normal flexing but also considerable abuse. Second, the method of securing the seal must not distort or stress the glass or plastic eyepieces, thus distorting the field of vision and increasing breakage of the eyepieces. Third, excessive stretching of the facepiece material, which reduces appreciably the serviceable life of the facepiece, must be avoided.

F. Eyeglasses

Providing respiratory protection for individuals wearing corrective glasses is a serious problem. A proper seal cannot be established if the temple bars of the eyeglasses extend through the sealing edge of the full face mask. The U.S. Army furnishes each user of corrective glasses a corrective lens mounted in a wire bracket that snaps into place in the eyepiece socket of the facepiece, which preserves the seal but does not provide really satisfactory vision.

At least three manufacturers of full face masks have developed systems for mounting corrective lenses inside the facepiece. One mounts the lenses in a special frame attached to a center-mounted adjustable mount inside the facepiece (see Fig. 3.8). Another provides corrective glasses with special short temple bars that are supported by a special mount on each side of the facepiece but inside the sealing surface (see Fig. 3.9). A third supports with a suction cup a frame which holds prescription glasses from which the temple bars have been detached (see Fig. 3.10). An alternative used for many years, but which generally is not very satisfactory, is to remove temple bars or leave one-half inch of bar and tape the eyeglasses to the wearer's head.

The ability to wear corrective glasses with a half mask depends on the face fit. It is possible to obtain a seal with a poorly fitting respirator, but quite often the device will rest so high on the face as to make it impossible to wear glasses.

G. Limitation of Vision

Any respirator affects the wearer's ability to see. The adverse effect may be due to:

1. Reduced total field of vision.
2. Reduced binocular field of vision.

Fig. 3.10. Full face mask illustrating method of mounting prescription glasses inside facepiece with center mounted suction cup and nose cup insert.

would not wear a respirator often enough to gain this facility. This lack of depth perception may very well be responsible for the sense of uneasiness experienced by many individuals when wearing a respirator; certainly most workers react favorably to a facepiece allowing greater binocular vision even though the total field of vision is somewhat reduced.

Although minor scratches and opacities on an eyepiece are annoying, usually the annoyance is not extreme, and workers endure scratched eyepieces much as spectacle wearers tolerate dirty corrective lenses. Impaired vision from fogged eyepieces, however, is intolerable. When water in warm humid air condenses on cold eyepieces, it fogs them. Thus a worker wearing a respirator under cold temperature conditions finds the eyepieces immediately fogged on the outside when he enters a warm room with relatively high humidity. On the other hand, the eyepieces may become fogged on the inside when the worker is in a cold environment because of condensation of water produced by exhalation and by facial perspiration.

It is impossible and impractical to try to prevent fogging of the eyepieces merely by sealing off exhaled air from the cavity behind the lens, thus creating a sealed goggle physically attached to a half mask respirator. It is possible to prevent fogging successfully for a limited period in a full face mask with a nose cup (see Figs. 3.8 through 3.10) to lead the exhaled air directly to the exhalation valve and an air inlet system which directs the incoming air across the inside of the eyepieces. In the Army assault mask, a nose cup with proper valves prevents exhaled air from contacting the lenses. With nose cup and deflector tubes (see Fig. 11.1), the Army mask can be used at low temperatures with reduced fogging or frosting of the lenses, for limited periods.

Antifogging compounds, an effective adjunct in efforts to reduce eyepiece fogging, should be used routinely. If such a practice is not followed regularly, a situation will inevitably develop in which dangerous fogging of the eyepiece will occur that could have been prevented or alleviated by the use of an antifogging compound.

H. Speech Transmission

The ability to communicate while wearing a respirator affects both the wearer's comfort and the effectiveness of the respirator. Communication may make the difference between a safe, efficient operation and confusion and panic, especially in difficult and dangerous jobs, when it is imperative to maintain constant control over a situation. Speech transmission through a respirator is extremely difficult, and irritating as well as fatiguing, so workers may insert a finger and pull the facepiece away from the face in order to communicate. Even if they do not, mere movement of the jaws in speaking may cause leakage between the facepiece and the face, especially with the half mask respirator. The Army Chemical Corps[15] has established criteria for evaluating speech transmission through a respirator. Factors considered are the volume of air in the facepiece cavity, the composition and placement of the exhalation valve and the diaphragm, the characteristics of the nose cup and facepiece, and the freedom of jaw movements within the facepiece.

A properly designed diaphragm in the facepiece helps materially in speech transmission, although the diaphragm adds a maintenance problem to the routine cleaning program. The condition of the diaphragm should be checked carefully after each cleaning of the respirator. Several manufacturers market a combination voice transmitter diaphragm and outlet valve for use in full face

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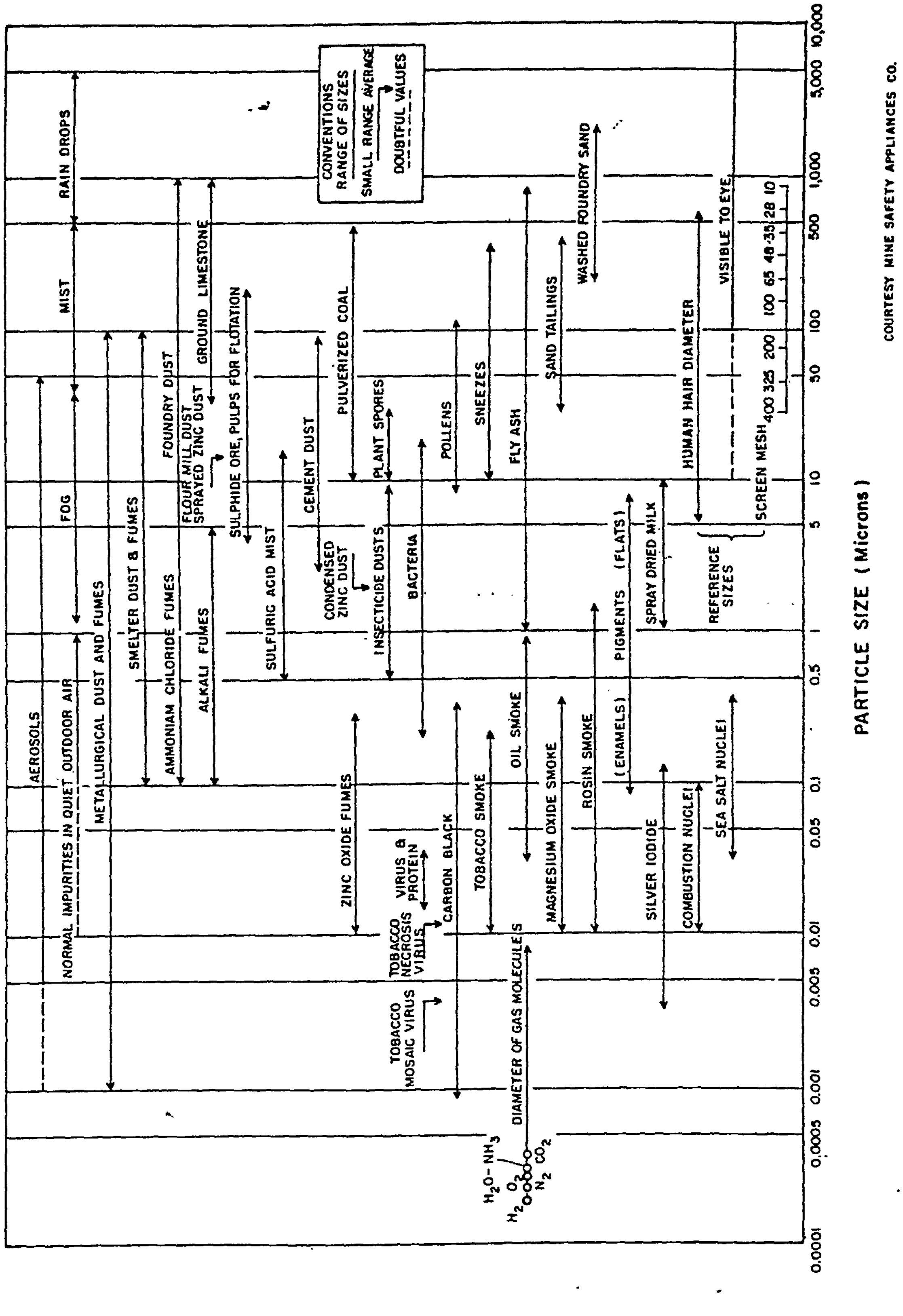

Fig. 4.1. The sizes of airborne contaminants.

respects to those used for respiratory protection.

Respirator filter media do not behave merely as screens or sieves which remove particles larger than the pore size with extremely high plugging rates. They achieve their air-cleaning ability from a number of mechanisms which contribute to the over-all filter performance. The primary filtration mechanisms that act upon a particle when it encounters a fibrous bed are: direct interception, inertial impaction, and diffusion. Under certain conditions with various types of filter media, electrostatic attraction and gravity may also be of significance. The relation between these separation mechanisms and particle size is given in Table 4.1.

TABLE 4.1

PARTICLE SIZE RANGE FOR SEPARATING MECHANISMS

Force	Particle Size Range, μ
Direct Interception	> 1
Impaction (inertial contact)	> 1
Diffusion (Brownian motion)	$<0.1 - 0.2$
Electrostatic Attraction	> 0.01
Gravity	> 1

A. Direct Interception

Direct interception of a particle occurs when a particle of radius "r" approaches a fiber along a streamline which passes closer to the fiber than the distance "r," and thus the particle makes contact with the fiber and is collected (see Fig. 4.2).

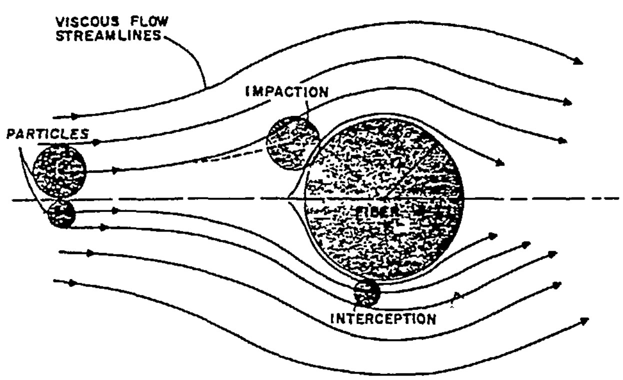

Fig. 4.2. Particle removal by fibrous filter through mechanisms of interception and impaction.

Thus the direct interception parameter for particles which do not deviate from the streamline is:

$$R = \frac{r}{r_f} = \frac{d_p}{d_f}$$

where R = direct interception parameter
r = particle radius
r_f = fiber radius
d_p = particle diameter
d_f = fiber diameter

The target efficiency of the interception mechanism is a function of R and the Reynold's number of the system. While, strictly speaking, direct interception is a collecting mechanism only for particles which do not deviate from streamlines (small particles or particles of low density), the mechanism does increase the effectiveness of other forces. Hence R is a significant parameter of filtration.

B. Inertial Impaction

Inertial impaction occurs when a particle has sufficient mass to deviate by inertia from the line of flow as the air stream passes around the fiber and when the center of the particle passes within the distance r', contacting the surface of the fiber (see Fig. 4.2). Inertial forces are a function of a number of factors which influence the amount of deviation of a particle from the path of streamline flow. This can be seen from the classical inertial parameter:[2]

$$\psi = \frac{C \rho v d_p^2}{18 \mu d_f}$$

where ψ = inertial parameter
C = Cunningham correction factor
ρ = density of aerosol particle
v = velocity of air flow
μ = viscosity of gas (air)
d_p = particle diameter
d_f = fiber diameter

The inertial parameter is related to the target efficiency in a complex manner which cannot be stated in a simple equation. The relationship has been presented graphically and confirmed by experiment by several writers.[3,4] The efficiency increases as the value of the parameter increases.

The inertial parameter is one of the most influential forces in the filtration of particulates, especially with particles over 1 μ in size. The

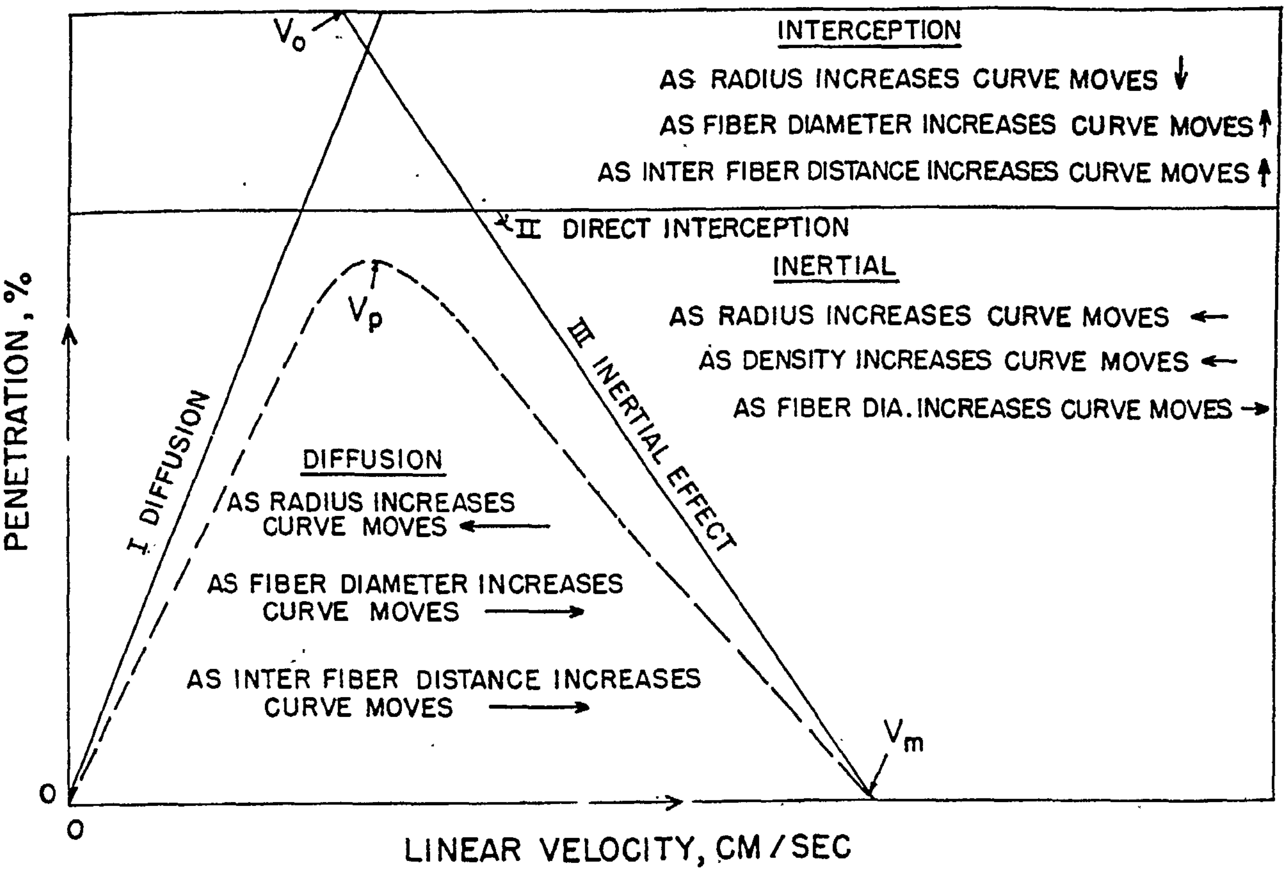

Fig. 4.3. Filtration mechanisms (after Ramskill and Anderson). Copyright, Journal of Colloid Science.

absorption by particles of such ions and electrons.[8,9] Uncharged nonconducting particles can be collected by electrostatic forces as a result of polarization.

It has been shown that oil mists,[10,11] high humidity, and wet smoke[12] may dissipate the electrostatic charge from filter fibers. Another force that adversely affects electrostatic charge is the presence of radioactive substances in the filter bed. The resultant ionization from the radiation fields causes the fiber charge to be dissipated.

E. Gravity

Gravity as a force in the removal of particulates by a fibrous bed is a function of the terminal settling velocity of the particles, and the important parameter is:

$$G = \frac{u}{v} = \frac{C \rho d_p^2 g}{18 \mu v}$$

where G = settling parameter

u = terminal settling velocity of the particle

v = velocity of air flow

μ = viscosity of gas (air)

ρ = density of aerosol particle

d_p = particle diameter

g = acceleration of gravity

The target efficiency due to gravity is directly proportional to G and is approximately equal to G/π for unoriented fibers. Since u is very small compared to v for airborne dust, gravitational force is of minor importance in respirator filtration. Since the velocity of air passing through a respirator filter medium is proportional to the air movement produced during inhalation, it can vary from a negligible value to one that is relatively high in a fraction of a second during the inhalation and exhalation cycle.

F. Over-all Efficiency

The over-all target efficiency of a filter fiber cannot be accurately calculated by adding the efficiencies due to interception, impaction, diffusion, electrostatic forces, and gravity. The following equation, which is based on the work of Davies,[3] expresses the total target efficiency of an isolated fiber for interception, impaction, and diffusion. Davies did not consider the effects of gravitational and electrostatic mechanisms.

$$\eta_o = 0.16\,[R + (0.5 + 0.8\,R)\,(\psi + D) - 0.1052\,R\,(\psi + D)^2]$$

where η_o = total target efficiency

R = direct interception parameter

ψ = inertial parameter

D = diffusion parameter

The over-all efficiency of a mass of fibers comprising a filter mat can be calculated from η_o, the packing density of the mat and the filter thickness using the method of Davies. Modifications of this last step have been proposed by Chen,[13] and a somewhat different method has been used by Stairmand.[14] The application of Stairmand's method to a filter composed of slag wool has been detailed by Silverman.[15]

IV. FILTER PERFORMANCE CHARACTERISTICS

The filtration forces discussed in the preceding section, when associated with the physical characteristics of the filter bed and the aerosol, permit an appraisal of the two major performance characteristics of filter media used in respiratory protective devices—efficiency and pressure drop.

A. Efficiency

Air-cleaning efficiency is probably the most important performance characteristic of a filter medium in a respiratory protective device. If this quality is impaired, a serious inhalation risk may occur. The degree of removal of contamination from the air, or the efficiency of a filter, is dependent on the characteristics of the medium and of the particulate matter. Respirator filters designed for use against substances of low toxicity may demonstrate relatively low efficiencies, in the range of 20 to 90 per cent. Filters designed for use against material of high toxicity must have high efficiencies—above 99.95 per cent. Some of the factors which influence efficiency are filtering velocity, fiber diameter, loading, and particle size.

1. Filtration Velocity

The velocity of air passing through a filter is normally kept as low as possible to increase the efficiency of small particle removal and to decrease the resistance to air flow. Reduced velocity has been achieved largely by increasing the area of the filter media by folding, pleating, or convoluting or by joining the edges of properly spaced flat filter sheets. These methods achieve compactness and provide a greater surface area, with associated low pressure drop and improved loading characteristics. Examples of configurations that increase surface area are shown in Fig. 4.4.

Filter efficiency for small particles is normally increased with reduced velocities since the filtration forces of diffusion and, in certain instances, electrostatic attraction are enhanced, although the inertial force is less effective.

For a given filter medium there is a velocity at which any given particulate of a definite size will show a maximum penetration. In general, the smaller particles penetrate most readily at higher velocities, indicating the reduced opportunity for diffusion. Stern et al.[2] have demonstrated this for spherical polystyrene particles of density 1.05 and for dioctyl phthlate (DOP) smoke, using Institute of Paper Chemistry filter mat (see Fig. 4.5).

Of particular interest in the filtration of particulate contamination is the effect of pulsating air flow on efficiency because velocity has been shown to strongly influence the filtration parameters (see Section III). It can be seen in Chapter 2, Section IIC, that the inhalation phase of the respiration cycle produces air flow rates ranging from zero at the beginning of inspiration to levels of almost 300 liters per minute (l/min) at the point of maximum inspiratory air flow under a work rate of 1,660 kilogram-meters per minute (Kg-M/min). This effect of pulsating air flow on efficiency has been studied by Jordan and Silverman,[16] and a comparison of pulsating flow efficiency with that from steady flow is shown in Fig. 4.6.

The following conclusions were made by these investigators:

1. The efficiency of collection for a filter subjected to pulsating flow is not equal to the efficiency obtained under conditions of steady flow with a velocity equal to the mean velocity of the pulsating flow.

2. Under conditions of pulsating flow, the character of stream flow is altered in such a manner as to increase the effective range of velocities for the inertial diffusion and settling mechanisms. At low mean velocities, the effect of this change is to increase the efficiency of collection for pulsating flow over the efficiency obtained under

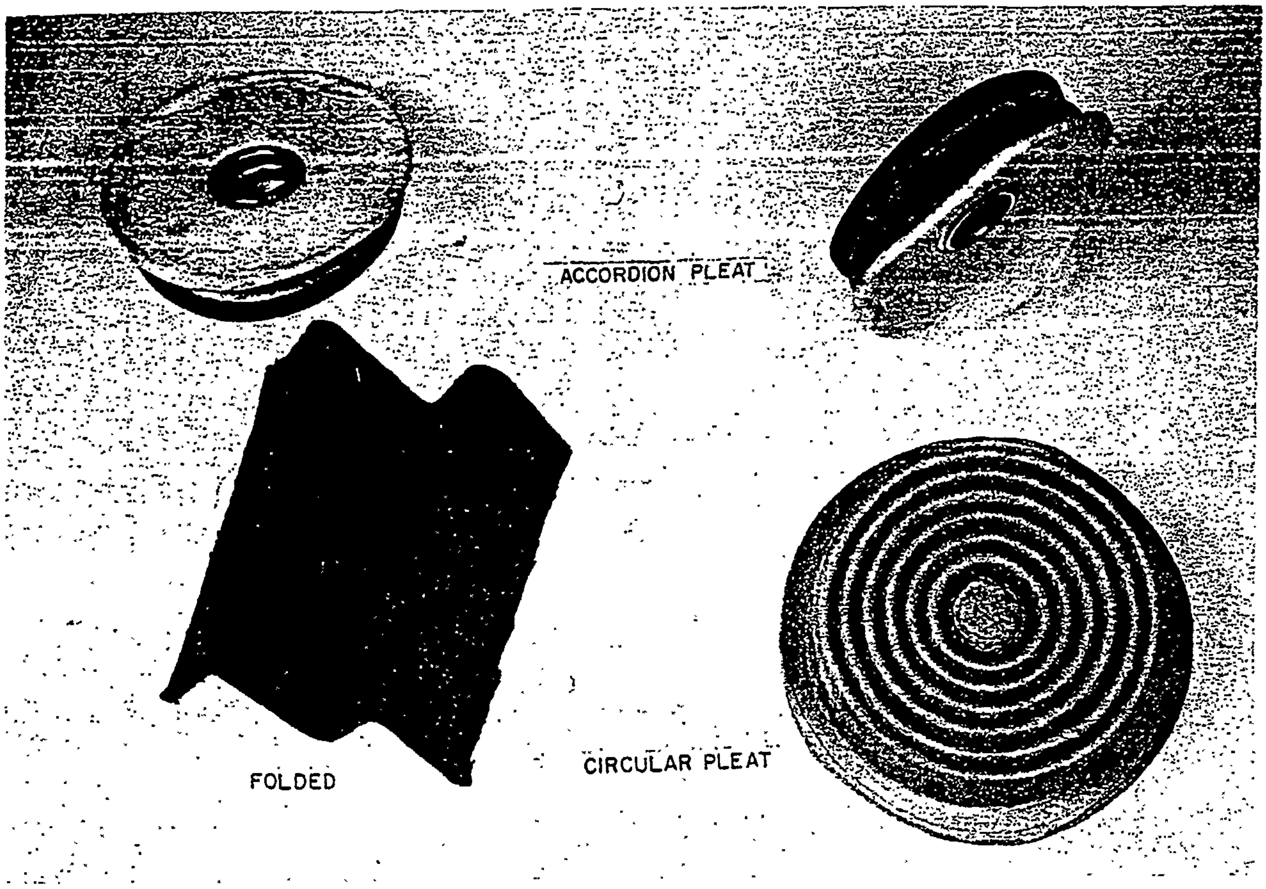

Fig. 4.4. Filter media configurations for increasing surface area.

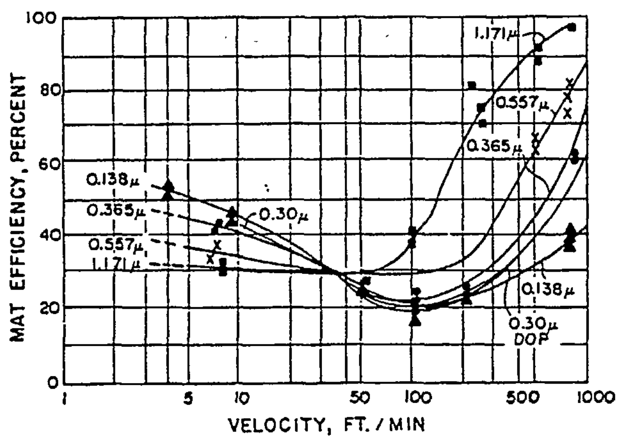

Fig. 4.5. Experimental collection efficiencies of the IPC filter mat for special polystyrene particles of density 1.05 and DOP smoke at ambient pressure (after Stern, Zeller, and Schekman). Copyright, Journal of Colloid Science.

conditions of steady flow at a velocity equal to the mean velocity.

3. At high velocities the collection efficiency obtained under pulsating flow conditions is less than the efficiency obtained under conditions of steady flow at a velocity equal to the mean pulsating velocity.

4. For the range of velocities to which a filter for a respiratory protective device would be subjected, the effect of pulsating flow would be to increase the efficiency of collection.

2. Fiber Size

The technology of fine fiber production has made outstanding advances in recent years. It is now possible to produce on a commercial scale fine fibers of materials such as glass, plastics, and ceramics. Some of these are available in fiber diameters of less than 1 μ.

Fine fibers, in many instances, do not possess sufficient strength to withstand the required air flows and have to be supported by the inclusion of fibers of larger diameter or by a backing with greater strength. Fine fibers predispose to higher

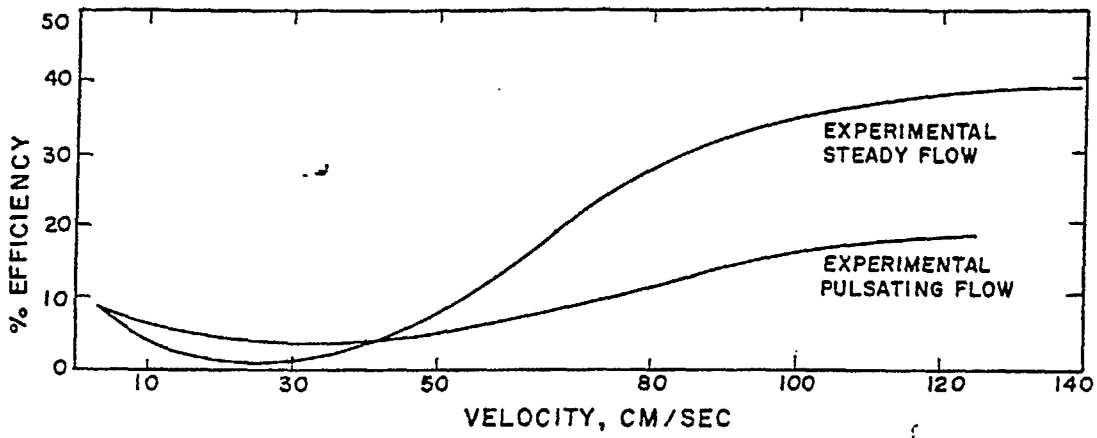

Fig. 4.6. Comparison of efficiency-velocity relations for experimental and theoretical values (after Jordan and Silverman).

efficiencies because of the favorable effect on the filtration mechanisms, and they are normally employed whenever possible. This is evident from the impaction and diffusion equations in Section III, which demonstrate that a filter bed composed of fine fibers provides a greater opportunity for impaction to occur, as well as a greater surface for particles to contact when under the influence of Brownian motion.

3. Loading

In addition to the increase in resistance caused by the presence of a filter loading, there is an accompanying increase in efficiency due to the filtering action of the dust or fume deposit. The effect of loading on the efficiency of a filter medium has been shown by Smith and Stafford[1] (see Fig. 4.7).

As mentioned in Section II, various types of filter medium construction are possible. Those for use in respiratory protective devices, however, are normally designed with loading characteristics to provide long life. Davies[3] has presented the relative loading characteristics of three typical filter media, from which the difference in the rate of pressure drop increase due to loading is evident. This can be seen in Fig. 4.8. Because of high pressure drop due to loading, cotton sheet is not practical as a filter medium for respirator cartridges.

4. Particle Size

The parameters related to the particulate matter involved have an important influence on the performance of a filter medium as noted in Section III. It has been demonstrated by Thomas and Yoder[17] that for any given filtration velocity there is a particle size that penetrates a filter most readily (see Fig. 4.9). With fibers of approximately 1.5 μ diameter and a face velocity of about 1.8 ft/min (0.94 cm/sec), penetration increases with a decrease in particle size below 0.5 μ and reaches a maximum at about 0.25 μ. Numerous investigations have shown this peak in penetration to be within the range of 0.1 to 0.4 μ, which means that particulates smaller and larger than this range are normally removed with greater efficiency. Those of larger size are affected to a greater degree by the forces of interception, impaction, and gravity. Those below this size are primarily removed by diffusion.

B. Pressure Drop

The efficiency of a filter medium is at its lowest when it is new, since its effectiveness relies entirely on the characteristics of the medium itself. As a respirator is used, the medium gradually loads with particulates removed from the air. A portion of these particles, especially the smallest size fraction, penetrates into the filter bed, although most remain on or near the surface.[18] As the loading increases, it supplements the filtering ability of the medium, thereby increasing the over-all efficiency as well as the resistance.

Since the filtration afforded by deposited dust or fume supplements that provided by the medium itself, it is apparent that the over-all resistance will be increased as loading progresses. The important factors which influence filter resistance as a function of loading are:

1. Particle size.

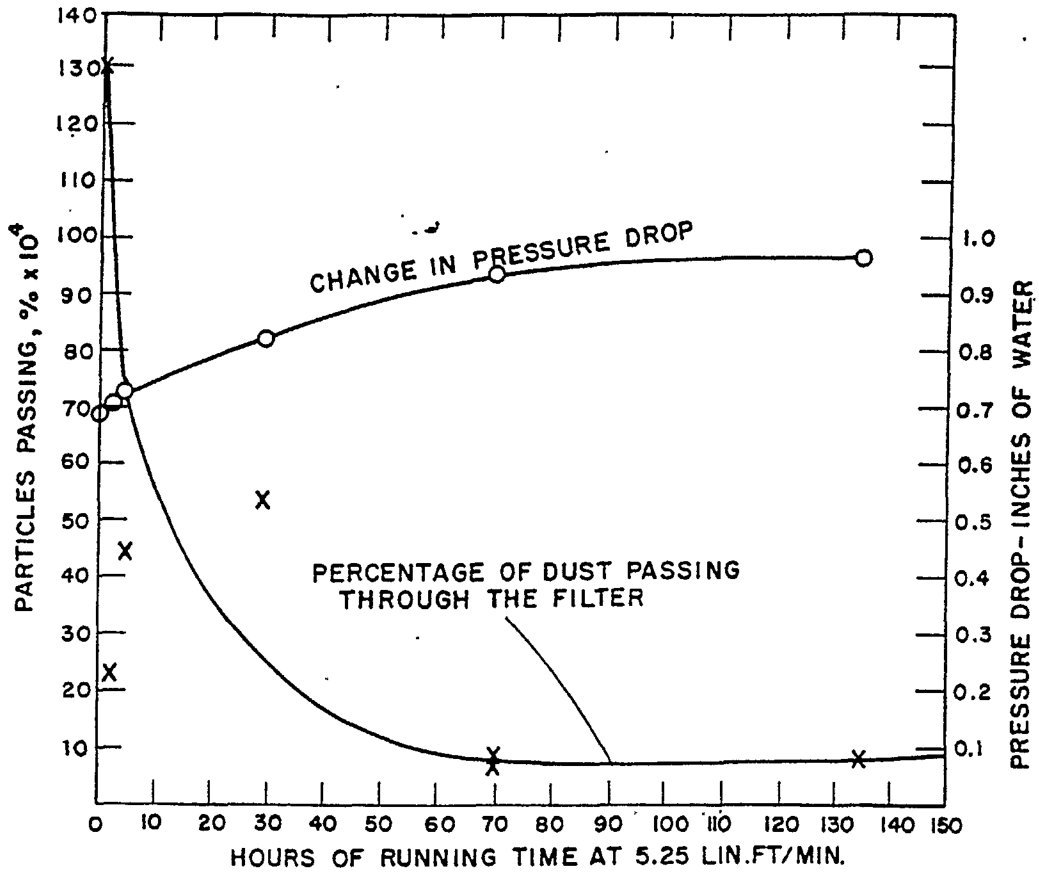

Fig. 4.7. Effect of running time on efficiency of AEC filter paper at a flow rate of 5 linear feet per minute (after Smith and Stafford).

2. Particle shape.
3. Particle density.
4. Particle surface characteristics.
5. Packing characteristics of deposited material.
6. Amount of dust or fume on filter.
7. Gas density.
8. Gas viscosity.

The resistance to gas flow through a filter medium containing a deposit of dust or fume will normally be influenced by each of these factors. For practical consideration, the resistance due to the presence of its loading has been expressed by Silverman[10] as:

$$R_f - R_i = R = \frac{K_1 L T V^2}{7000}$$

where R_f = final resistance, inches of water

R_i = initial resistance, inches of water = $K_o V$

R = net resistance due to dust

K_o = resistance coefficient for clean filter

V = filtering velocity, ft/min

L = dust load in air to filter, gr/cu. ft.

T = time, in minutes, for filter resistance to increase R inches of water

K_1 = specific resistance of the dust in inches of water per pound of dust per square foot of cloth area per foot per min. filtering velocity

The above relationship between resistance and use time prevails until the interstices are greatly reduced in size. After this the resistance increases exponentially with time.

High initial efficiency is an essential quality when a device is used as protection against a highly hazardous substance. This is particularly true where radioactive particulates are involved, for

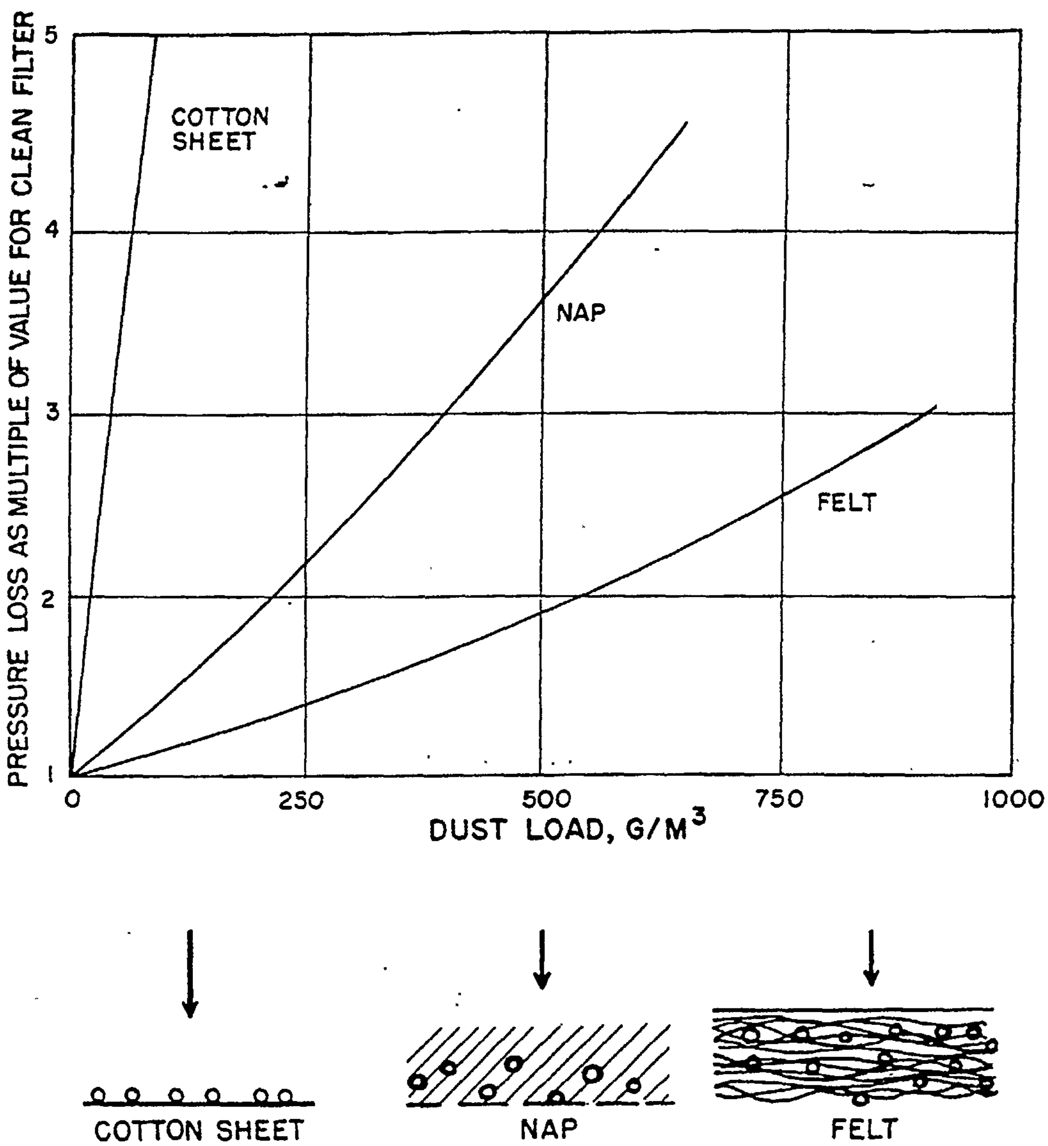

Fig. 4.8. Clogging of various types of filter material (after Davies). Copyright, British Institution of Mechanical Engineers Journal.

in such instances dust levels encountered are seldom high enough for loadings to increase efficiencies significantly. Some respirator filter media are purposely preloaded with asbestos fibers or floc at the time of manufacture to ensure that initial filtering efficiencies will be relatively high.

Although the efficiency of a filter medium will increase with an increase in loading, it should be emphasized that a filter should not be used in a respirator beyond the point where the pressure drop causes the resistance to inhalation to be objectionable. When the resistance attains this magnitude, it not only fatigues the wearer, but, more important, it will probably result in an increase in the leakage around the facepiece which will markedly increase the over-all penetration of the device.

Respiratory protective devices approved by the U.S. Bureau of Mines meet limitations on the maximum resistance to inhalation. Such limits are based partly on the physiological requirements for inhalation as described in Chapter 2, Section II. When a person wearing a respirator is engaged in

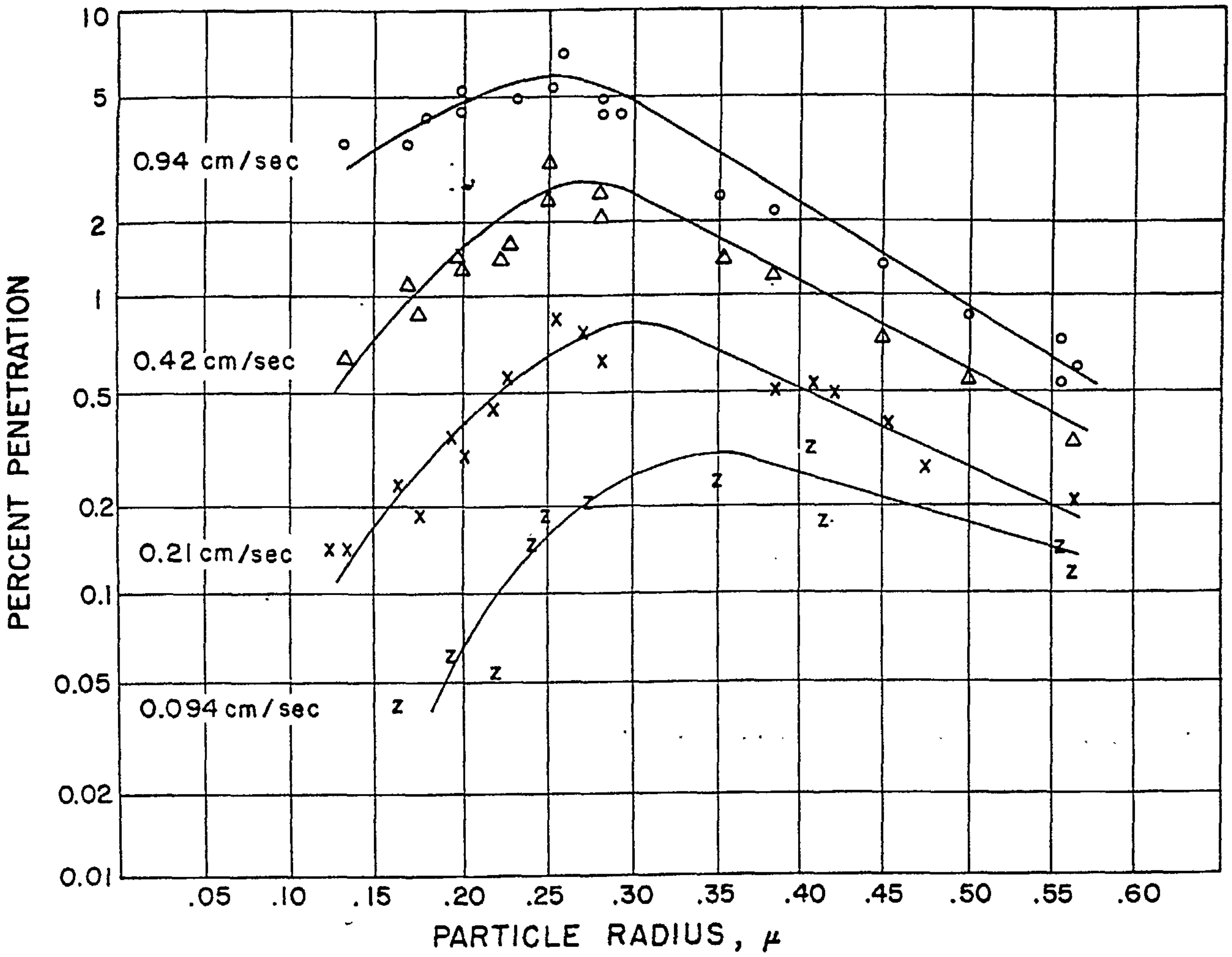

Fig. 4.9. Penetration of homogeneous DOP aerosols through a fiberglass FG-50 filter mat (after Thomas and Yoder). Copyright, A.M.A. Archives of Environmental Health.

active exercise, the increase in respiration produces relatively high air flows and an accompanying increase in resistance of the device. According to current approval schedules of the Bureau of Mines, the limiting pressure drop for a complete particulate respirator is 50 mm of water at an air flow rate of 85 l/min. Tests on a series of eleven currently available filter cartridges of various types showed pressure drops ranging from 15 to 50 millimeters (mm) of water at a flow rate of 85 l/min.

Pressure drop is also a function of several properties of the filter medium itself. It varies directly as the filter density, which is related to the filter thickness or the degree of calendering. It is also affected directly as the loading and the air velocity, which is determined by the filter surface area. Normally, a decrease in fiber diameter is accompanied by an increase in resistance.

V. PERMISSIBLE FILTER MEDIUM PENETRATION

It has been described elsewhere in this manual that penetration of contamination into a respirator facepiece may originate from several sources. With respect to air-purifying respirators using particulate-removing filters, there is always a certain inherent penetration through the filter medium itself since no medium is 100 per cent efficient.

In view of this and because modern filter manufacturing techniques enable filters with relatively high efficiencies to be produced, the Bureau of Mines has established permissible penetration values for the various air-purifying respirators. The approval schedule requirements can be seen in Table 9.11 (Chapter 9). These data are presented in Table 4.2 as calculated in terms of the minimum filter media efficiencies that will meet the approval requirements of the Bureau of Mines test schedules.

The test schedules outlined in Tables 9.11 and 4.2 apply only to contaminants not significantly more toxic than lead. As discussed in Chapter 1, Section V, the Bureau has prepared tentative approval requirements for dusts and fumes more toxic than lead. Protection against highly toxic and radioactive materials requires, among other things, filter media which furnish dependably high efficiencies.

Respirator filter media that are presently available provide efficiencies as high as 99.99 per cent, as tested with DOP smoke of 0.3 μ diameter. Recent performance tests[19] on a representative group of 100 commercially available respirator filter cartridges demonstrated efficiencies as shown in Fig. 4.10. Ninety-five per cent of the filters tested had efficiencies $\geq$ 99.97 per cent. Since this test was made, manufacturers have obtained greater quality control by routine testing of all filters with dioctyl phthlate.

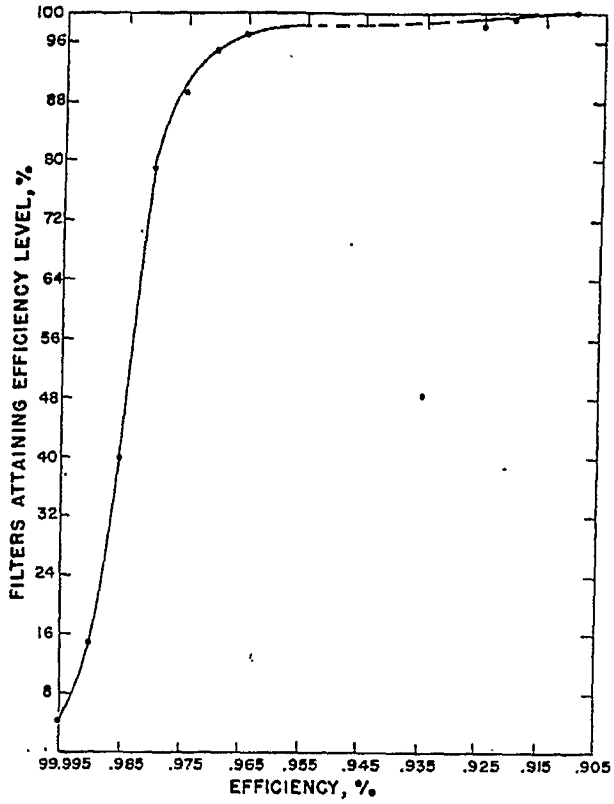

Fig. 4.10. Efficiency of respirator filter cartridges.

VI. FILTER TESTING

Several methods are currently used to evaluate efficiencies of particulate-removing filter media. These include the use of liquid aerosols such as DOP; solid aerosols such as methylene blue, uranine, sodium chloride, silica dust, and lead fumes; insecticide aerosols; and bacteriological aerosols.

TABLE 4.2

EFFICIENCY OF APPROVED DISPERSOID-REMOVING RESPIRATORS

Dispersoids Covered by Respirator	Test Dispersoid	Minimum Efficiency for Approval Performance, %
Pneumoconiosis-producing and nuisance dusts	Silica dust	97.4
Toxic dusts (not significantly more toxic than lead)	Litharge 75%; free metallic lead 25%	98.5
Metal fumes (not significantly more toxic than lead)	Lead fume	98.5
Chromic acid mists	Chromic acid mist	99
Pneumoconiosis-producing and nuisance mists	Silica mist (atomized silica dust-water mist)	90

A brief summary of each of the more common test methods is given below. Not included are the National Bureau of Standards dust spot method and other recognized standard methods commonly used for space filters, since these are not applicable to respirator filter testing.

Details of filter tests carried out under the several U.S. Bureau of Mines approval schedules are discussed in Chapter 9. Test aerosols used include silica dust, lead fumes, chromic acid mist, and a mixture of litharge and free metallic lead.

The U.S. Department of Agriculture carries out tests to evaluate the efficiency of respirator filters for various insecticides. In each case, the test aerosol is the insecticide in question. Details are included in Chapter 11, Section V.

A. Dioctyl Phthlate (DOP)

The DOP test aerosol[4,7,20] is generated by passing air through concentrated vapor produced by heating dioctyl phthlate to 170°C. The resulting aerosol is mixed with clean air at 25°C and adjusted to produce a concentration of approximately 100 milligrams per cubic meter (mg/M^3) of air. This produces a homogeneous liquid aerosol, with a median size of 0.3 μ, through condensation from the vapor state. Test efficiencies are similar to those obtained by atmospheric dust counting. Penetration down to 0.001 per cent can be achieved by light-scattering measurements before and after the filter. Details of the DOP smoke penetration test are available in the literature.[21]

B. Methylene Blue

A solid aerosol is produced by the atomization of a one per cent aqueous solution of methylene blue.[4,7,22] The resulting aerosol is mixed with larger quantities of dry air to evaporate water vapor present and adjusted to a concentration of approximately 25 mg/M^3 of air. The heterogeneous solid aerosol produced has a median size in the submicron range. Filter efficiencies are determined by discoloration comparisons with a filter standard after exposure to steam. The lower limit sensitivity is approximately 0.005 per cent penetration. Additional details are available in the literature.[23,24]

C. Sodium Chloride

A solid aerosol is produced by atomizing a 2 per cent aqueous salt solution, which is then diluted with dry air to produce solid sodium chloride particles.[7] Analysis is carried out with a comparison spectroscope, which is used to measure the intensity of a sodium light from a hydrogen flame in the test aerosol before and after the filter. This method produces relative efficiencies and must be calibrated by some other method such as methylene blue. Details of this test procedure are available in the literature.[25]

D. Uranine

A solid aerosol is produced by atomizing a 2.35 per cent aqueous solution of uranine.[26] The resulting aerosol is mixed with large quantities of dry air to evaporate water vapor present. Using impinger cutoffs, a heterogeneous aerosol having a median diameter of 0.20 μ and a geometric standard deviation of 2.4 can be produced. Fluorometric analysis is carried out by light excitation at 4400 to 5000 angstroms (A), with a resulting light emission at 5700 to 5900 A. Fluorometric measurements can be made for as little as 10^{-9} g of uranine, permitting great sensitivity.

E. Other Test Aerosols

Of some interest is the use of bacterial spores, such as B. globiggi, as a test aerosol.[27] Other aerosols used include uranium, copper sulfate, and various radioactive materials.

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Chapter 5
SORBENTS FOR GASES AND VAPORS

I. INTRODUCTION

Molecules of gases and vapors, when in contact with a solid surface at ordinary temperatures, are attracted and held to some degree to the surface of the solid. This phenomenon is termed sorption. The solid substance is the sorbent and the gas or vapor being sorbed is the sorbate. If the molecules of the sorbate are held to the surface by physical forces, similar to that occurring in condensation, the process is termed adsorption. If strong interaction, such as electron transfer, takes place between the sorbate and the surface of the sorbent, the phenomenon is chemisorption. However, if the sorbate does not remain on the surface, but enters into the solid and reacts chemically with it, changing the chemical nature of each, the process is called absorption.

The rate at which sorption takes place varies with the sorption phenomena. In physical adsorption the molecules of the sorbate are adsorbed as fast as they contact a free surface. In chemisorption and in absorption phenomena, the rate of sorption is measurably slower than in adsorption, being controlled by the rate of chemical reaction or solution of the sorbate with the sorbent.

The amount of gas or vapor sorbed may be small or large; it is a function of the physical and chemical nature of both the sorbent and the sorbate. Since sorption is primarily a surface phenomenon, porous solids having a tremendously large surface area are potentially the most effective sorbents.

In air-purifying respirators, porous granular sorbents are utilized to remove the gas and vapor contaminants from the inspired air. The sorbents are dispersed in layers of varying depths in canisters and cartridges and must function under varying conditions of concentration of contaminant, flow rate, temperature, and humidity. The contaminant concentration may vary from a few parts per million (ppm) to a maximum of 2 per cent (20,000 ppm) or more. The maximum inspiratory flow may vary from 60 liters per minute (l/min), for a person performing light work, to over 200 l/min for heavy work. Under these extreme conditions, the sorbent layer must reduce the ambient concentration of contaminant to less than 1 ppm in a period of less than 0.1 second (sec).

II. SORBENT REQUIREMENTS

A. Sorbent Properties

Sorbents for air-purifying respirators should exhibit the following properties: (1) activity or ability to sorb the contaminant at a high rate; (2) capacity or ability to sorb appreciable quantities of the contaminant; (3) retentivity or ability to retain the sorbate once it has been sorbed; (4) hardness or ability of granules to retain their size and shape when subjected to crushing and abrasion; (5) stability or ability to retain these properties under normal conditions of storage and use.

B. Bed Depth

The effective utilization of the sorbent in a canister or cartridge is largely influenced by the depth of layer through which the air stream is drawn. As the initial portion of the air stream contacts the initial layer of sorbent granules, the contaminants are partially sorbed and the concentration is greatly reduced. This process is repeated at each succeeding layer of granules until at some specified layer the concentration of contaminant approaches zero. Each succeeding portion of the air stream will continue to be free of contaminant at this point, until the capacity of the initial layer is exceeded. At this time, the depth of the sorption bed is advanced slightly and traces of contaminant appear in the air stream at the exit of the initial sorption bed.

This initial sorption bed is referred to as the 'critical bed depth' and is defined as the minimum depth of sorbent required to remove the contaminants from the air stream under specified test conditions. As the sorption bed is extended beyond the critical bed depth, the upper layers of the bed are exposed to very low concentration of the contaminant, which considerably increases the time a unit layer of sorbent remains effective. Major factors contributing to the critical bed depth are:

1. Concentration of contaminant. As the concentration is increased, a larger percentage of the molecules escape the initial layer of sorbent and penetrate to the next layers.

2. Rate of flow. At higher rates of flow, the contact or dwell time of the contaminant with the

sorbent is significantly reduced, permitting some of the molecules to escape being sorbed by the initial layer of sorbent.

3. Size of granules. In a specified volume of sorbent composed of small granules, the external surface area is greater than a similar volume of large granules, which facilitates the sorption process.

4. Activity of sorbent.

5. Capacity of sorbent.

III. ADSORBENTS

Granular adsorbents are characterized by an extraordinarily large internal surface area which, in some materials, may approximate 1500 square meters per gram (M^2/g). This massive internal area is due to a system of pores, whose diameter may vary from a few angstroms to 1,000 angstroms (A) or more. The pore size distribution (number of large pores versus small pores) may also vary widely, depending on the material and the treatment it has been given.

Many theories have been advanced regarding the nature of adsorption. For a detailed discussion of these theories, a few references are presented for review.[1-6]

It is generally accepted that adsorption is a surface phenomenon in which the molecules of the sorbate and the molecules of the sorbent are attracted to each other by either physical or chemical forces. These forces may vary in intensity and are influenced to some extent by the electron configuration of the molecules. Polar substances have strong attraction for each other; hence polar gas molecules, such as ammonia, are strongly attracted to the surface of polar sorbents, such as silica gel. Nonpolar gas or vapor molecules, such as carbon tetrachloride, may become polarized when they reach the field of force exerted by the surface of the sorbent, and the induced polarization attracts them to the surface.

With some compounds, these attractive forces may permit adsorption to occur in thin layers only, one or several molecules thick—indicative of low capacity of the sorbent for that compound. With other compounds, whose vapors are more easily liquefied, these forces are sufficient to coalesce the molecules and condense them—indicative of high capacity. As additional molecules are adsorbed, the strength of the forces are altered and the molecules tend to rebound or evaporate from the surface.

At this threshold point, a decrease in the activity and retentivity of the sorbent is initiated. In air-purifying respirators, the granules in the effluent zone of the sorbent layer must operate below this threshold point; otherwise contaminant would appear in the effluent air stream.

A. Activated Charcoal

Granular activated charcoal is the most versatile of the sorbents utilized in air-purifying respirators. Its millions of pores create an internal surface area ranging from 600 to 1,200 M^2/g, depending on the type of carbon and the conditions of activation. Because of its wide pore size distribution, both large and small size molecules can diffuse through the pores to its active surfaces. It is utilized primarily as an adsorbent for organic vapors, but it also exhibits significant capacity for some acid gases and vapors. Moreover, it can be successfully impregnated with selected materials which enhance its capacity for certain gases or vapors, without seriously impairing its original capacity for others.

The adsorption of organic vapors by activated charcoal is primarily physical adsorption or condensation. Hence, the critical temperature and the boiling point of organic compounds serve as broad criteria for the relative capacity of activated charcoal for specific organic gases or vapors. Compounds with low boiling points are adsorbed only slightly, whereas compounds which are liquid at or near ordinary temperatures and pressure are adsorbed more readily. This is specifically applicable in a homologous series of organic compounds, where the next higher member of the series is adsorbed more readily than the lower member. Figure 5.1 illustrates the increase in adsorption capacity of activated charcoal for a homologous series of paraffin hydrocarbons.

The introduction of halogen atoms into an organic molecule usually increases the adsorbability of the resulting compound. This is illustrated in Fig. 5.2 by the comparative adsorbability of chlorine derivatives of methane. Methane is adsorbed only very slightly, but as substituent chlorine atoms are introduced into the molecule, greater adsorption occurs.

Since the adsorbability of a vapor is also a function of the nature of the molecule and its electron configuration, the boiling point criterion does not apply for many organic compounds. Methyl bromide, whose boiling point is considerably lower than ethyl mercaptan, is adsorbed to a greater extent than ethyl mercaptan. The capacity for pentane is considerably higher than for ethyl mercaptan, although their boiling points are nearly the same.

The retentive capacity of activated charcoal is important during long service of charcoal canisters. The retentive capacity of a sorbent is the ratio of the weight of the retained substance to the weight of the carbon. It is measured by passing clean, dry air at constant pressure and temperature continuously through a bed of granular carbon previously saturated with a specific gas or vapor present in concentrations not exceeding 1,000 ppm, is also adsorbed satisfactorily although the capacity is not large.

Activated charcoal is also effective as a catalyst or a catalyst support for certain reactions, which results in an apparent increase in its capacity for certain sorbates. Many substances, when sorbed, become highly reactive. When chlorine and water vapor are sorbed simultaneously in charcoal, hydrochloric acid is formed. Phosgene reacts with sorbed water vapor to form hydrochloric acid and carbon dioxide.

Charcoal exhibits limited capacity for many highly toxic gases and vapors, such as mercury, arsine, phosgene, ozone, ammonia, hydrogen sulfide, and cyanogen chloride. When charcoal is impregnated with selected compounds, its effectiveness as a sorbent for these substances is greatly augmented. When impregnated with iodine, for example, its capacity for mercury vapor and hydrogen sulfide is increased tremendously. Salts of copper or cobalt improve the capacity for ammonia and ozone. Copper or copper oxide are effective agents for phosgene.

Figure 5.3 illustrates the improvement in capacity for hydrogen cyanide and hydrogen sulfide with four different impregnated charcoals. It also indicates that the capacity for chlorine is only

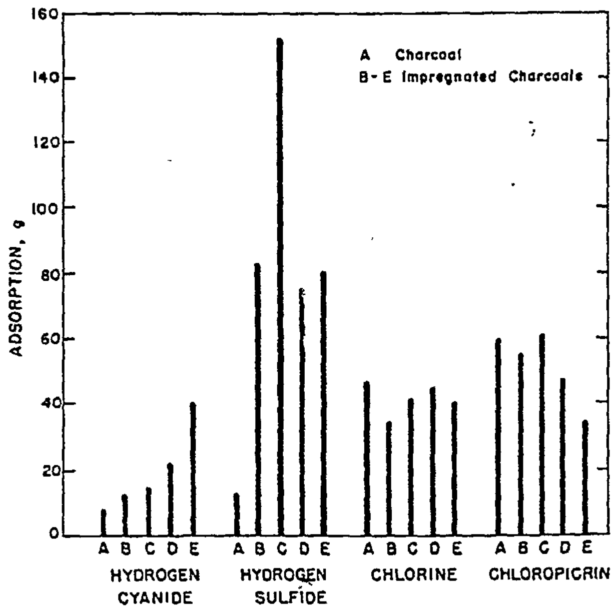

Fig. 5.3. Adsorption capacity of four commercially available impregnated charcoals for different contaminants. Test conditions: sorbent layer measuring 65 cm^2 by 11 cm; contaminant concentration of 5,000 ppm; and flow rate of 500 cm/min.

slightly reduced, whereas the capacity for chloropicrin is reduced significantly in only two of the four impregnated charcoals.

Although the preceding discussion demonstrates the versatility of activated charcoal and its impregnations, it also indicates that the actual capacity for a specific contaminant is dependent upon many factors and that even broad generalizations must be interpreted only as guides to specific problems.

B. Molecular Sieves

Most molecular sieves are synthetic crystalline zeolites, which in this discussion are treated as adsorbents. They are prepared by dehydrating crystalline alkali aluminosilicates to obtain a network of empty pores and cavities, which develop an internal surface area of 700 to 800 M^2/g^3. However, the cavities and pores are relatively uniform in size; that is, there is limited pore size distribution. This is in contrast to activated charcoal, which has an internal surface area of 600 to 1,200 M^2/g and whose pore size varies greatly. Molecular sieves have a high affinity for polar molecules; hence, they are excellent adsorbents for water vapor, particularly at low relative humidities. However, at 40 per cent relative humidity and above, the capacity of molecular sieves is less than that of silica gel.

The pores of molecular sieves, which are of molecular dimension and uniform size, adsorb small molecules but not large molecules. Because of the controlled pore size, the adsorbability of organic vapors will vary with the specific type of sieve, as well as with the specific compound. As a generalization, molecular sieves exhibit less capacity for most organic vapors than activated charcoal, but greater capacity than silica gel. Molecular sieves exhibit a capacity for ammonia comparable to silica gel. Sulfur dioxide and hydrogen sulfide are also adsorbed to some degree. Because of their capacity for ammonia and affinity for water vapor at low partial pressures, molecular sieves have been successfully used in a universal gas mask canister. Their general use in respirators has been limited because of economic factors.

C. Activated Alumina

Activated alumina is a porous aluminum oxide prepared by dehydrating alumina trihydrate. It exhibits an affinity for polar molecules and has good capacity for water vapor. However, its capacity for acid gases and organic vapors is limited. When it is impregnated with metal salts which hydrate readily, its capacity for ammonia is greatly enhanced. In contrast to other adsorbents, the hardness of the impregnated granules is low and extra precautions are required to preserve their size and shape. In air-purifying respirators, activated alumina has been utilized as a water vapor adsorbent and, when impregnated with metal salts, as an ammonia adsorbent.

D. Silica Gel

Silica gel is a partially dehydrated colloidal silica. In common with other adsorbents, it has a fine pore structure which develops a comparatively large internal surface area. However, this area is considerably less than that in activated charcoal. Silica gel exhibits an affinity for polar molecules and has good capacity for water vapor and ammonia. Its capacity for most organic vapors is considerably less than that of activated charcoal, and it does not possess the versatility of activated charcoal. When it is impregnated with metal salts, the capacity for ammonia is increased. Its use has been largely as a water vapor and ammonia adsorbent.

E. Hopcalite

Hopcalite is a porous granular mixture of manganese and copper oxides. The pore structure in the granules creates a large surface area, and it exhibits the properties of an adsorbent. Hopcalite has a high affinity for water vapor, organic vapors, acid gases, and ammonia, and it exhibits strong oxidizing properties for some of the adsorbates. However, it is primarily an oxidizing agent, being designed to catalyze the oxidation of carbon monoxide to carbon dioxide at ambient temperatures. This is accomplished by chemisorption and catalysis.

It is generally accepted that hopcalite, by virtue of its chemical and physical nature, chemisorbs carbon monoxide and holds it in an 'activated' condition on the surface. Oxygen molecules, chemisorbed on the surface and held in an 'activated' condition, react with the carbon monoxide to form carbon dioxide, which is immediately desorbed to the air stream. The 'active' sites on the surface which are depleted in oxygen and carbon monoxide immediately adsorb the required stoichiometric quantity of oxygen and carbon monoxide from the air stream, and the carbon monoxide oxidation process is repeated. In this process hopcalite is the catalyst.

Since this process is highly selective in nature, the surface of the hopcalite is very susceptible to poisoning by any adsorbates which would occlude the active sites or react with the hopcalite. It is therefore essential to remove all contaminants except carbon monoxide from the air stream prior to its contact with the hopcalite, if this activity is to be maintained. This is effectively accomplished in the Type N universal canisters approved by the Bureau of Mines, in which hopcalite is used as a carbon monoxide adsorbent.

During the oxidation of carbon monoxide by hopcalite, heat is generated in proportion to the amount of carbon monoxide being oxidized. When a mixture of 1% of carbon monoxide in air is oxidized, the temperature of the air is increased (theoretically) about 96°C (205°F). However, under practical conditions of use in canisters, the actual temperatures attained are somewhat lower. Breathing a mixture of 1% carbon monoxide in air at a rate comparable to conditions of vigorous work (32 l/min continuous flow), the effluent air temperature at the top of the canister reaches approximately 100°C (212°F), an increase of about 75°C (167°F) above ambient temperature. The heat has been known to "burn the paint off canisters" and even to "unsolder the canister necks." Practically, however, the effluent air in such a condition is so hot that a wearer will not be able to stay in the atmosphere (2% or higher of carbon monoxide) and will retreat before either combustion or deterioration of the canister sets in, as temperatures of 100°C are readily obtained.

IV. ABSORBENTS

Granular absorbents differ from adsorbents in that the granules, although porous, do not contain the myriad of fine microscopic pores nor the large internal surface area characteristic of adsorbents. The gases and vapors diffuse from the air stream onto the external surfaces and into the pores of absorbents in a manner comparable to that occurring with adsorbents, but the contaminants combine chemically with the absorbent. The capacity and activity of the absorbent are dependent upon the rate of reaction at the surfaces and the diffusion of the ions from the surface to the interior of the mass.

Granular alkaline absorbents are generally composed of mixtures of sodium or potassium hydroxide with lime and/or caustic silicate. They are primarily utilized as acid gas absorbents. Alkaline granules are prepared either with a low caustic content (5 to 10 per cent) or a high caustic content (> 50 per cent). These granules require a particular range of moisture content to attain reasonable capacity for acid gases.

Low caustic granules require a high moisture content (10 to 20 per cent) for greatest capacity and, conversely, high caustic granules exhibit greatest capacity with low moisture content (0 to 5 per cent). In general, high caustic granules exhibit equal or better capacity for the more toxic acid gases and vapors. The low moisture—high caustic absorbents are hygroscopic, while the high moisture—low caustic absorbents effloresce in normal air. These properties are used advantageously in their respective fields of application. Figure 5.4 illustrates the influence of moisture on the capacity of each type of alkaline absorbent when exposed to representative acid gases.

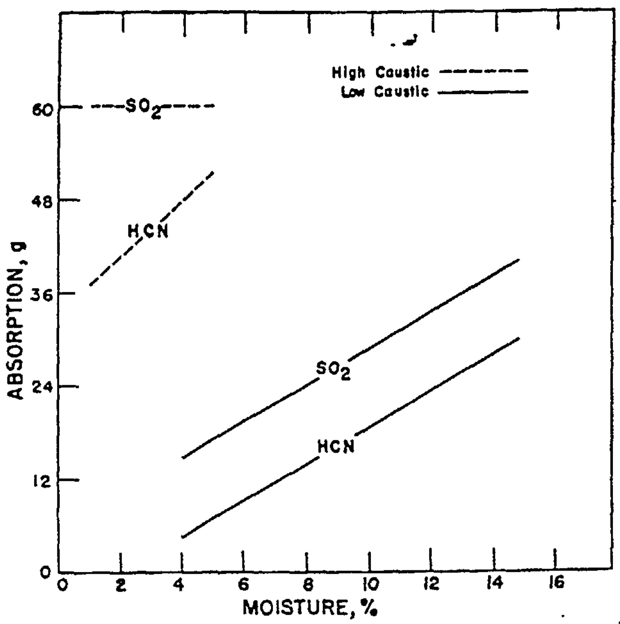

Fig. 5.4. Effect of moisture content on absorption capacity of alkaline absorbents. Test conditions: sorbent layer measuring 65 cm^2 by 11 cm; contaminant concentration of 5,000 ppm; and flow rate of 500 cm/min.

In addition to absorbing acid gases effectively, the high caustic absorbents also serve as water vapor absorbents. This absorbent is utilized in gas mask canisters, where highest capacity is required for both acid gases and water vapor. When high humidity air is encountered, the initial layers of the absorbent retain most of the moisture, thereby ensuring high capacity in the upper layers of the absorbent.

V. MIXTURES AND LAYERS IN CANISTER MANUFACTURE

Canister performance depends on the ability of the sorbents to remove all or all but a few parts per million of contaminants from a rapidly moving airstream. The dynamic test conditions established to evaluate performance generally make it impossible to predict performance data from static equilibrium data. Different arrangements of two or more sorbents (layers versus mixtures) in a given canister may give significantly different service lives against a specific contaminant. However, even in the simplest two-component case, no generalizations can be made regarding the service life difference between mixtures and layers of the same total quantities of ingredients.

A. Advantages of Different Arrangements

The advantages of layers versus mixtures depend upon specific reacting systems. For example, chlorine gas is absorbed better when it passes respectively through soda lime and charcoal layers than when these layers are reversed or mixed. However, when chlorine is adsorbed by charcoal, some of the chlorine is reduced to hydrochloric acid, which is not well retained. Thus, when charcoal is the last or "exit" layer, the hydrochloric acid escapes unless absorbed by an additional layer of soda lime.

Phosgene, although similar to chlorine in other respects, is absorbed better by a mixture of the two component parts than by either of the layer sequences. Similar behavior is shown when ammonia is absorbed by two different kinds of chemicals: the mixture is superior to either arrangement of layers. In the case of sulfur dioxide, there is no absorption difference between layers of soda lime and carbon or the mixture.

The improvement in service life due to a preferred arrangement of several sorbents is not very large, typically around 15 to 30 per cent better than the poorest arrangement. This magnitude of difference also is affected by normal variations in test conditions for canisters, as from low concentration and low rate of flow (5,000 ppm concentration at 32 l/m) to high concentration and high rate of flow (20,000 ppm concentration at 64 l/m).

B. Universal Canister

The Type N universal gas mask is designed to provide respiratory protection against all commonly occurring gases and vapors and against dusts, mists, fogs, and smoke, provided the contaminated air contains enough oxygen to support life.

The sorbents are required to be in layers and their relative position is controlled by their reactivity to various contaminants (see Chapter 6, Figure 6.1). Hopcalite is the only sorbent commercially used which is capable of oxidizing carbon monoxide to carbon dioxide. However, it also reacts with moisture, acid gases, ammonia, and many organic vapors, each of which can poison its catalytic action toward carbon monoxide. Locating the hopcalite near the "exit" end of the canister protects it from these contaminants, since the air stream must first pass through all the other purifying sorbents. A small layer of dryer tops the hopcalite, to protect it from moisture that may diffuse in from the top. Similar reasoning dictates that a highly efficient moisture sorbent must be located immediately below the hopcalite. Acid gas sorbents, which also have capacity for moisture, are generally located near the inlet end of the canister. Particulate filters are located so that the incoming air stream must first penetrate them.

VI. DISCUSSION AND RECOMMENDATIONS CONCERNING THE USE OF SORBENTS IN CANISTERS

A. Moisture

As discussed in Sections III and IV, a change in the moisture content of the sorbents may improve or adversely influence their performance. Gas mask canisters have very satisfactory shelf life when sealed and reasonable life when attached to a facepiece in readiness to give protection in an emergency or in routine use. The shelf life has arbitrarily been limited to three years for canisters completely sealed, except for the window-indicator universal gas mask canister. There is no definite time limit that sealed window-indicator canisters may be stored. Such canisters should be inspected periodically and should be discarded when the indicator shows that moisture has penetrated the hopcalite. If the facepiece is attached to the canister with bottom seal intact, the canister must be discarded after one year of such storage.

The change in canister moisture content occurs in the following ways:

1. Changes in temperature and barometric pressure. Increased temperatures or decreased pressures expand the atmosphere within the canister, and the pressure generated is relieved by escaping through tapes, corks, or inlet and outlet ports. If sorbents are moist, a loss of moisture occurs. Conversely, lowered temperatures or increased pressures cause ambient air (with its moisture) to leak into the canister. If sorbents are dry, the moisture is sorbed.

2. Migration. If, through use or by design, the humidity of the atmosphere surrounding the granules of the sorbent in one position is higher than that surrounding other granules, a migration of moisture occurs in proportion to their respective abilities to sorb moisture.

B. Maintenance

Maintenance of canisters is largely a matter of moisture control, prevention of mechanical damage, observation of resistance changes, and scheduling of replacement. Experience has shown that:

1. Moisture control is attained through storage in areas which are nominally dry and in which temperature variations are at a minimum.

2. Mechanical damage may distort the body, resulting in (a) leaks; (b) crushing granules into finer particles, which can result in higher resistance to air flow; or (c) channeling, an area of decreased resistance and reduced sorptive capacity.

3. Resistance changes may indicate undue water adsorption, excessive gas absorption, damage of granular structure, or a combination of these factors that result in decreased life and/or efficiency. Resistances for typical canisters as manufactured and upper limits at the end of effective life specified by the Bureau of Mines are shown in Table 5.2.

TABLE 5.2

NOMINAL RESISTANCES OF CANISTERS ONLY

Canister	As Manufactured, in. of H_2O	Upper Limit at End of Effective Life, in. of H_2O
Supersize		
Universal	1.7	3.00
Universal with filter	2.5	3.25
Intermediate size		
Industrial (chest canister)	2.6	3.00

C. Use

1. Scheduling of replacement of canisters is advisable to assure maximum usability and maximum protection. The factors involved are:
   a. Observation of recommended dates printed on labels of canisters.
   b. Setting up advisable limits of canister use for each operation based on: (1) time, (2) moisture of air, (3) concentration of toxic gases, and (4) degree of effort used by wearer.

2. Several factors affect the choice of canister size. They include:
   a. Where nuisance concentrations of relatively nontoxic gases, or concentrations only slightly exceeding maximum allowable concentration limits of toxic gases exist, use chemical cartridges (50 to 200 cm^3).
   b. Where high concentrations for short duration or emergencies are to be

encountered, use chin style canisters (250 to 500 cm^3).

c. For higher concentrations up to the maximum recommended or for longer duration, use 1,000 to 2,000 cm^3 canisters as the situation may indicate.

VII. SORBENTS FOR SPECIFIC GASES AND VAPORS

The earlier sections of this chapter have emphasized that the actual capacity of a sorbent for any specific contaminant is dependent upon many varied factors. Any list of sorbents for specific gases and vapors must be interpreted only as a guide to specific problems. Such a guide is the list of sorbents for the gases and vapors listed in Table 5.3. They are the gases and vapors for which threshold limit values were listed by the American Conference of Governmental Industrial Hygienists in 1961.

An examination of this table shows that activated charcoal is the best sorbent for the majority of the gases and vapors listed. Obviously, it is

TABLE 5.3

SORBENTS FOR GASES AND VAPORS INCLUDED IN ACGIH THRESHOLD LIMIT VALUES FOR 1961
This sorbent information is not necessarily based on actual tests but in many cases is based on "educated guesses."

Sorbent Code

1. Activated charcoal.
2. Soda lime.
3. Combination charcoal and soda lime.
4. Silica gel.
5. Hopcalite.
6. Treated carbon for specific chemical; example, carbon treated to absorb ammonia.
7. Special sorbents or mixtures (different manufacturers may have different sorbents for same chemical); example, ammonia sorbent is indicated as 7a.
8. Universal canister.

Substance[a]	Sorbent[b]	Substance[a]	Sorbent[b]
Acetaldehyde	1	Butyl cellosolve (2-butoxyethanol)	1
Acetic acid	1 (3)	p-tert. butyltoluene	1
Acetic anhydride	3 (1)	Carbon dioxide	2
Acetone	1	Carbon disulfide: skin, gas mask	1
Acetylene tetrabromide: gas mask	1	Carbon monoxide: gas mask	5, 8
Acrolein: gas mask	1	Carbon tetrachloride: skin	1
Acrylonitrile: skin, gas mask	1, 3	Cellosolve (2-ethoxy-ethanol)	1
Allyl alcohol: skin	1	Cellosolve acetate (2-ethoxyethyl acetate)	1.
Allyl chloride	1 (3)	Chlorine: gas mask	1.3, 7
Allyl propyl disulfide	3	Chlorine dioxide: gas mask	1, 7
Ammonia	7a (6)	Chlorine trifluoride: gas mask, no organic sorbent	2
Amyl acetate	1	Chlorobenzene (monochlorobenzene)	1
Amyl alcohol (isoamyl alcohol)	1	Chloroform (trichloromethane)	1
Aniline: skin, gas mask	1, 7	1-Chloro-1-nitropropane	1
Arsine: gas mask	6 (8)	Chloropicrin: gas mask	1
Benzene (benzol)	1	Chloroprene (2-chloro-1,3-butadiene)	1
Benzyl chloride: gas mask	3 (1): filter	Cresol (all isomers): skin, gas mask	1
Boron trifluoride: gas mask	8	Cyclohexane	1
Bromine: gas mask	3	Cyclohexanol	1
Butadiene (1,3-butadiene)	1	Cyclohexanone	1
2-Butanone (methyl ethyl ketone)	1		
Butyl acetate (n-butyl acetate)	1		
Butyl alcohol (n-butanol)	1		
tert. butyl alcohol	1		
Butylamine	1 + 7		

TABLE 5.3—continued

Substance[a]	Sorbent[b]
Cyclohexene	1
Decaborane: skin, gas mask	4: filter
Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone)	1
Diborane: gas mask	5, 8
o-Dichlorobenzene	1
p-Dichlorobenzene	1
Dichlorodifluoromethane	1
1,1-Dichloroethane	1
1,2-Dichloroethane (ethylene dichloride)	1
1,2-Dichloroethylene	1
Dichloroethyl ether	1
Dichloromonofluoromethane	1
1,1-Dichloro-1-nitroethane	3
Dichlorotetrafluoroethane	1
Diethylamine: gas mask	1, 7
Difluorodibromomethane	1
Diisobutyl ketone	1
Dimethylaniline (N,N-dimethyl-aniline): skin	1
Dimethylformamide	3, 8
1,1-Dimethylhydrazine[c]: skin, gas mask, special fill	4 + 6
Dimethylsulfate: skin, gas mask	1, 3
Dipropylene glycol methyl ether	1
Dioxane (diethylene dioxide)	1
Ethyl acetate	1
Ethyl acrylate: skin	1
Ethyl alcohol (ethanol)	1
Ethylamine: gas mask	1, 7
Ethyl benzene	1
Ethyl bromide	1
Ethyl chloride	1
Ethyl ether	1
Ethyl formate	1
Ethyl silicate	1
Ethylene chlorohydrin: skin, gas mask	1
Ethylenediamine: gas mask	1, 7
Ethylene dibromide (1,2-dibromo-ethane)	1
Ethylene imine: skin, gas mask	1, 7
Ethylene oxide[c]	1
Fluorine[c]: gas mask	3, 8
Fluorotrichloromethane	1
Formaldehyde: gas mask	1
Furfural: gas mask	1
Furfuryl alcohol	1
Gasoline	1
Heptane (n-heptane)	1
Hexane (n-hexane)	1
Hexanone (methyl butyl ketone)	1
Hexone (methyl isobutyl ketone)	1
Hydrazine[c]: skin, gas mask	4, 7a
Hydrogen bromide: gas mask	2, 3: filter
Hydrogen chloride: gas mask	2, 3: filter
Hydrogen cyanide: skin, gas mask	7
Hydrogen fluoride: gas mask	2, 7
Hydrogen peroxide, 90 per cent: gas mask	3: filter for mist
Hydrogen selenide: gas mask	6, 8
Hydrogen sulfide: gas mask	3, 6
Iodine: gas mask	1: filter
Isophorane	1
Isopropylamine: gas mask	1 + 7
Mesityl oxide	1
Methyl acetate	1
Methyl acetylene	1
Methyl acrylate: skin	1
Methylal (dimethoxymethane)	1
Methyl alcohol (methanol)	1
Methyl bromide: skin, gas mask	1
Methyl cellosolve (2-methoxy-ethanol)	1
Methyl cellosolve acetate	1
Methyl chloride: gas mask	1
Methyl chloroform (1,1,1-tri-chloroethane)	1
Methylcyclohexane	1
Methylcyclohexanol	1
Methylcyclohexanone	1
Methyl formate	1
Methyl isobutyl carbinol (methyl amyl alcohol)	1
α-Methyl styrene	1
Methylene chloride (dichloro-methane)	1
Monomethyl aniline: skin, gas mask	1 + 7

a. The notation "gas mask" after an entry means that a gas mask only should be used and that a chemical cartridge respirator should not be used regardless of concentration or length of exposure. The notation "skin" indicates that the liquid compound can penetrate the skin to cause systemic effects.

b. Sorbents listed in parentheses are second choices; where parentheses are not used, sorbents are equally good. The notation "filter" indicates that filter is needed with the sorbent.

c. The sorbent recommended is for low to medium concentrations of the substance. For respiratory protection against high concentrations such as would occur after a spill, a self-contained breathing apparatus should be used.

TABLE 5.3—continued

Substance[a]	Sorbent[b]	Substance[a]	Sorbent[b]
Naphtha (coal tar)	1	Toluene (toluol)	1
Naphtha (petroleum)	1	o-Toluidine: skin, gas mask	1
Nickel carbonyl: gas mask	5: filter	Tolylene-2,4-diisocyanate: gas mask	1
Nitric acid[c]: gas mask	3, 8	Trichloroethylene	1
p-Nitroaniline: skin, gas mask	1	Triethylamine	1
Nitrobenzene: skin, gas mask	1	Trifluoromonobromomethane	1
Nitroethane	1	Turpentine	1
Nitrogen dioxide: gas mask	8	Vinyl chloride (chloroethylene)	1
Nitroglycerin: gas mask	1	Vinyl toluene	1
Nitromethane: gas mask	1	Xylene (xylol)	1
2-Nitropropane	1	Xylidine: skin, gas mask	1
Nitrotoluene: skin	1		
Octane: gas mask	1		
Ozone	6	Tentative Values	
Pentane	1		
Pentanone (methyl propyl ketone)	1	Acetonitrile: gas mask	1, 3
Perchloroethylene (tetrachloroethylene)	1	Allyl glycidyl ether (AGE)	1
Phenol: skin, gas mask	1	tert. butyl chromate (as CrO_3)	6(3)
Phenylhydrazine: skin, gas mask	1, 7	n-Butyl glycidyl ether (BGE)	1
Phosgene (carbonyl chloride): gas mask	3, 6	Butyl mercaptan	1
Phosphine: gas mask	6(8)	Chloroacetaldehyde: gas mask	1
Phosphorus trichloride: gas mask	3: filter	Chlorobromomethane	1, 3
Propyl acetate	1	Diglycidyl ether (DGE)	1
Propyl alcohol (isopropyl alcohol)	1	Dimethyl acetamide	1
Propyl ether (isopropyl ether)	1	Ethanol amine: gas mask	1 + 7
Propylene dichloride (1,2-dichloropropane)	1	Ethyl mercaptan	1
Propylene imine: skin	1	Glycidol	1
Propylene oxide	1	sec-Hexyl acetate	1
Pyridine	1	Isopropyl glycidyl ether (IGE)	1
Quinone: gas mask	1: filter	Ketene: gas mask	1
Stibine: gas mask	6(8)	Methyl mercaptan	1
Stoddard solvent	1	1-Nitropropane	1, 3
Styrene monomer (phenylethylene)	1	Pentaborane: gas mask	1
Sulfur dioxide	2	Perchloromethyl mercaptan: gas mask	1
Sulfur hexafluoride: gas mask	3	Phenyl glycidyl ether (PGE)	1
Sulfur monochloride: gas mask	3: filter	n-Propyl nitrate[c]	1
Sulfur pentafluoride: gas mask	8, 3	Teflon decomposition products (as F): gas mask	3: filter
1,1,2,2-Tetrachloroethane: skin, gas mask	1	1,2,3-Trichloropropane	1
Tetrahydrofuran	1	1,1,2-Trichloro-1,2,2-trifluoroethane	1
Tetranitromethane: gas mask	3	Triorthocresyl phosphate	3: filter
		Triphenyl phosphate	3: filter

a. The notation "gas mask" after an entry means that a gas mask only should be used and that a chemical cartridge respirator should not be used regardless of concentration or length of exposure. The notation "skin" indicates that the liquid compound can penetrate the skin to cause systemic effects.

b. Sorbents listed in parentheses are second choices; where parentheses are not used, sorbents are equally good. The notation "filter" indicates that filter is needed with the sorbent.

c. The sorbent recommended is for low to medium concentrations of the substance. For respiratory protection against high concentrations such as would occur after a spill, a self-contained breathing apparatus should be used.

Chapter 6

AIR-PURIFYING RESPIRATORS

I. INTRODUCTION

An air-purifying respirator is, as its name implies, a respirator that removes contaminants from air inhaled by the wearer.

II. TYPES OF AIR-PURIFYING RESPIRATORS

Air-purifying respirators may be divided into the following types: particulate-removing (mechanical filter), gas- and vapor-removing (chemical filter), and a combination particulate-removing and gas- and vapor-removing.

A. Particulate-removing Respirators

Particulate-removing respirators are designed to protect the wearer against the inhalation of particulate matter in the ambient atmosphere. They may be designed to protect against a single type of particulate, such as pneumoconiosis-producing and nuisance dusts, toxic dusts, metal fumes, or mists, or against various combinations of these types.

B. Gas- and Vapor-removing Respirators

Gas- and vapor-removing respirators are designed to protect the wearer against the inhalation of gases or vapors in the ambient atmosphere. They are designated as gas masks, chemical cartridge respirators (nonemergency gas respirators), and self-rescue respirators. They may be designed to protect against a single gas such as chlorine; a single type of gas, such as acid gases; or a combination of types of gases, such as acid gases and organic vapors.

Gas masks are for protection against relatively high concentrations (up to 1 to 3 per cent) of gases and vapors (1 per cent for chlorine, 3 per cent for ammonia, and 2 per cent for all other gases and vapors).

Chemical cartridge respirators are for protection against low concentrations (up to 0.1 per cent) of gases and vapors.

Self-rescue respirators (mouthpiece type) are, as the name implies, for assisting escape from, but not entry into, intermediate concentrations of gases and vapors on the order of 1 per cent. The carbon monoxide self-rescuer is the only one of these devices approved by the Bureau of Mines at this time.

C. Combination Particulate-removing and Gas- and Vapor-removing Respirators

Combination particulate-removing and gas- and vapor-removing respirators are designed to protect against particulates, gases, and vapors in various combinations. They may be either gas masks or chemical cartridge respirators.

III. DESCRIPTION AND PRINCIPLES OF OPERATION

A. Particulate-removing Respirator

A particulate-removing respirator consists of a facepiece (either full or half mask) and a mechanical filter.

The facepiece has an exhalation valve through which the air exhaled by the wearer passes to the ambient atmosphere. It is desirable that it be equipped with an inhalation valve that closes during exhalation and prevents the expired air from entering the filter. The facepiece is held securely on the wearer's face by a head harness, in the case of a full facepiece, or by headbands, in the case of a half mask. A knitted cloth cover ("facelet") is sometimes used on the face-contacting edge of a half mask to absorb perspiration and to prevent irritation of the skin when the respirator is worn in hot places or in air containing substances such as lime. Covers should not be used on respirators for protection against fumes because these fine particles will pass through the covers and into the facepiece cavity.

The filter portion of the respirator consists of a single unit, or two units in parallel, designed to remove dispersoids from air inhaled through them. The size and shape of the units depend upon the materials of which they are made and upon the type or types of particulates against which they are designed to give protection. For a complete discussion of the factors affecting filtration of particulates, see Chapter 4.

At present, most filters for particulate-removing respirators are designed to be used only once; that is, they are to be discarded after the wearer of the respirator notices an increase in the inhalation resistance. Filters for some of the older types of dispersoid respirators that are still in use are designed to be cleaned and reused. These reusable filters should be cleaned mechanically according to the manufacturer's instructions, but never washed or treated with solvents.

The performance requirements for particulate respirators that are approved by the Bureau of Mines are given in Chapter 9, Section II, D.

B. Gas- and Vapor-removing Respirators

A gas- and vapor-removing respirator consists basically of a granule-filled container connected to a full facepiece for the gas mask, to a half mask for the chemical cartridge respirator, or to a mouthpiece for the self-rescue respirator. The performance requirements for gas- and vapor-removing respirators that are approved by the Bureau of Mines are given in Chapter 9, Section II, B and E.

1. Gas Masks

The facepiece of the gas mask is the full facepiece type that covers the eyes, nose, and mouth. It should be designed so that all of the air inhaled by the wearer is drawn in over the inner surface of the eyepiece or eyepieces to minimize the formation of droplets of moisture on this surface. It has an exhalation valve through which the air exhaled by the wearer passes to the ambient atmosphere. Most gas mask facepieces have a flexible, kink-resisting breathing tube which connects the facepiece to the gas mask canister. Some gas masks have the canister attached directly to the facepiece. The facepiece is held securely on the wearer's face by means of an adjustable head harness.

The gas mask canister is a container filled with granular sorbent of the type and amount necessary to remove the gas or vapor contaminant from the inhaled air. The canister may contain a single type of granular material, a mixture of two materials, or successive layers of two or more materials, depending on the type or types of gases and vapors to be removed. A complete discussion of gas sorbents and factors concerned with their use in gas mask canister design is given in Chapter 5.

The arrangement of the granular sorbent is different for each type and make of canister. Figure 6.1 shows a composite cross section of a universal gas mask canister and indicates the function of the various components. It is customary to use screens to separate the adjacent layers of granules to keep them from mixing and to maintain the integrity of the layers when the canister is in use. The corrugations in the outer shell of the canister serve to prevent "channeling" of the gas along the walls of the shell. In canisters without corrugations in the outer shell, baffles are usually inserted at the periphery of the screens to prevent channeling.

The granular fill of the canister is supported by a screen or perforated metal plate so arranged as to allow even distribution of the incoming gas-air or vapor-air mixture. The fill is held firmly in place by a spring. The various parts within the canister, as well as the coating of the interior of the shell, should be made of materials that are not affected by either the granular sorbent or the gases that might be expected to enter the canister. A check valve or valves should be incorporated in the gas mask to allow air to pass through the canister toward the facepiece and to prevent air from the facepiece from entering the canister during exhalation.

Some universal gas mask canisters have built-in indicators that enable the user to determine the effectiveness of the canister for protection against carbon monoxide and give a positive indication when the canister is no longer effective against this gas. The indicators, visible through small circular windows in the front of the canisters, contain dark blue indicating panels and light blue reference panels with which the indicating panels are compared. The indicating panels, which are sensitive to moisture, change color progressively to that of the reference panel, as moisture is absorbed by the canister contents, and turn pink with continued use of the canister. When the color of the indicating panel approaches or matches that of the reference panel, the canister is no longer effective for protection against carbon monoxide, and should not be used, even though it has never been used or used only in fresh air. The colors of the indicator and reference panels should be compared, when practicable, in daylight or under daylight-type lamps. Light from incandescent light bulbs or battery-operated cap lamps may accentuate the blue color of the indicator panel; therefore, canisters observed under these types of lights should be discarded when the color of the indicator panel is still somewhat darker than that of the reference panel. Window indicators in universal canisters do not show their service life against other gases. An auxiliary external check valve is required for universal window-indicator gas mask canisters which have no check valves in them.

All gas mask canisters have some filter material above the top layer of granular fill, primarily to keep small particles ("fines") of the fill from entering the breathing zone of the wearer. Some gas mask canisters, particularly the universal gas mask canisters, have special filters to remove particulates from the air entering the canisters. This is discussed in Section III, C.

The primary means of identifying a gas mask canister is a properly worded label. Canisters of

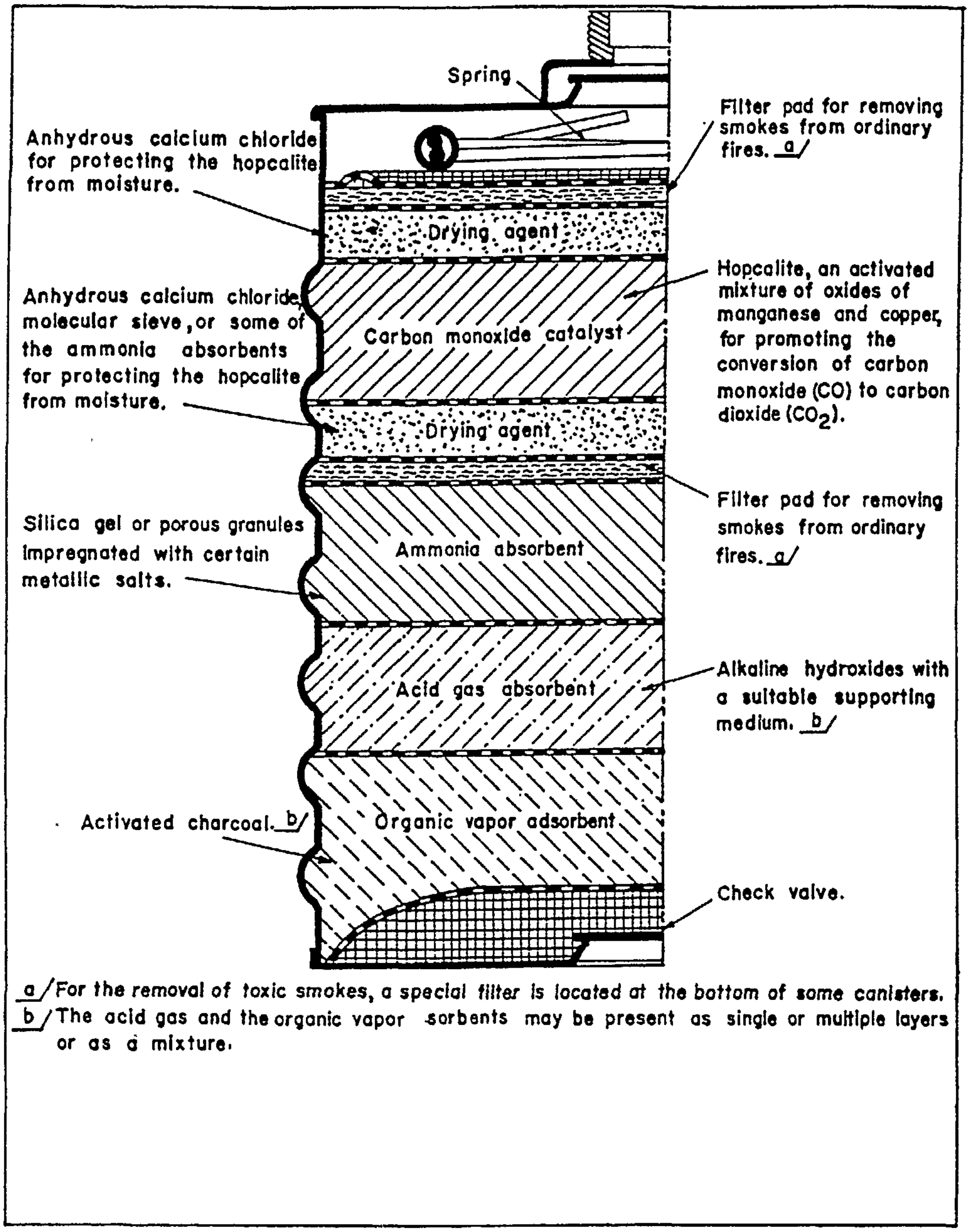

Fig. 6.1. Universal gas mask canister.

gas masks that have been approved by the Bureau of Mines bear a label, as discussed in Chapter 9, Section I. The secondary means of identifying a gas mask canister is a color code. The Bureau of Mines and the American Standards Association (ASA) are the two recognized authorities for color coding of gas mask canisters. The color coding specified by the Bureau of Mines is given in Schedule 14, and revisions thereto.[1] The ASA[2] Code is listed in Table 6.1.

The gas mask canister is held securely to the wearer's body in a convenient position by means of a canister harness. Conventionally, the canister is held in front of the wearer's chest or abdomen. However, many gas masks are supplied with canister harnesses that hold the canister on the wearer's back. The back position is preferred if the wearer must lean over the opening of a

TABLE 6.1

ASA COLOR CODE FOR GAS MASK CANISTERS

Contaminants	Color Assigned[a]
Acid gases	White
Hydrocyanic acid gas	White with 1/2 in. green stripe completely around the canister near the bottom
Chlorine gas	White with 1/2 in. yellow stripe completely around the canister near the bottom
Organic vapors	Black
Cyanogen chloride gas	Black with 1/2 in. white stripe completely around the canister near the bottom
Ammonia gas	Green
Carbon monoxide	Blue
Acid gases and organic vapors	Yellow
Hydrocyanic acid gas and chloropicrin vapor	Yellow with 1/2 in. blue stripe completely around the canister near the bottom
Hydrocyanic acid gas and cyanogen chloride gas	Yellow with 1/2 in. black stripe completely around the canister near the bottom
Acid gases, organic vapors, and ammonia gas	Brown
Acid gases and ammonia gas	Green with 1/2 in. white stripe completely around the canister near the bottom
Dusts, fumes, mists, and fogs in combination with any of the above gases or vapors	1/2 in. gray stripe completely around the canister near the top
All of the above atmospheric contaminants	Red with 1/2 in. gray stripe completely around the canister near the top

a. The following requirements apply to color assignment: (1) Gray shall not be assigned as the main color for a gas mask canister. (2) Canisters other than those listed in this table shall be painted orange in color. This will require the user to refer to the canister label to determine the type of protection that the canister will afford. (3) Canisters having a special filter for dusts, fumes, mists, and fogs shall have a statement of the type and degree of protection afforded by the filter imprinted on either a label affixed to the neck end of the canister or the gray stripe which is around the canister near the top. The degree of protection shall be marked as the per cent penetration of the canister by 0.3 micron (μ) diameter DOP smoke at a flow rate of 85 l/min. [Editor's Note Re Part (3): Filter penetration standards based on the penetration of 0.3 μ DOP have not been published. The generally acceptable limit of DOP penetration for a high efficiency filter is less than 0.05% at 85 l/min.]

container, such as at the top of a grain bin under fumigation or an oil storage tank during a tank gauging operation. When the canister is worn in the front position, the bottom or inlet end of the canister could be in a high concentration of gas or vapor present in or near the container opening. If, however, the canister is worn in the back position, it is farther removed from the area of high concentration. Both types of canister harness have some provision for attaching the facepiece to a shoulder strap of the harness when the facepiece is not being worn.

Each gas mask should be stored and transported in a sturdy case designed to protect it from damage and to prevent the facepiece from becoming distorted. A properly worded label should be prominently displayed on the exterior of the case; it should state the gaseous contaminant or contaminants against which the gas mask is designed to give protection. Adequate instructions regarding the safe use of the gas mask should be inside the case.

2. Chemical Cartridge Respirators

The facepiece of the chemical cartridge respirator is limited to the half mask type. This limitation has been applied because of the possibility of a chemical cartridge respirator with a full facepiece being used as a "junior" gas mask in a highly contaminated atmosphere, which could result in disastrous consequences to the wearer. Since this is a nonemergency respirator with a rather limited volume of sorbent in the gas- and vapor-removing unit, it would not be able to cope with a high concentration of contaminant. The half mask facepiece is similar to the facepiece for the particulate-removing respirator. In fact, several respirator manufacturers use the same facepiece for both types of respirators. For reliable chemical cartridge respirator performance, it is essential to have an inhalation valve to prevent the expired air from entering the sorbent. The Bureau of Mines considers an inhalation valve desirable but optional on the facepiece for the particulate-removing respirator; however, it is mandatory on the facepiece for Bureau of Mines approved chemical cartridge respirators. A knitted cloth cover or facelet must not be used on the face-contacting edge of the facepiece of a chemical cartridge respirator because it may allow contaminated air to enter the facepiece.

Some chemical cartridge respirators use only a single cartridge; others use two cartridges in parallel. For comparable performance, the total volume of sorbent in the cartridges is essentially the same in both cases. If two cartridges are to be used in parallel, their resistances to air flow should be essentially equal. If this were not so, more air would be drawn through the cartridge with the lower resistance and it would be exhausted before the other cartridge was exhausted. Thus, the over-all life of the unmatched pair of cartridges would be less than that of a matched pair. The cartridges usually are attached directly to the facepiece assembly, and the gas-tightness of the assembly is maintained by means of suitable gaskets. In some chemical cartridge respirators the cartridges are attached to a holder carried on the wearer's back and are connected to the facepiece by a flexible breathing tube.

The construction of the cartridge for a chemical cartridge respirator is much simpler than that of a gas mask canister. Usually, the cartridge has neither a check valve for controlling the direction of air flow nor a spring to compress the fill. The fill is contained between two screens or perforated metal plates which exert sufficient pressure on the fill to hold it in place. Suitable baffles in the cartridge prevent channeling of contaminated air. A filter pad on the effluent end of the cartridge prevents "fines" from entering the breathing zone of the wearer.

3. Mouthpiece Respirators

Mouthpiece respirators are usually designed to be carried on the user's person whenever he is in a situation where the atmosphere may be contaminated suddenly. They are used primarily to escape from a contaminated atmosphere, not to enter one. In certain industries where low levels of contamination are encountered intentionally, they are used under careful supervision.

Mouthpiece respirators, as the name implies, are equipped with a mouthpiece, which can be placed in the wearer's mouth and gripped firmly by his teeth. An exhalation valve is incorporated in the device through which exhaled air passes to the ambient atmosphere. To prevent inhalation through the nose, a rubber-padded spring clip is furnished to close off the wearer's nostrils. There is no protection for the eyes.

In some mouthpiece respirators the mouthpiece is attached directly to a cartridge or small canister filled with appropriate sorption media. A neck strap may be furnished to prevent loss of the respirator in case it is accidentally knocked from the wearer's mouth. In other self-rescue respirators the mouthpiece is connected by a flexible breathing tube to a regular gas mask canister which is held on the wearer's person by a carrying harness. In some instances, the canister is merely carried inside the wearer's shirt with the mouthpiece hanging outside in a readily accessible position.

C. Combination Particulate-removing and Gas- and Vapor-removing Respirator

1. Gas Masks

Some gas mask canisters, especially universal gas mask canisters, are provided with special filters to remove particulate matter from the air drawn through them. These filters are usually located at the inlet end of the canisters and are in addition to the aforementioned filter material at the top of each gas mask canister. These special filters may be designed to protect against the inhalation of one or more types of particulate matter. For instance, the filter for universal gas possible to make gas masks and particulate respirators that would have practically no resistance to air drawn through them. However, they would be impractically bulky and, in the case of the gas mask, heavy. The present inhalation resistance of these devices is a compromise between inhalation resistance on the one hand and bulk and weight on the other. It appears that there is more likelihood of reducing the resistance of particulate respirators as new filter materials or methods of filter construction are developed than there is of reducing the resistance of gas mask canisters.

F. Facepiece Fit

In all air-purifying respirators a negative pressure occurs inside the facepiece throughout the inhalation phase of the breathing cycle. This requires a very tight seal between the face and the face-contacting portion of the facepiece to prevent inward leakage of contaminated air. Facepiece fit is discussed in detail in Chapter 3, Section II.

In spite of these limitations, air-purifying respirators have been widely accepted and, when used within their limitations, have been the mainstays of respiratory protection.

Readers who are interested in further information on air-purifying respirators, concerning either general usage or specialized applications in particular industries, can find a number of good discussions in the literature.[4-7]

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Chapter 7

SUPPLIED AIR RESPIRATORS

The important advantages of air-supplying respirators are simplicity of design, broad application, and good protection when properly selected, adequately supplied with respirable air, and used in the manner or for the purposes for which they are designed and approved. They are applicable without regard to the kind or physical state of contaminant. Resistance to inhalation and service life are not dependent upon plugging of particulate filters or capacity of chemical sorbents.

Hose-type atmosphere-supplying respirators (supplied air respirators) make air available to the wearer through a hose connected to a supply of respirable air. They may be divided into six main subgroups:

1. Hose mask with blower
2. Hose mask without blower
3. Air line respirator
4. Abrasive blasting respirator
5. Supplied air hood
6. Supplied air suit

The first four subgroups are standard terminology for protectors used by the U.S. Bureau of Mines in approval schedules[1] and by the American Standards Association in its code.[2] Items 5 and 6 are included because of the wide usage of these devices in industry and laboratories. For additional information on the performance requirements of the various types of supplied air respirators, see Chapter 9.

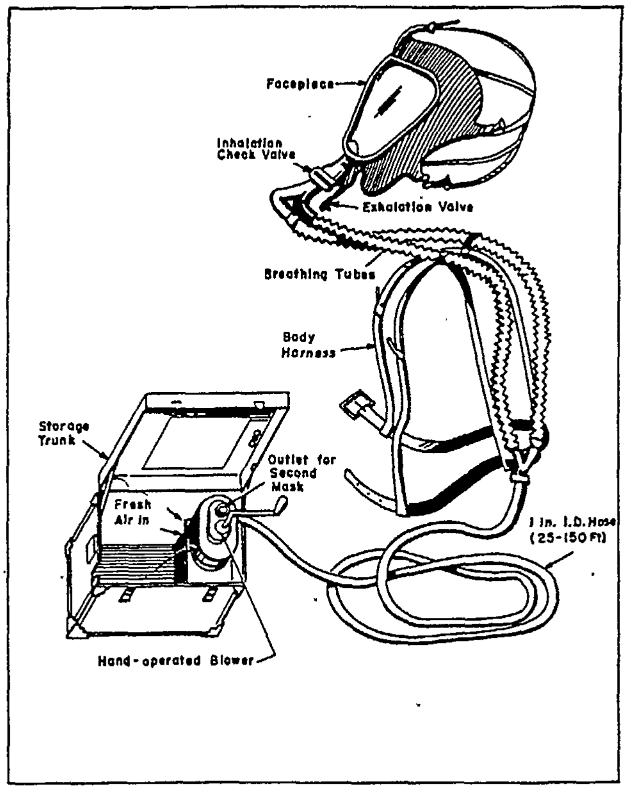

Fig. 7.1. Type A hose mask with hand-operated blower.

I. HOSE MASKS

There are two types of hose mask: the hose mask with blower (Type A) and the hose mask without blower (Type B). These designations conform with the classification system used by the Bureau of Mines (see Chapter 10).

The Type A hose mask with blower (see Fig. 7.1) is approved by the Bureau of Mines for respiratory protection in any atmosphere, regardless of the type or concentration of the contaminant, provided that enough respirable air is supplied to the wearer by means of the blower.

It consists of a full facepiece connected by a flexible breathing tube, or tubes, and a large diameter (approximately 1 in. inside diameter) hose to a hand- or motor-operated blower, which must be operated in respirable air. Two hose lines, each up to 150 ft in length, may be served by the hand-operated blower, and more by a motor-operated blower. The hose is attached to the wearer by a sturdy body harness to which a life line may be secured. The respirator is designed for use with the blower in continuous operation, and with a man in constant attendance at the blower (see Fig. 7.2 for an example of typical use). In the event that the blower should cease to operate, the wearer can still inhale respirable air through the hose with no more effort than when wearing a gas mask. Check valves in the facepiece and breathing tube assembly prevent exhaled air from entering the hose and cause it to leave the facepiece through the exhalation valve. Each hose mask has a serviceable trunk for storage and transportation.

The Type B hose mask without blower is

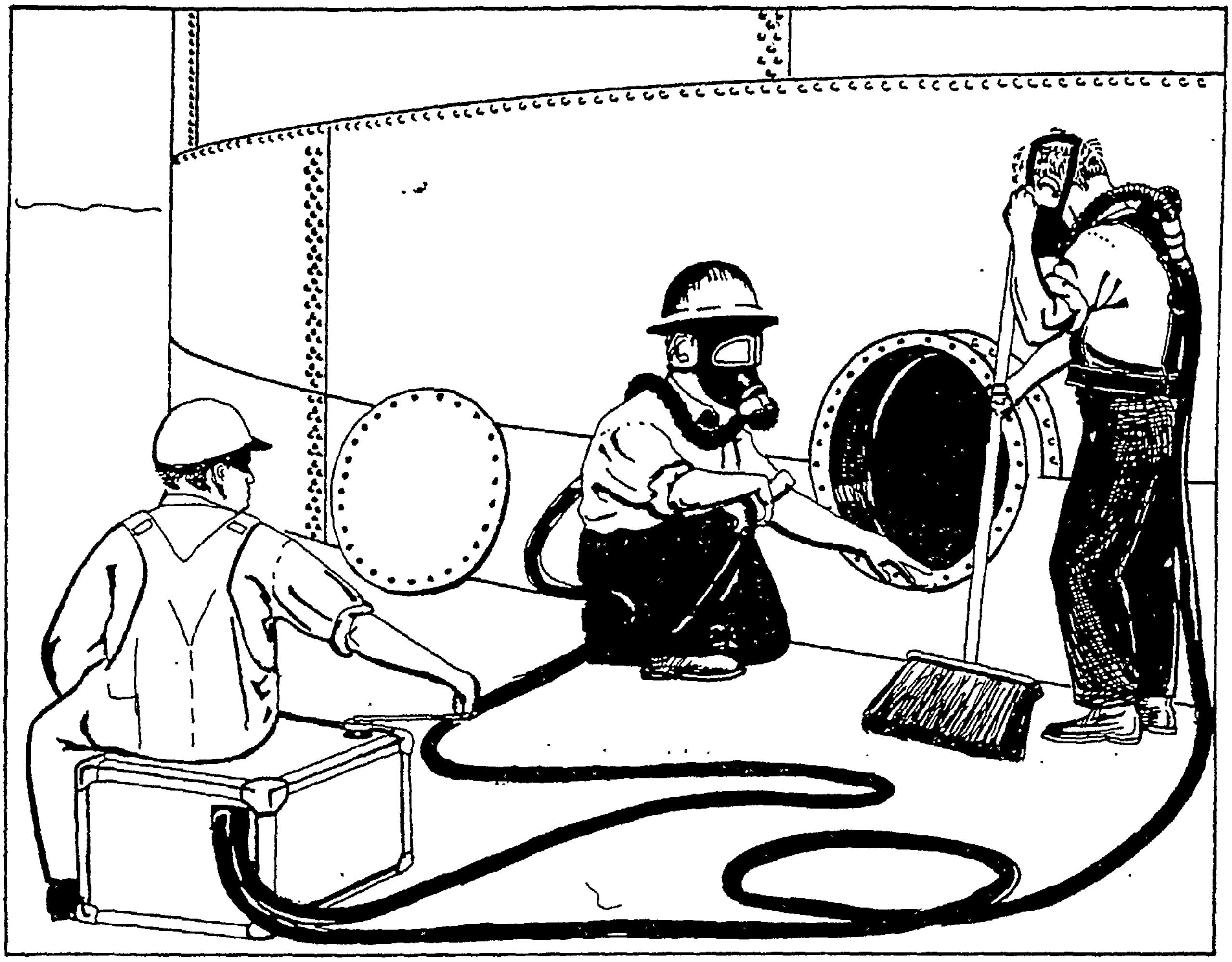

Fig. 7.2. Typical use of hose mask with blower.

approved by the Bureau of Mines for respiratory protection in any atmosphere from which the wearer can escape without the aid of the respirator. It consists of a full facepiece connected by a flexible breathing tube, or tubes, to a large diameter (approximately 1 in. inside diameter) hose, on the inlet end of which is a filter screen and a means of anchoring it in respirable air. The wearer obtains respirable air by means of his own inspiratory effort. Check valves in the facepiece and breathing tube assembly prevent exhaled air from entering the hose and cause it to leave the facepiece through the exhalation valve. The hose is attached to the wearer by a body harness. A maximum of 75 ft of hose may be used with this respirator.

Only hose masks without blowers (Type B) and those with hand-operated blowers (Type A) are approved by the U.S. Bureau of Mines. Hose masks with power-operated blowers are not included in current Bureau of Mines schedules (see Chapter 9). The choice of the proper respirator for any situation requires consideration and integration of pertinent factors, which include contamination of the air, the place, and the kind of work to be done.

II. AIR LINE RESPIRATORS

The air line respirator (Type C) may be used for protection in any atmosphere that is not immediately hazardous to life. It is particularly adapted to some types of jobs because it is light and may be worn for a long period of time without appreciable discomfort. For example, it is often used for spray painting, insecticide applications, welding, metalizing, and prolonged production work in hazardous areas.

The air line respirator consists of a

compressed air supply, a pressure release valve, a small diameter (approximately 3/8 to 1/2 in. diameter) compressed air hose, a quick disconnect coupling, an air flow control device designed to permit regulation of the air flow, and either a half or full facepiece. Like the hose masks, the air line respirator is provided with a low resistance exhalation valve. The pressure release valve setting is stated for each Bureau of Mines approval and depends upon supply system pressures, length of hose used, and the required air flows. To a large extent these requirements are closely related to performance and safety of the respirator.

There are two basic types of flow for air line respirators—the continuous flow and the demand flow. In the first type, a set amount of air is fed continuously to the facepiece. The amount is regulated by an air control valve or special air inlet design which is not susceptible to accidental changes of the setting even when jarred. This valve and a small filter may be placed in the air line between the short length of flexible tubing leading to the facepiece and the small diameter pressure hose from the air source. It can be clipped to the wearer's belt or mounted on a belt permanently. A slight positive pressure on the inside of the mask is always maintained to prevent inward leakage of the contaminated outside atmosphere. The continuous flow respirator, with either the half or full facepiece, is the most common type. It is best suited for use with air compressor systems.

When the air must be conserved, as could be the case when the supply is from a cylinder of compressed air, the demand flow respirator is preferred (see Fig. 7.3). The demand flow type contains a demand regulator at the lower end of the breathing tube. A demand regulator has a diaphragm-actuated valve which opens upon inhalation, permitting air to be supplied, and closes upon exhalation. This permits air to flow to the facepiece only when the wearer inhales. Such conservation of air allows one man about five hours of service from one standard high pressure cylinder of compressed air containing about 220 cubic feet of air at 1800 psi. Such service life is, of course, related to the physical activity required to do the job and may vary widely.

It should be emphasized at this point that the demand flow types must always be used with a tight fitting facepiece, whereas the continuous flow type may be assembled with a half mask, full facepiece, or hood. Also, the demand type usually requires a pressure regulator when a high pressure air supply is used.

The cost of an air line respirator may be more than that of a hose mask or it may be less, depending on whether or not an air supply must be

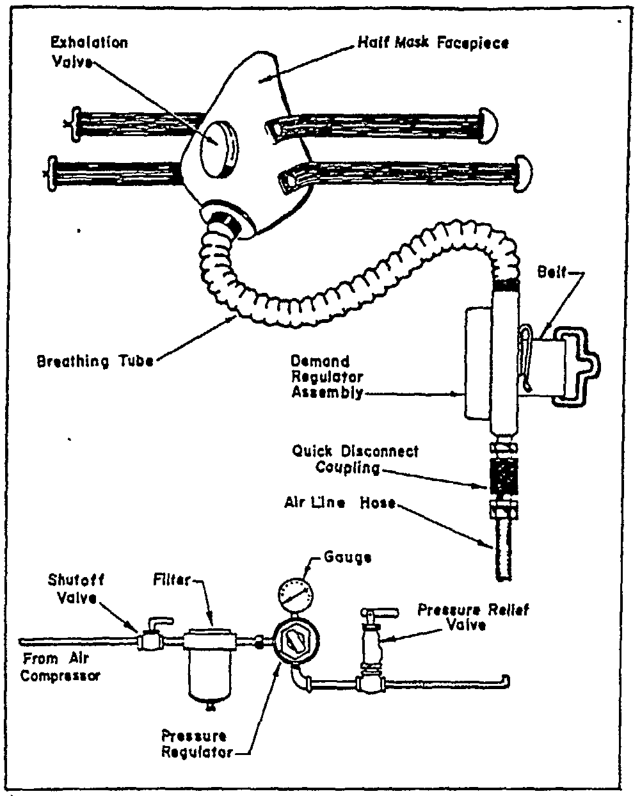

Fig. 7.3. Air line respirator of the demand flow type.

provided or an existing one of determined safe quantity and quality is available. Since an air line respirator is not to be used in lethal atmospheres, no life line is needed. If something does go wrong with the air supply, the mask can simply be removed and the wearer can move out of the contaminated air. Because of the trailing hose, the travel of the user is limited to a specified area.

A variation of both the continuous flow and the demand types of air line respirator is a device which has a regular and an emergency source of air supply. The emergency source may consist of a small bottle of compressed air or oxygen, or a canister, attached so that in case either the supply of higher pressure air to the small supply hose is cut off or the hose is disconnected, the changeover to the bottle or canister is automatic and the wearer can take his time getting out of the atmosphere. Even though air line respirators are equipped with emergency bottles or canisters, they are not approved by the U.S. Bureau of Mines for atmospheres that are immediately hazardous to life.

Air line equipment which does not include a manual control valve worn on the wearer's belt is also available. It can be used where there is a reason to set up a given air supply for the individual and not leave it to his discretion, with a possible waste of air. This type depends upon a setting of the regulator for a given pressure or upon the design of the equipment. The wearer cannot change the supply of air within the facepiece.

III. ABRASIVE BLASTING RESPIRATORS

Abrasive blasting respirators fall into two general designs: (1), a full mask, tight fitting facepiece connected to a supply of air (continuous or possibly demand flow), assembled with a hood and cape of flexible material for protecting the head and shoulders from abrasive rebound; and (2), a rigid, loose fitting helmet covering the head and neck with a loose fitting collar around the neck, the helmet being connected through a hose line to a continuous flow air supply (see Fig. 7.4). The helmet is fitted with a flexible collar or short cape for protection from abrasive rebound. Abrasive blasting respirators are essentially modifications of air line respirators of the continuous flow type. When the letter E is added to type designation of supplied air respirators, such as Type AE and Type CE, it indicates that Type A or Type C respirators were modified for use as abrasive blasting respirators.

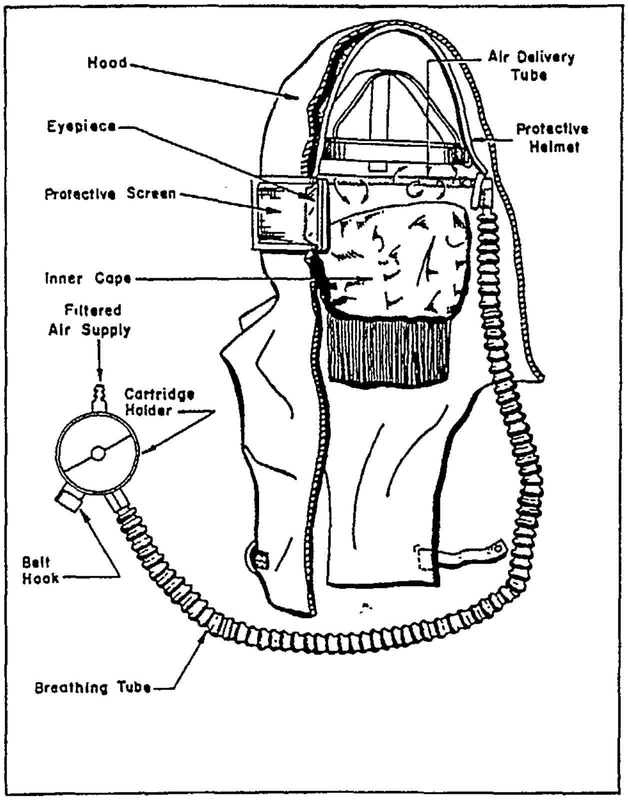

Fig. 7.4. Abrasive blasting respirator of the helmet type.

The quantity of air supplied to an abrasive blasting respirator should be such that a slight positive pressure is maintained at all leakage points so that no contaminant can enter from the outside. Approximately 6 cubic feet per minute (ft^3/min) of free air (ambient pressure) is the minimum requirement by the Bureau of Mines for a well designed, continuous flow, helmet-type, abrasive blasting respirator. The minimum requirement for a demand (Type CE) respirator is 4 ft^3/min of free air.

The manner in which the air enters the helmet is very important and much care must be taken to avoid injection effects that will cause localized low pressure areas inside the helmet, with resulting inflow of external contaminated atmosphere. Within certain ranges, increase in air flow may increase contamination, the reasons being evident from the behavior of nozzles. Considerable attention is being directed to the noise caused by air rushing through the air supply line and the sound being amplified in the helmet. The Bureau of Mines has recently taken this problem under consideration, and each helmet now approved is examined subjectively for discomfort due to noise. Where excessive noise is found, the manufacturer of the helmet is asked to provide muffling or other means for reducing the noise level.

IV. SUPPLIED AIR HOODS

The supplied air hood is similar to the abrasive blasting respirator except that the hood is generally constructed of lighter material, such as duck, other sturdy cloth, or plastic, with a large transparent area for viewing the work. In many instances, such as for paint spraying and use with radioactive materials, these hoods are made of inexpensive materials and are disposable. Many variations in design and materials are available for specific uses. Figure 7.5 illustrates one of the many types that are commercially available.

Various methods of air entry into the hoods are employed. These range from the splash of air on a diffusion plate near the back or top of the hood to the downward and upward flow of air from a number of small streams of air from orifices evenly distributed in the bottom and top of a circular plenum attached to the head frame. One type consists of a flexible vinyl hood without headgear or frame. Air from the supply source inflates the hood like a balloon, causing it to float around the wearer's head. Drawstrings under the chin hold it in place to ensure a snug fit, and there is a large window for viewing the work. This type could be

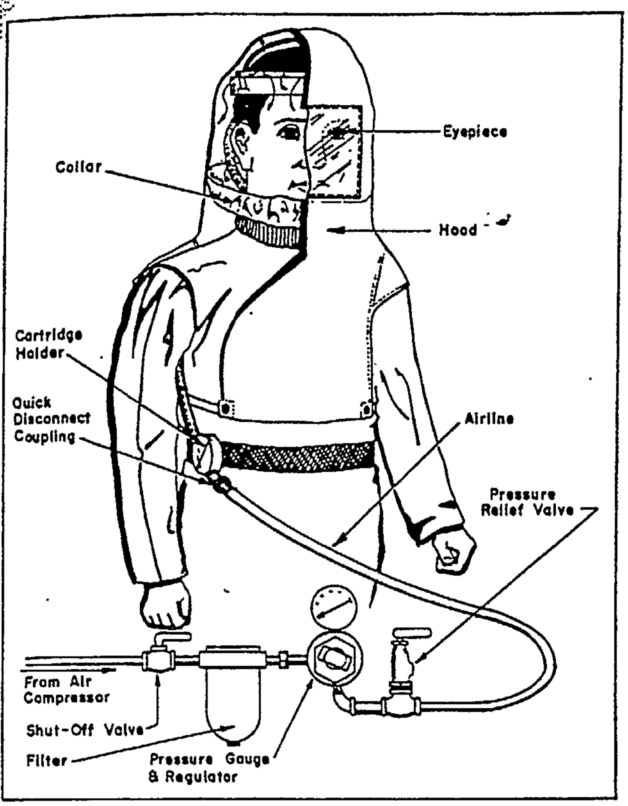

Fig. 7.5. One type of supplied air hood.

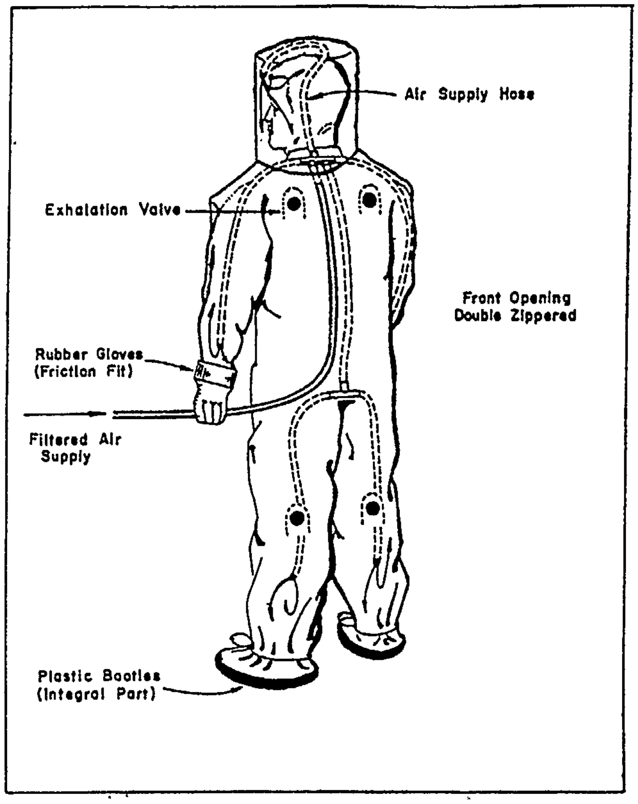

Fig. 7.6. Supplied air suit of continuous flow type.

used for paint spraying operations. The hood acts as a positive pressure chamber which is being continuously purged with fresh air at low velocity.

The Bureau of Mines requirement is 6 ft^3/min of free air (ambient pressure). Only well designed hoods will meet this requirement. Others may require more free air. The control valve is generally supported on the wearer's belt at the lower end of the breathing tube in a position where the user is free to regulate the supply to his own requirements within certain limits. As in other types of supplied air respirators, it is desirable to include a device in the supplied air line to remove odors, mists, and particulates which may arise from the compressor.

V. SUPPLIED AIR SUITS

Supplied air or air-inflated suits are forms of supplied air respiratory protective equipment which provide purified air not only for breathing purposes but also for insulating the whole body from the surrounding atmosphere (see Fig. 7.6). Although these suits are not covered by Bureau of Mines schedules, they are finding increasing use industrially. This type of protection is needed only in the most extreme conditions where there is an exposure to substances that are irritating or corrosive to the skin and mucous membranes and are also toxic or hazardous to life. Examples of such conditions would be the escape of toxic and corrosive gases, like chlorine, beta propiolactone hydrocyanic acid gas, and tritium (H^3). One very specific use of a supplied air suit is in biological laboratories, where the worker is isolated from large scale, dangerous cultures. The isolation of the man from the work rather than the isolation of the work from the man seems to be much more efficient in this instance. In any event, a complete suit of protective clothing plus some arrangement for supplied air must be used.

Another type of supplied air suit is one designed to protect workers from high temperature environments. Suits for fire use should be both insulating and reflective to mitigate the radiant energy of the flames. Various combinations of wool, asbestos, glass fiber, and aluminized cloth with synthetic rubber as a vapor barrier have been offered on the market. Such a suit should be water resistant not only because of its primary use, but also so that it can be worn under a hose stream for cooling without becoming soaked. The wearing of respiratory equipment under or with fire suits will depend on whether they are used for disaster control or for industrial use. If for industrial use, such as repair of a conveyor in a process oven, the conditions may indicate canister gas masks, supplied air respirators, or self-contained breathing apparatus. Disaster fire control usually requires the use of self-contained breathing equipment.

There is more hazard to life in the use of supplied air suits than is ordinarily apparent, particularly if they are used in atmospheres that are immediately hazardous to life. Loss of continuous air supply and deficiency of oxygen caused by rebreathing can cause very rapid onset of unconsciousness and death without significant warning. The need for an adequate continuous supply of clean air to such suits is more important than with other types of supplied air respirators, owing to the small inside diameter of the hose line and the inability of the wearer to get air by his own inspiratory effort. In selecting such suits, attention must also be given to impermeability of the suit material by the harmful agent against which protection is needed. Some materials may be sorbents for a harmful constituent and in that manner enhance permeability.

VI. COMPRESSED AIR SUPPLY

The compressed air supply, whether it is obtained from a compressor directly or from a cylinder of compressed air, can be a source of contamination unless adequate precautions are taken. It is preferable to use equipment which does not need internal lubrication, rather than high pressure compressors as sources of respirable air. Water-lubricated compressors offered by several distributors are safe so far as production of carbon monoxide and oil mists or vapors is concerned. Diaphragm, graphite-ring, and graphite-vane nonlubricated types of compressors are available.

It is necessary to provide a trap and filter on the line side of the compressor to remove oil, water, scale or other extraneous matter before it comes to the regulator or mask. The compressor intake must be kept away from all sources of contamination, including engine exhausts. If an internally lubricated compressor is used, it should be well maintained so as to keep it from overheating to the point of forming dangerous amounts of carbon monoxide. As an extra safeguard, the compressor should be equipped with a temperature-actuated alarm which also can be made to shut off the compressor if it starts to overheat.

Any positive detectable amount of carbon monoxide in air supplies for respiratory protection is a definite sign of some source of contamination. In the absence of valid information to the contrary, such contamination cannot be considered to be a constant value but instead may be considerably higher or lower at other times, depending on a number of factors, such as leaky compression valves, excessive overheating of compressors, pyrolysis or combustion of lubricating oil, and contamination of the compressor intake. The positive finding of as much as 0.005 per cent or 50 parts per million (ppm) of carbon monoxide in air should condemn it for respiratory purposes for three reasons: (1) it can be a possible uncontrolled source of danger; (2) long periods of exposure can produce up to 12 per cent carboxyhemoglobin, which alone is not dangerous but undesirable particularly if there are additional sources of carbon monoxide at the work place, on the streets, or through smoking; and (3) there is no reason for not providing clean air. The finding of 0.001 per cent (10 ppm) could be tolerated, if the source is positively identified and determined to be relatively constant, or if measures are instituted to achieve such control.

For safety practices and precautions recommended for air supplies to air line respirators used in natural gas processing plants, see Bureau of Mines Bulletin 588.[3]

VII. MAINTENANCE AND SUPERVISION

Maintenance and supervision of equipment are very important phases of any protection program, and they are no less important for respiratory protective devices and appurtenances. Rubber and some plastic parts can and do deteriorate rapidly if exposed to oxidizing materials, air pollution, and sunlight. Strain points are usually the first areas to give way. Inhalation and exhalation ports may corrode and cease to operate. Air lines that have not been used for some time, as well as control valves, may tend to clog. Deterioration of rubber parts may occur because of prolonged contact with grease or oil. Filters need periodic replacement; blowers should be regularly inspected and overhauled as required; harnesses should be checked for strength; and all components of the facepiece should be cleaned and disinfected regularly.

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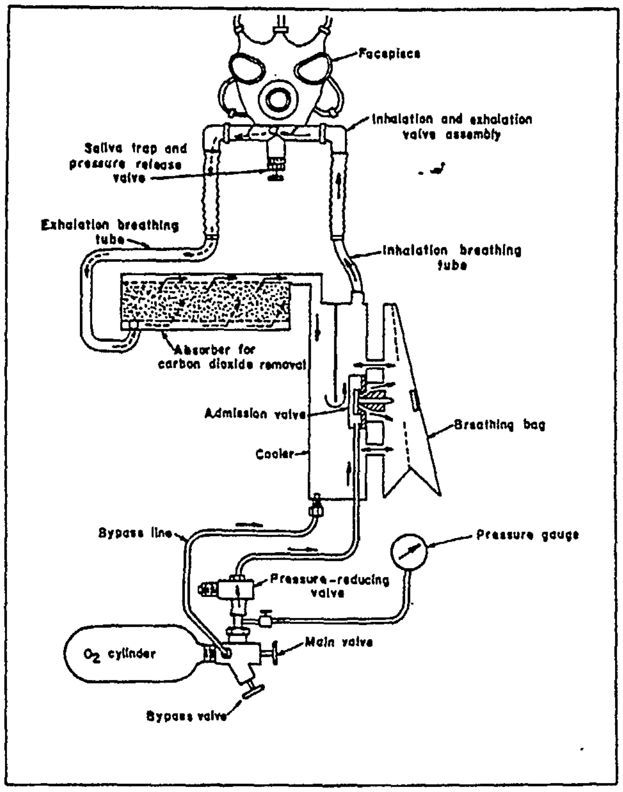

Fig. 8.2. Recirculating compressed oxygen self-contained breathing apparatus.

valve to a breathing bag from which the wearer inhales through a flexible inhalation tube connected either to a mouthpiece or a full facepiece. A check valve allows the oxygen to flow to the facepiece only through the inhalation tube. The wearer's exhaled breath passes through a flexible exhalation tube to a container of chemical that removes the exhaled carbon dioxide. A check valve allows the exhaled breath to flow only from the wearer's breathing zone through the exhalation tube.

After the carbon dioxide has been removed, the exhaled breath passes to a cooler and thence to the breathing bag. Oxygen from the compressed oxygen cylinder enters the breathing bag only when the bag has collapsed sufficiently to cause a pressure plate to press on the stem of the admission valve and open it. The valve closes when the bag is expanded enough so that the pressure plate no longer presses on the stem of the admission valve. Thus, oxygen is recirculated in the apparatus by the wearer's breathing, and oxygen is added to this closed system only as needed. If a mouthpiece is used, the nostrils are closed with a nose clip.

A pressure gauge is located in a convenient position to indicate the pressure in the oxygen cylinder. A manually adjusted bypass valve is provided, by means of which an adjustable flow of oxygen can be delivered to the cooler in the event of failure of the main cylinder valve, the pressure-reducing valve, or the admission valve. A saliva trap and release valve are provided so that the wearer can eliminate accumulated saliva and nitrogen when necessary. (Supplied oxygen may contain as much as 2 per cent of nitrogen, which would build up in the closed system as the oxygen is consumed.) The apparatus is attached to the wearer's body by means of a suitable harness.

C. Oxygen-generating Self-contained Breathing Apparatus

In the oxygen-generating apparatus[2] (see Fig. 8.3), water vapor from the wearer's exhaled breath reacts with a chemical (potassium tetroxide) in a canister to form oxygen, which passes to a breathing bag. When the wearer inhales, oxygen passes from the bag to a full facepiece through a flexible inhalation tube which has a check valve to allow oxygen to flow only to the facepiece. The wearer's exhaled breath passes to the canister through a flexible exhalation tube which has a

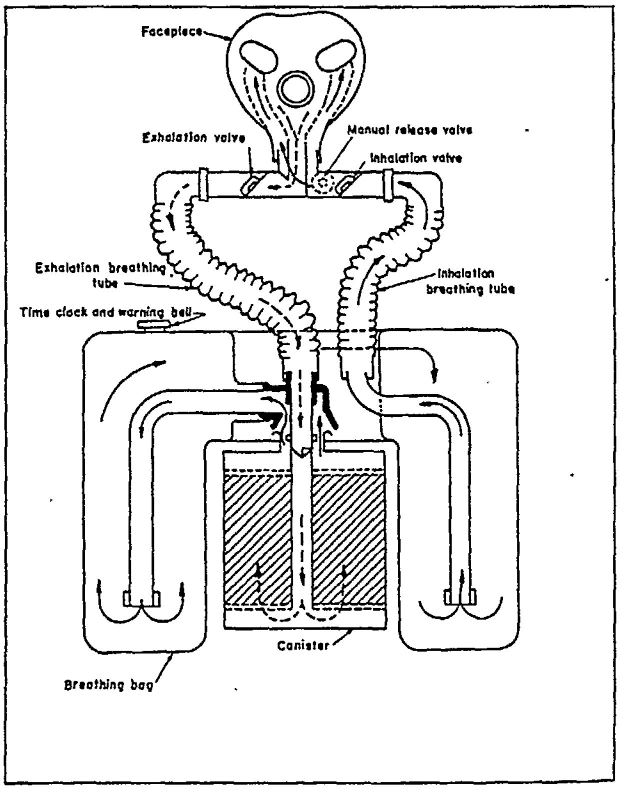

Fig. 8.3. Oxygen-generating self-contained breathing apparatus.

check valve to allow the exhaled breath to flow only to the canister. The chemical in the canister removes the carbon dioxide from the exhaled breath and reacts with the moisture to form oxygen, which then passes to the breathing bag. The rate of evolution of oxygen is governed by the volume rate of breathing of the wearer.

The formulae for the basic chemical reactions involved in generating oxygen in a typical canister are as follows:

$$2KO_2 + CO_2 \ (+H_2O) \rightarrow K_2CO_3 + 3/2 \ O_2 \ (+H_2O)$$

$$2KO_2 + 2CO_2 + H_2O \rightarrow KHCO_2 + 3/2 \ O_2$$

A timer, which is actuated by clockwork and not by the wearer's breathing, gives an audible signal after a preset time. A pressure release valve is provided to release excess pressure and saliva, as well as to purge the apparatus to prevent the accumulation of nitrogen. The apparatus is attached to the wearer's body by means of a suitable harness.

A quick start cartridge has been developed for use with a 30 min oxygen-generating self-contained breathing apparatus to provide quick starting at temperatures as low as -20°F and to enable the wearer to start the apparatus in toxic atmospheres without drawing in outside air. The cartridge, which is filled principally with sodium chlorate and iron, is inserted in a retainer in the apparatus and fired by striking. Burning of the cartridge fill liberates more oxygen than is required to fully inflate the breathing bag so that some oxygen is vented automatically to the atmosphere. This enables the wearer of the apparatus to begin work immediately. The heat from the cartridge further aids the initial canister oxygen production caused by the wearer's exhaled breath.

IV. ADVANTAGES AND LIMITATIONS OF SELF-CONTAINED BREATHING APPARATUS

The self-contained breathing apparatus has no limitation as to the concentration of gaseous or particulate contaminants in which it may be worn. Since the wearer of a self-contained breathing apparatus carries his own supply of respirable atmosphere with him, he may leave the work area through any available exit.

The chief limitations of this type of apparatus are weight and bulkiness, limited service life, and the training required for its maintenance and safe use. The self-contained breathing apparatus provides only respiratory protection. If used in gases that may be absorbed through the intact skin, such as hydrocyanic acid gas, or in gases that burn or blister the skin, adequate body protection must be afforded by other means.

V. FACTORS AFFECTING THE USE OF SELF-CONTAINED BREATHING APPARATUS

The weights of the various types of self-contained breathing apparatus range from 13.5 to 40 lb. Some models of approved self-contained breathing apparatus have the breathing bag and oxygen supply located on the chest and abdomen of the wearer, and other models have them located on his back. In choosing apparatus for a particular job, consideration should be given to the effect of the location of the bulky parts of the apparatus and of the size and weight of the apparatus on the wearer's ability to perform the job efficiently and safely.

Each self-contained breathing apparatus that has been approved by the Bureau of Mines is rated according to the length of time that it will afford respiratory protection while the user is performing strenuous manual labor. The length of time that the various types may be safely used without replenishing the source of respirable air or oxygen ranges from 30 min for the demand type to 2 hr for one model of the recirculating type. Severe emotional strain or extreme exertion might cause the wearer to use up the available air or oxygen in less than the rated time. On the other hand, the apparatus will afford respiratory protection for much longer than the rated time if the wearer is calm and his activity is only moderate. Practical weight and bulk restrictions limit the quantity of air or oxygen that can be carried by the wearer and, hence, limit the safe operating period for self-contained breathing apparatus.

When used in the conventional manner, self-contained breathing apparatus that supplies oxygen from a cylinder cannot be used with safety for a practicable period in situations where the pressure of the ambient atmosphere is more than 2 atmospheres absolute because of the danger of oxygen poisoning.[3] However, the Bureau of Mines has developed a modified technique by means of which the 2 hr self-contained oxygen breathing apparatus can be worn safely for 1 hr or more where the pressure of the ambient atmosphere is as high as 4 atmospheres absolute.[4]

The modified technique is based on flushing the apparatus with air at atmospheric pressure and donning the facepiece, or mouthpiece and nose clip, in the pressure lock at the working pressure before entering the pressurized contaminated atmosphere. The air contained in the lungs and breathing tubes of the apparatus serves to dilute and reduce the partial pressure of the oxygen in the closed breathing system below that which would cause oxygen poisoning. It is essential that the diluting air thus trapped in the closed system be maintained throughout the period at elevated pressure, and that the apparatus at no time during this period be purged with oxygen.

Under high ambient pressures, the period of use of demand type of self-contained breathing apparatus that supplies air is restricted because the rate at which the air is used from the compressed air cylinder is directly proportional to the absolute pressure of the ambient atmosphere. Thus, the air supply in a conventional demand apparatus, which would be adequate for 30 min at sea level pressure, would be used up in 15 min under the same working conditions at 2 atmospheres absolute or 14.7 pounds per square inch gauge (psig) and in 10 min at 3 atmospheres absolute or 29.4 psig. The use of a larger air cylinder or of multiple air cylinders would prolong the period of use of the apparatus, but the added weight and bulk would hamper the wearer.

Self-contained breathing apparatus are much more complex and complicated than the other types of respiratory protective devices. Furthermore, they are designed for use in highly dangerous atmospheres. Hence, no one can safely use these apparatus unless he is physically fit and well trained in the care, use, and limitations of the apparatus. In almost all cases where men have encountered serious difficulties while wearing self-contained breathing apparatus, the difficulties could be traced to one or more of the following factors: poor physical condition of the wearer, poorly assembled or otherwise defective apparatus, lack of or improper training, or improper procedure.[5]

Self-contained underwater breathing apparatus (SCUBA) should not be used as a substitute for approved self-contained breathing apparatus, since SCUBA is not designed for respiratory protection against atmospheric contaminants.

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Chapter 9

U. S. BUREAU OF MINES APPROVAL SCHEDULES AND TESTS

I. APPROVAL SYSTEM FOR RESPIRATORY PROTECTIVE DEVICES

The Bureau of Mines has in operation five schedules under which specific types of respiratory protective devices are tested and approved. These schedules cover self-contained breathing apparatus,[1] gas masks,[2] supplied air respirators,[3] dispersoid (particulate) respirators,[4] and chemical cartridge respirators, including paint spray respirators.[5] The Bureau has no regulatory power requiring that all respirators must be submitted to it for approval testing. Submitting respiratory protective devices to the Bureau of Mines for approval is entirely voluntary on the part of the manufacturer. The Bureau acts as an impartial testing agency that serves by making available to the public a list of respiratory protective devices that have met definite published performance requirements.

These performance requirements are based on the field of use of the respirator and on the three following fundamental requirements for a satisfactory device: (1) it must provide adequate protection for a suitable period, (2) it must be reasonably comfortable and convenient to wear, and (3) it must be constructed of durable materials. The performance requirements are set forth in the pertinent schedules.

The Bureau of Mines offers free consulting service to manufacturers contemplating the development and manufacture of respiratory protective devices which are later to be submitted for testing and approval. A fee is charged for the approval testing.

After all the pretest requirements of a respirator have been met, the Bureau tests the respirator according to the requirements of the pertinent schedule. If the respirator meets these requirements, the manufacturer is notified that the respirator has been approved, and copies of the official approval plate or plates are sent to the manufacturer.

These approval plates give the limitations of the approval, such as the type and maximum concentration of gas in which a gas mask may be worn, or a statement such as that on the approval label of a Type C supplied air respirator: "Approved for respiratory protection in any atmosphere not immediately harmful or from which the wearer can escape unharmed without the aid of the respirator." The label lists the approval marking on the parts that make up the approved assembly, and it lists any special precautions that should be taken when using the respirator (see Figs. 9.1 and 9.2 for typical labels). If a respirator is used under conditions other than those covered by the approved label, the approval of that individual respirator is invalidated.

The Bureau of Mines approval applies only to a respiratory protective device as a unit and not to its integral parts. For instance, if approvals were granted to four respirator manufacturers A, B, C, and D on four entirely different universal gas masks, an assembly of A's canister harness, B's canister, C's timer or external check valve, and D's facepiece would not constitute an approved assembly, even though the individual items were parts of approved gas masks.

To maintain the approval status of a respirator, the manufacturer must make the respirator

PERMISSIBLE RESPIRATOR
FOR
DUSTS

U.S. DEPARTMENT OF THE INTERIOR — BUREAU OF MINES

APPROVAL **NO. 2100**

ISSUED TO THE
MANUFACTURER'S NAME
Address

Approved for protection against the inhalation of dusts that are not significantly more toxic than lead (dispersoids or particulate matter formed by the disintegration of solid materials by such processes as crushing, grinding and abrading).

The approved assembly consists of: BM-2100 facepiece and BM-2100 filter.

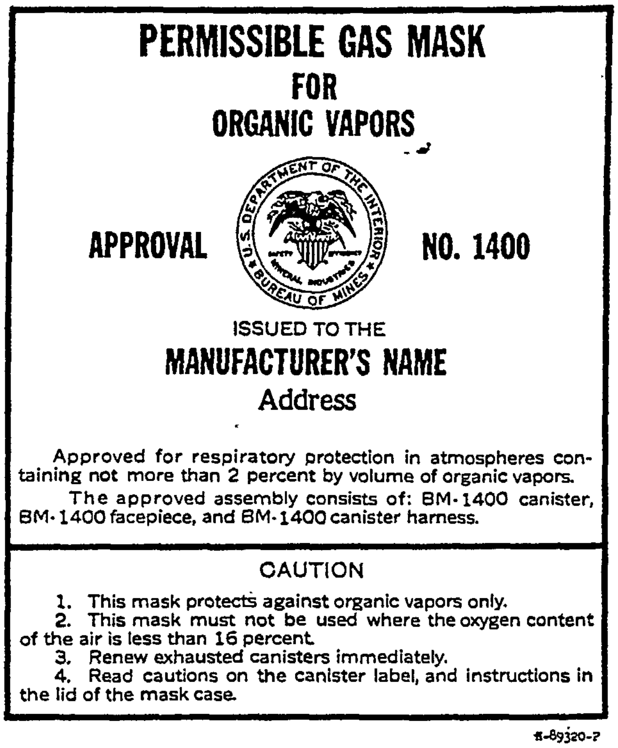
In making renewals or repairs, parts identical with those furnished by the manufacturer under the pertinent approval shall be maintained.

CAUTION

This respirator removes only dispersoids from the air. It gives no protection against gases, vapors, or an insufficiency of oxygen.

Follow the manufacturer's instructions for fitting the respirator to the face, for changing the filter, for cleaning the respirator, and for caring for it while not in use.

Fig. 9.1. Dust respirator approval label. (Courtesy U.S. Bureau of Mines)


PERMISSIBLE GAS MASK
FOR
ORGANIC VAPORS

APPROVAL NO. 1400

ISSUED TO THE
MANUFACTURER'S NAME
Address

Approved for respiratory protection in atmospheres containing not more than 2 percent by volume of organic vapors.

The approved assembly consists of: BM-1400 canister, BM-1400 facepiece, and BM-1400 canister harness.

CAUTION

1. This mask protects against organic vapors only.
2. This mask must not be used where the oxygen content of the air is less than 16 percent.
3. Renew exhausted canisters immediately.
4. Read cautions on the canister label, and instructions in the lid of the mask case.

Fig. 9.2. Organic vapor mask label. (Courtesy U.S. Bureau of Mines)

according to the drawings, design, and model that were submitted to the Bureau and that were considered and included in the original approval or subsequent extensions of approval. If the manufacturer desires to make any change in the design of an approved respirator, prior approval of the change must be obtained. From time to time, approved respirators are purchased on the open market. They are tested and inspected to ascertain whether or not they conform to the approved respirator in physical make-up and performance.

II. TEST METHODS

As stated at the beginning of this chapter, the performance requirements for the various types of respiratory protective devices that may be approved by the Bureau of Mines are set forth in the pertinent Bureau of Mines schedules.[1-5] These schedules should be consulted for full details of the performance requirements. The remainder of this chapter discusses the main points that are considered during the approval testing of the various types of respiratory protective devices. Tables list the more significant test conditions and performance requirements.

A. Self-contained Breathing Apparatus

Most of the approval tests made on self-contained breathing apparatus are man tests; that is, they are made while the apparatus is being worn by men. The tests are designed to provide answers to the following questions regarding the performance of the apparatus:

1. Will the apparatus supply air or oxygen fast enough to meet the needs of the wearer?
2. Can the wearer breathe freely at all times?
3. Does the temperature of the inspired air remain within prescribed limits? (The temperature of the inspired atmosphere shall not exceed 110°F when the temperature of the ambient atmosphere does not exceed 85°F.)
4. Are vital parts of the apparatus protected so as to prevent damage or excessive wear?
5. Is the concentration of carbon dioxide in the inspired air within prescribed limits? (See Table 9.1)
6. Does the harness hold the apparatus on the wearer's body without undue discomfort to him?
7. For what period of time will the apparatus provide adequate respiratory protection for the wearer under the test conditions?

The men who wear the apparatus during the man tests must first pass a physical examination by a qualified physician. They then put on the apparatus and perform definite timed schedules of exercise that include walking, running, carrying and lifting weights, sawing wood, crawling, and lying in various positions. This is done in a test space containing an irrespirable formaldehyde—air atmosphere.

The specific activities of the test subject and the duration of each activity for the 15 tests are given in Tables 9.2 through 9.6. During the 2 minute (min) periods for "sampling and readings" samples of the atmosphere within the apparatus are taken, and readings are made of the temperature of the inspired air, as well as the pulse and frequency of respiration of the wearer. The atmosphere within the apparatus is sampled as near to the point of inspiration as practicable, only while the wearer is inhaling and over a period covering several inhalations. The limits for the carbon dioxide content of these samples are given in Table 9.1.

Each self-contained breathing apparatus, except the oxygen-generating type, must be equipped with a bypass valve that will permit an adjustable flow of compressed oxygen or air from the gas cylinder to the circulatory system of the apparatus independent of the pressure reducing valve. The maximum acceptable weight of a fully charged self-contained breathing apparatus is 40 pounds (lb).

TABLE 9.1

LIMITS FOR CARBON DIOXIDE CONTENT OF ATMOSPHERE WITHIN SELF-CONTAINED BREATHING APPARATUS DURING APPROVAL TESTS

Type of Apparatus	Carbon Dioxide, % Inhalation Tube Maximum[a]	Inhalation Tube Average[a]	Facepiece Maximum[b]	Facepiece Average[b]
Recirculating with mouthpiece	2.5	1.0	--	--
Recirculating with facepiece	2.5	1.0	2.5	2.0
Demand with mouthpiece	2.5	1.0	--	--
Demand with facepiece	--	--	2.5	2.0

a. From inhalation tube near point of inspiration.
b. From interior of facepiece near nose and mouth of wearer.

B. Gas Masks

The approval tests of gas masks may be divided into two groups: machine tests of the canisters and man tests of the facepiece and the complete gas mask.

The continuous flow machine tests on gas mask canisters are of two types: tests with low concentrations and low rates of flow and tests with high concentrations and high rates of flow. The low concentration, low rate of flow tests are primarily to determine the capacity and retentivity of the sorbents. The high concentration, high rate of flow tests are primarily to determine the activity of the sorbents (see Chapter 5).

Some tests are made to determine the effect of passing either dry air (25 per cent relative humidity) or moist air (85 per cent relative humidity) through the canisters for several hours. Canisters tested by machine must not allow more than 5 parts per million (ppm) of the test gas (100 ppm for ammonia) to penetrate them before the end of a specified minimum test period. The inhalation resistances of the canisters to an air flow of 85 liters per minute (l/min) must not exceed 3 inches (in.) of water (3.25 in. of water for universal gas mask canisters or canisters with special mechanical filters) at any time during the machine test.

Special machine tests are made on universal gas mask canisters to determine the protection afforded to the catalyst (hopcalite) against water vapor, which adversely affects its ability to promote the conversion of carbon monoxide to carbon dioxide (see Fig. 9.3).

A summary of the test conditions and performance requirements for machine tests of gas mask canisters is given in Tables 9.7 and 9.8.

To detect any gross leakage, the facepiece is attached to an ammonia gas mask canister and is worn by 15 to 20 men (with widely varying facial shapes and sizes) in a mixture of 1 per cent ammonia gas in air. Each of the 15 to 20 men must obtain a gas-tight fit; otherwise, the device is not approved. The complete gas mask is then assembled with an appropriate canister and canister carrying harness and is worn by the same group

TABLE 9.2

DURATION OF SPECIFIC ACTIVITIES FOR TESTS 1 THROUGH 4 OF SELF-CONTAINED BREATHING APPARATUS

Wearer Activity	Duration, min Type A	Type B	Type C	Type D
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	8	13	18	28
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	8	12	17	28
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	6	12	17	28
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	--	--	--	26
Sampling and readings	--	--	--	2
Total	30	45	60	120

Type A is 1/2 hr apparatus.
Type B is 3/4 hr apparatus.
Type C is 1 hr apparatus.
Type D is 2 hr apparatus.

TABLE 9.3

DURATION OF SPECIFIC ACTIVITIES FOR TESTS 5 THROUGH 8
OF SELF-CONTAINED BREATHING APPARATUS

Wearer Activity	Duration, min			
	Type A	Type B	Type C	Type D
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	2	3	6	10
Carries 50 lb weight over overcast[a]	2 times in 4	3 times in 6	4 times in 8	5 times in 10
Walks at 3 miles/hr	2	4	4	10
Sampling and readings	2	2	2	2
Carries 45 lb weight and walks at 3 miles/hr	2	3	4	8
Raises 45 lb weight 5 ft vertically	30 times in 2	45 times in 3	60 times in 4	75 times in 5
Saws wood as indicated	2	6	10	15
Sampling and readings	2	2	2	2
Carries 50 lb weight over overcast[a]	3 times in 6	4 times in 8	5 times in 10	10 times in 20
Walks at 3 miles/hr	2	4	6	8
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	--	--	--	24
Sampling and readings	--	--	--	2
Total	30	45	60	120

a. A passage through which the ventilating current is conveyed over an entry or air course in a mine. This overcast is 6 ft high and 24 ft long.

TABLE 9.4

DURATION OF SPECIFIC ACTIVITIES FOR TESTS 8 THROUGH 11
OF SELF-CONTAINED BREATHING APPARATUS

Wearer Activity	Duration, min			
	Type A	Type B	Type C	Type D
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	2	3	4	5
Crawls as indicated	25 ft in 3	40 ft in 4	60 ft in 6	100 ft in 10
Lies on his side	2	4	5	10
Lies on his back	1	2	3	5
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	2	6	6	10
Runs at 6 to 8 miles/hr	300 ft in 1	400 ft in 2	600 ft in 3	600 ft in 3
Walks at 3 miles/hr	3	4	7	15
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	2	3	6	10
Carries 50 lb weight over overcast[a]	2 times in 4	3 times in 6	4 times in 8	5 times in 10
Walks at 3 miles/hr	2	3	4	8
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	--	--	--	24
Sampling and readings	--	--	--	2
Total	30	45	60	120

a. A passage through which the ventilating current is conveyed over an entry or air course in a mine. This overcast is 6 ft high and 24 ft long.

TABLE 9.5

DURATION OF SPECIFIC ACTIVITIES FOR TESTS 12 THROUGH 14 OF SELF-CONTAINED BREATHING APPARATUS

Wearer Activity	Duration, min			
	Type A	Type B	Type C	Type D
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	1	2	2	8
Runs at 6 to 8 miles/hr	300 ft in 1	300 ft in 1	600 ft in 2	600 ft in 2
Raises 45 lb weight 5 ft vertically	30 times in 2	45 times in 3	60 times in 4	75 times in 5
Carries 45 lb weight as indicated	200 ft in 1	400 ft in 2	400 ft in 2	1,000 ft in 5
Carries 50 lb weight over overcast[a]	2 times in 4	2 times in 4	4 times in 8	5 times in 10
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	2	2	4	8
Carries 50 lb weight over overcast[a]	2 times in 3	6 times in 9	8 times in 12	10 times in 15
Raises 45 lb weight 5 ft vertically	30 times in 2	45 times in 3	60 times in 4	75 times in 5
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	2	3	4	8
Raises 45 lb weight 5 ft vertically	30 times in 2	45 times in 3	60 times in 4	75 times in 5
Walks at 3 miles/hr	2	5	6	15
Sampling and readings	2	2	2	2
Walks at 3 miles/hr	--	--	--	24
Sampling and readings	--	--	--	2
Total	30	45	60	120

a. A passage through which the ventilating current is conveyed over an entry or air course in a mine. This overcast is 6 ft high and 24 ft long.

TABLE 9.6

DURATION OF SPECIFIC ACTIVITIES FOR TEST 15 OF SELF-CONTAINED BREATHING APPARATUS

Wearer Activity	Duration, min			
	Type A	Type B	Type C	Type D
Sampling and readings	2	2	2	2
Sits quietly	8	12	18	28
Sampling and readings	2	2	2	2
Sits quietly	8	13	18	28
Sampling and readings[a]	2	2	2	2

a. Wearer continues sitting quietly. Samples and readings are taken at the same listed intervals until the supply of compressed oxygen or compressed air is exhausted.

of men in a 2 per cent phosgene gas—air mixture for a more severe test of the gas-tightness of the facepiece and of its ability to fit various types of faces. The gas mask is worn for 2 min in the maximum concentration of each type of gas to be covered by the approval. As a final test, the inlets of two canisters are attached to the chamber containing the same gas—air mixture, facepieces with long breathing tubes are attached, and two men wear the facepieces while performing the schedule of exercise listed in Table 9.9 (see Fig. 9.4).

To meet the requirements of this test, the gas masks must give complete respiratory protection to the wearers for 30 min for all types except the universal gas mask, which shall give complete respiratory protection against carbon monoxide for 30 min, organic vapors for 25 min, acid gases for 15 min, and ammonia for 15 min. Complete respiratory protection means that the wearers of the gas masks shall not detect the test gas or vapor by odor, taste, or eye or throat irritation, and that they shall experience no subjective or objective effects attributable to carbon monoxide when testing the gas masks against this gas. Excessive fogging of the eyepieces must not occur, and undue discomfort must not be experienced because of the

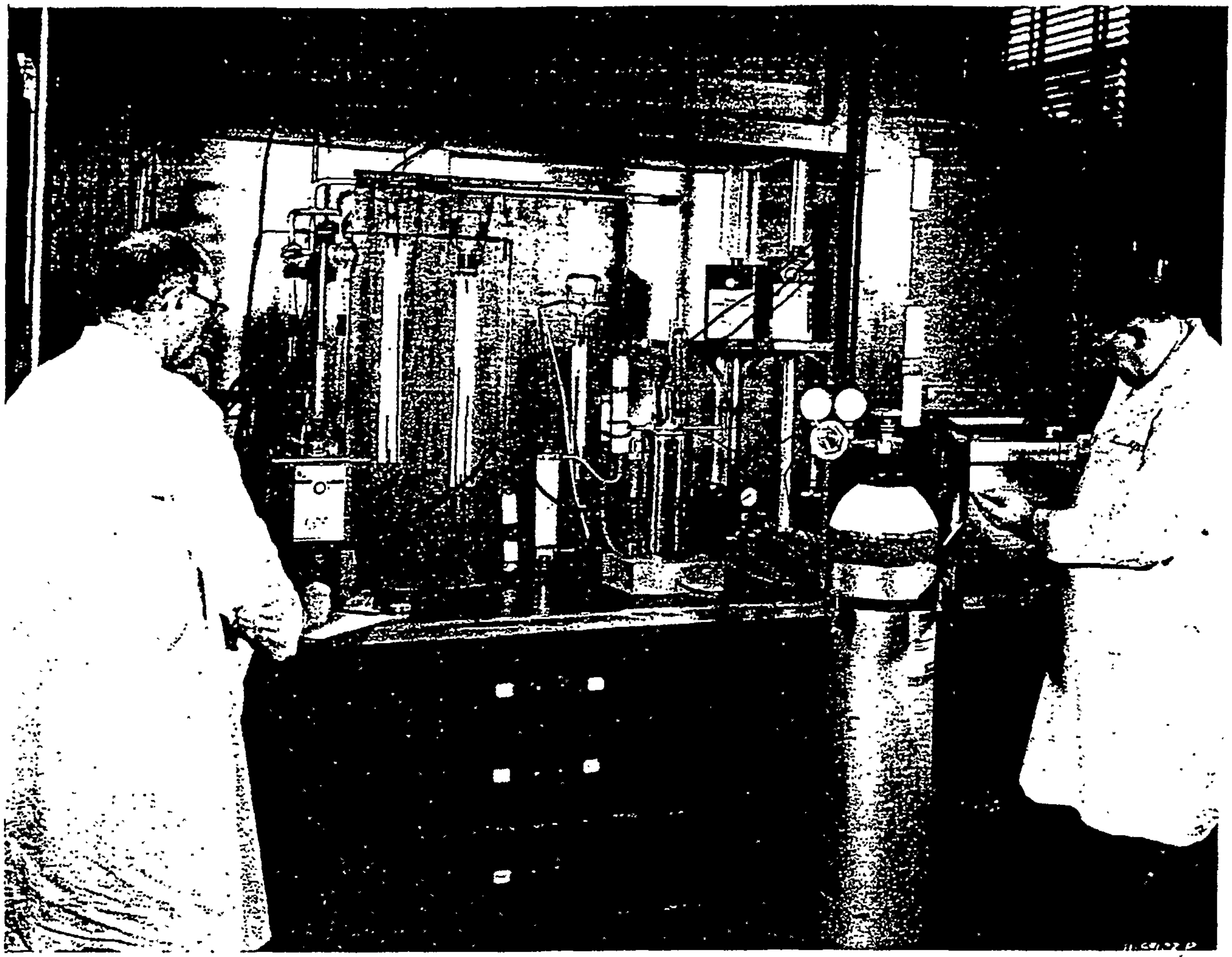


Fig. 9.3. Test equipment used to determine effectiveness of universal gas mask canisters against carbon monoxide—air mixtures. (Courtesy U.S. Bureau of Mines)

fit or other physical or mechanical features of the gas mask.

C. Supplied Air Respirators

The mechanical tests of supplied air respirators are designed to provide the following information regarding the performance characteristics of supplied air respirators:

1. The air flow characteristics; that is, the rates of flow of air to the breathing zone of the wearer with various lengths of air supply line and with either the hand-operated blower for the hose mask operated at several different crank speeds or with various air pressures applied to the inlet of the air supply line for air line or abrasive blasting respirators.

2. The strength and noncollapsibility of the air supply line and its resistance to permeation by liquid gasoline.

3. The strength of the body harness of the hose mask.

Some of the more significant test conditions and performance requirements for mechanical tests of supplied air respirators are listed in Table 9.10.

Man tests provide information regarding the fit of facepiece, helmet, or hood; the distribution of air in the facepiece, helmet or hood; the available clarity and field of vision; other factors that might influence the safety and convenience of the wearer; and, primarily, the degree of respiratory protection afforded the wearer.

Man tests in a 1 per cent ammonia—air atmosphere and in a silica dust—air atmosphere are made on all types of supplied air respirators.

TABLE 9.7

TEST CONDITIONS AND PERFORMANCE REQUIREMENTS FOR MACHINE TESTS ON GAS MASK CANISTERS AT LOW CONCENTRATIONS AND LOW RATES OF FLOW[a]

Type of Canister and Gas or Vapor	Concentration, %	Maximum Leakage Allowed	Minimum Life, min: Regular Test	Minimum Life, min: After Equilibration[b]
A: Acid gas				
Chlorine	0.5	5 ppm	88[c]	44
Hydrogen cyanide	0.5	5 ppm	88	44
Sulfur dioxide	0.5	5 ppm	88[c]	44
B: Organic vapor				
Carbon tetrachloride	0.5	5 ppm	96	48
C: Ammonia	2.0	100 ppm	36	18
D: Carbon monoxide				
Regular service	1.0	770 cm^3[d]	240	--
	0.5	770 cm^3[d,e]	60	--
Self-rescue	1.0	770 cm^3[d]	60	--
	0.5	770 cm^3[d,e]	30	--
AB,AC,BC,ABC	--	--	f	Half of regular test
N: Universal				
Chlorine	0.5	5 ppm	44	--
Hydrogen cyanide	0.5	5 ppm	44	--
Sulfur dioxide	0.5	5 ppm	44	--
Carbon tetrachloride	0.5	5 ppm	48	--
Ammonia	2.0	100 ppm	18	--
Carbon monoxide	1.0	770 cm^3[d]	240	--
	0.5	770 cm^3[d,e]	60	--

a. Relative humidity of test atmosphere, 50 $\pm$ 5 per cent; temperature, room temperature (approximately 25°C); rate of air flow, 32 l/min continuous flow; number of canisters, three for each test atmosphere.

b. Canister was equilibrated with air of 25 or 85 per cent relative humidity.

c. This value is for canisters on which approval for the maximum permissible concentration is desired. It should be reduced proportionately for canisters on which approval for a lower concentration is desired. For example, the minimum life would be 44 min for canisters on which approval for a concentration of 1 per cent is desired.

d. This represents total carbon monoxide leakage for entire minimum life period shown in next column. In terms of concentration, it is equivalent to a uniform flow of 0.04 per cent carbon monoxide for 1 hr at 32 l/min. Maximum leakage shall not exceed 1,000 ppm.

e. This test is made to determine the activity of the catalyst, which effects the oxidation of carbon monoxide to carbon dioxide, under the adverse condition of a low temperature. The canister and precooling coil for the entering test atmosphere are immersed in an ice-water bath. The relative humidity of the test atmosphere is 100 per cent at 0°C.

f. These combination gas canisters must meet the life requirements for each type of contaminant against which they are designed to give protection.

TABLE 9.8

TEST CONDITIONS AND PERFORMANCE REQUIREMENTS FOR MACHINE TESTS ON GAS MASK CANISTERS AT HIGH CONCENTRATIONS AND HIGH RATES OF FLOW[a]

Type of Canister and Gas or Vapor	Maximum Approval Concentration, %	Maximum Leakage Allowed	Minimum Life, min.
A: Acid gas			
Chlorine	2.0	5 ppm	11
Hydrogen cyanide	2.0	5 ppm	11
Phosgene	2.0	5 ppm	11
Sulfur dioxide	2.0	5 ppm	11
B: Organic vapor			
Carbon tetrachloride	2.0	5 ppm	12
C: Ammonia	3.0	100 ppm	12
D: Carbon monoxide			
Regular service	2.0	$770 cm^3$ [b]	15
Self-rescue			No test
AB,AC,BC,ABC	--	--	c
N: Universal			
Chlorine	2.0	5 ppm	5.5
Hydrogen cyanide	2.0	5 ppm	5.5
Phosgene	2.0	5 ppm	5.5
Sulfur dioxide	2.0	5 ppm	5.5
Carbon tetrachloride	2.0	5 ppm	6
Ammonia	3.0	100 ppm	6
Carbon monoxide	2.0	$770 cm^3$ [b]	15

a. Relative humidity of test atmosphere, 50 ± 5 per cent; temperature, room temperature (approximately 25°C); concentration of gas or vapor: concentration for which approval is requested; rate of air flow, 64 l/min continuous flow; number of canisters, two for each test atmosphere.

b. This represents total carbon monoxide leakage for entire minimum life period shown in next column. Maximum leakage shall not exceed 1,000 ppm.

c. These combination gas canisters must meet the life requirements for each type of contaminant against which they are designed to give protection.

In addition, man tests involving a sandblasting operation are made on the abrasive blasting (Type CE) respirators. For the first test, the air flow of tight fitting facepieces is maintained at 4 cubic feet per minute (ft^3/min) and for helmets or hoods at 6 ft^3/min. Each test is repeated with the maximum air pressure applied to the minimum length of air supply hose.

The protection afforded by the respirator during the man tests against the 1 per cent ammonia—air atmosphere is evaluated by the wearer's subjective observations. The respiratory protection afforded during the man tests against a silica dust aerosol and during a sandblasting operation is evaluated by sampling the air within the facepiece, helmet, or hood, at 32 l/min, as close as possible to the breathing zone of the wearer. The net amount of particulate matter in the air so sampled for 30 min must not exceed 0.5 milligram (mg).

TABLE 9.9

SCHEDULE OF EXERCISE FOR MAN TESTS OF GAS MASKS

Activity	Duration, min			
	Universal (Against Carbon Monoxide)	Universal (Against Organic Vapors)	Universal (Against Acid Gases and Ammonia)	All Other Gas Masks[a]
Walking vigorously	5	5	5	5
Sitting at rest	5	5	5	5
Stationary running and calisthenic arm movements	10	5	5	10
Sitting at rest	5	5	--	5
Pumping air with a hand-operated tire pump into a 1 ft^3 cylinder to a pressure of 25 psig or equivalent work	5	5	--	5
Total	30	25	15	30

a. Whether for a single contaminant or a specified combination of contaminants.

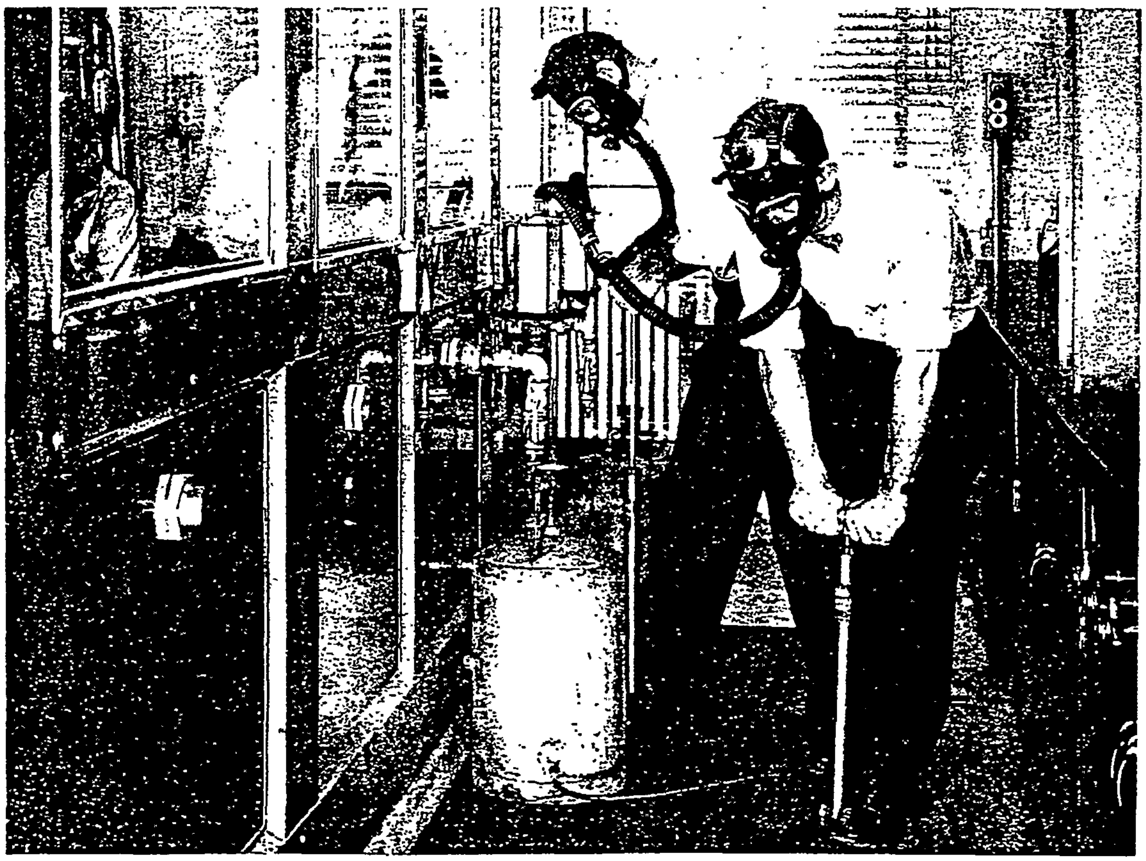


Fig. 9.4. One of the man tests for gas mask canisters. Men are in fresh air with canisters attached to a 1,000 ft^3 gas chamber as reservoir of test atmosphere. (Courtesy U.S. Bureau of Mines)

TABLE 9.10

TEST CONDITIONS AND PERFORMANCE REQUIREMENTS FOR MECHANICAL TESTS OF SUPPLIED AIR RESPIRATORS[a]

Respirator	Maximum Hose Length, ft	Maximum Air Pressure at Hose Inlet, psig	Air Flow to Breathing Zone, ft^3/min	Pull Strength of Hose and Couplings, lb	Resistance, in. of H_2O	
					Inhalation	Exhalation
Type A: Hose mask with blower	150	0.18	At least 1.8 with blower hand-operated at < 50 rpm	250	2.5 at 85 l/min	1 at 85 l/min
Type B: Hose mask without blower	75	Atmospheric	Regulated by wearer's breathing	250	1.5 at 85 l/min	1 at 85 l/min
Type C: Air line respirator						
Continuous flow class	250	25[b]	4 (facepiece) 6 (helmet or hood)	100	--	1 at 170 l/min
Demand class	250	125	Regulated by wearer's breathing	100	2 at 115 l/min	1 at 85 l/min
Type CE: Abrasive blasting respirator						
Continuous flow class	250	25[b]	4 (facepiece) 6 (helmet or hood)	100	--	1 at 85 l/min
Demand class	250	125	Regulated by wearer's breathing	100	2 at 115 l/min	1 at 85 l/min

a. The permeation of the hose by gasoline is tested by immersing 25 ft of hose and a coupling in liquid gasoline and passing air through the hose at 8 l/min for 6 hr for Types A and B and for 1 hr for Types C and CE. The air from the hose must now show more than 0.1 per cent gasoline vapor by volume at the end of this period.

b. For the majority of approved continuous flow respirators, the maximum inlet pressure is 25 psig.

D. Dispersoid Respirators

The approval tests on dispersoid respirators are set up as follows:

The face-contacting edges of the respirator are sealed to a test fixture so that all air drawn through the respirator will pass through an electrostatic precipitator which will collect any unretained dispersoid in this air and allow it to be quantitated. The physical characteristics of the test aerosols (dispersoids suspended in air) simulate those that might be encountered in the use of the respirator. The aerosol is drawn to the respirator at a steady rate of 32 l/min for set periods. The amount of unretained dispersoid, and the exhalation and inhalation resistance of the respirator before and after the above test, are determined. The respirator is worn by 15 to 20 men with widely varying facial shapes and sizes as a check on its face fitting qualities (see Figs. 9.5 and 9.6).

Some respirators are tested and approved for

Fig. 9.5. Use of dioctyl phthalate (DOP) smoke to locate and quantitate leakage where aerosol respirator contacts face. The penetrometer gives an instaneous reading of DOP leakage. (Courtesy U.S. Bureau of Mines)

protection against only one type of dispersoid, whereas others are approved for protection against two or more types.

The test aerosols used, and the types of dispersoid covered by the approval granted on respirators which are tested against these aerosols, are listed in Table 9.11.

E. Chemical Cartridge Respirators

The approval tests on chemical cartridge respirators for organic vapors, which are the only type approved at present, are similar, in general, to those described for gas masks except that the test concentrations are lower. Some chemical cartridge respirators are approved for respiratory protection against dispersoids in addition to gases or vapors after having been tested by methods described for dispersoid respirators. Still other respirators are approved for protection against paint spray after having been tested against carbon tetrachloride vapor and against aerosols made by atomizing lead paint, enamel, and lacquer (see Fig. 9.7).

The inhalation resistance of the respirator to an air flow of 85 l/min must not exceed 2 in. of water for those without dispersoid filters or 3 in. of water for those with dispersoid filters. The exhalation resistance of both types of respirator must not exceed 1 in. of water at the same air flow rate.

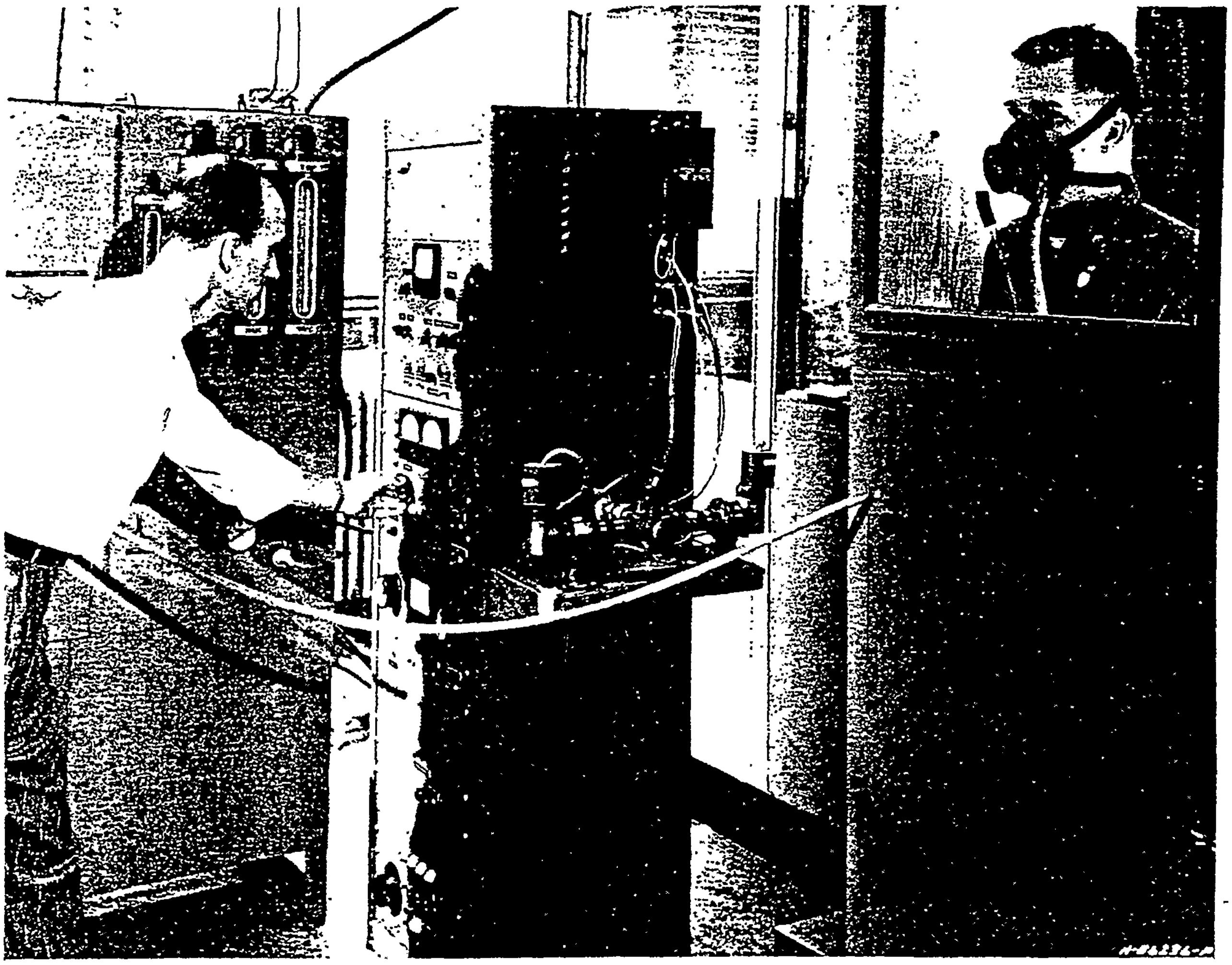


Fig. 9.6. Illustrating use of DOP smoke generator and penetrometer to quantitate over-all peripheral face seal. (Courtesy U.S. Bureau of Mines)

The test conditions and performance requirements for machine tests of chemical cartridge respirators for organic vapors are listed in Table 9.12.

The test conditions and performance requirements for machine tests of dispersoid filters for paint spray respirators are listed in Table 9.13.

The respirator is worn by 15 to 20 men with widely varying facial shapes and sizes to test the suitability of the fit of the respirator to their faces. Eight of these men then wear the respirator in an atmosphere containing 0.01 per cent (100 ppm) isoamyl acetate vapor for 10 min while walking, moving their heads from side to side, nodding, bending the body at the waist, and pump-air with a hand-operated tire pump. To meet the requirements of this test, no isoamyl acetate shall be detected by odor in the air breathed, and undue encumbrance and discomfort shall not be experienced because of the fit or other features of the respirator. The respirator, with fresh cartridges, is then worn by two men in an atmosphere containing 0.5 per cent (5,000 ppm) carbon tetrachloride vapors while the men perform the schedule of exercise listed in Table 9.14.

To meet the requirements of this test, the respirators shall give complete respiratory protection to the wearers for 30 min. Undue discomfort must not be experienced because of fit or other physical or mechanical features of the respirator.

TABLE 9.11

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 μ; $\sigma_g = 1.9$	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 μ; $\sigma_g = 1.9$	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.

TABLE 9.12

TEST CONDITIONS AND PERFORMANCE REQUIREMENTS FOR MACHINE TESTS OF CARTRIDGES OF ORGANIC VAPOR CHEMICAL CARTRIDGE RESPIRATORS[a]

Test	Number of Cartridges[b]	Rate of Flow, l/min	Maximum Allowable leakage, ppm	Minimum Life, min[c]
Low rate of flow	3	32	5	100
High rate of flow	2	64	5	50
Chemical stability[d]	4	32	5	45

a. Relative humidity of test atmosphere, 50 ± 5 per cent; temperature, room temperature (approximately 25°C); test atmosphere, carbon tetrachloride vapor, 0.1 per cent by volume (1,000 ppm).
b. This number refers to pairs of cartridges if two are used in parallel on the respirator.
c. The values given for minimum life apply to each cartridge or to each pair of cartridges if they are used in parallel. Tests are continued until the maximum allowable leakage occurs.
d. Two cartridges or two pairs of cartridges are treated at room temperature by passing carbon dioxide-free air of 25 per cent relative humidity through them at a rate of 25 l/min for 6 hr. Two cartridges of two pairs of cartridges are treated similarly with air of 85 per cent relative humidity.

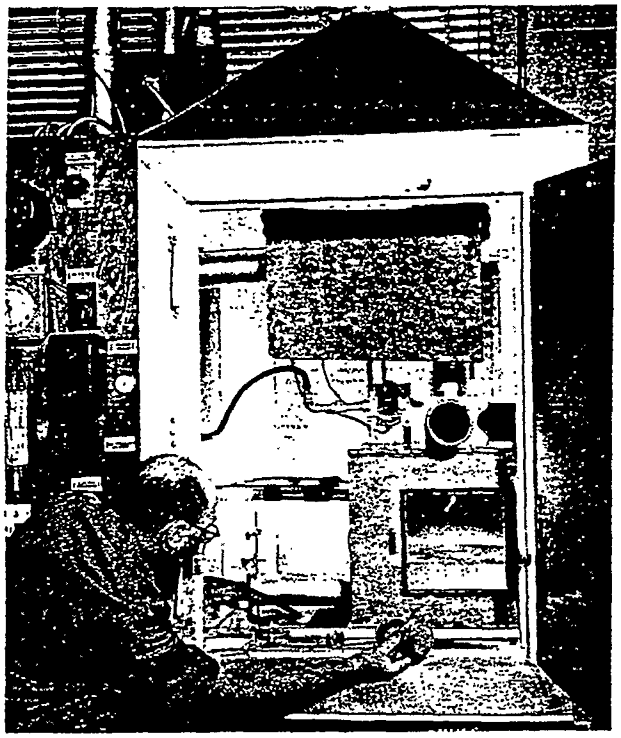


Fig. 9.7. Test chamber for paint spray respirators. Operator is preparing to test paint spray cartridge.
(Courtesy U.S. Bureau of Mines)

TABLE 9.14

SCHEDULE OF EXERCISE FOR MAN TESTS OF CHEMICAL CARTRIDGE RESPIRATORS

Activity	Duration, min
Walking vigorously	5
Sitting at rest	5
Stationary running and calisthenic arm movements	10
Sitting at rest	5
Pumping air with a hand-operated tire pump into a 1 ft^3 cylinder to a pressure of 25 psig or equivalent work	5
Sitting at rest	5

TABLE 9.13

TEST CONDITIONS AND PERFORMANCE REQUIREMENTS FOR MACHINE TESTS OF DISPERSOID FILTERS FOR PAINT SPRAY RESPIRATORS[a]

Test Dispersoid	Concentration of Dispersoid, mg/M^3	Duration of Test, hr	Maximum Allowable Leakage, mg
Lead paint mist[b]	95-125[c]	5.2	1.5[c]
Lacquer mist[d]	95-125[e]	2.6	5[e]
Enamel mist[f]	95-125[g]	5.2	2[g]

a. Temperature, room temperature (approximately 25°C); rate of air flow through respirator, 32 l/min continuous flow; rate of air flow through test chamber, 20 to 25 air changes per minute; atomizer, Spraying Systems Company 1/4 J Pneumatic Atomizing Nozzle with Set-up 1A, or equivalent, operating at an air pressure of 10 psig.
b. Red lead paint, Fed. Spec. TT-P-86a, Type 1.
c. Determined as lead (Pb).
d. Clear cellulose nitrate lacquer, Fed. Spec. TT-L-31.
e. Weighed as cellulose nitrate.
f. White enamel, Fed. Spec. TT-E-4896, having a phthalic alkyd resin vehicle and a titanium dioxide pigment.
g. Weighed as ash after dry ashing.

REFERENCES

1. Bureau of Mines: Respiratory Protective Apparatus, Tests for Permissibility, Fees, Part 11, Self-Contained Breathing Apparatus, Schedule 13D, Sept. 22, 1956, 12 pp. (Code of Federal Regulations reference, 30 CFR, Part 11).
2. Bureau of Mines: Respiratory Protective Apparatus, Tests for Permissibility, Fees, Part 13, Gas Masks, Schedule 14F, Apr. 23, 1955, 9 pp. (Code of Federal Regulations reference, 30 CFR, Part 13).
3. Bureau of Mines: Respiratory Protective Apparatus, Tests for Permissibility, Fees, Part 12, Supplied-Air Respirators, Schedule 19B, Apr. 19, 1955, 14 pp. (Code of Federal Regulations reference, 30 CFR, Part 12).
4. Bureau of Mines: Respiratory Protective Apparatus, Tests for Permissibility, Fees, Part 14, Filter-Type, Dust, Fume, and Mist Respirators, Schedule 21A, Apr. 19, 1955, 7 pp. (Code of Federal Regulations reference, 30 CFR, Part 14).
5. Bureau of Mines: Respiratory Protective Apparatus, Tests for Permissibility, Fees, Part 14a, Nonemergency Gas Respirators (Chemical Cartridge Respirators, Including Paint Spray Respirators), Schedule 23B, Aug. 8, 1959, 8 pp. (Code of Federal Regulations reference, 30 CFR, Part 14a).

Chapter 10

RESPIRATORY PROTECTIVE DEVICES APPROVED BY THE U. S. BUREAU OF MINES

As stated in Chapter 9, The Bureau of Mines tests and approves various types of respiratory protective devices submitted to it by respirator manufacturers. The Bureau publishes a list of approved respiratory protective devices. From time to time, this list is revised to show currently available devices that have been approved.[1]

Information on the approval status of respirators that may have been put on the market since the most recently published listing may be obtained by communicating with the Branch of Health Research, U.S. Bureau of Mines, 4800 Forbes Avenue, Pittsburgh 13, Pennsylvania.

I. TYPES APPROVED

The following is a list of the various types of currently available respiratory protective devices that have been approved by the Bureau of Mines to July 1, 1962. Section II lists the names and addresses of manufacturers of approved devices.

A. Self-contained Breathing Apparatus Approved under Schedules 13, 13A, 13B, 13C, and 13D

1. McCaa 2 hr oxygen breathing apparatus. Approval BM-1303, issued to Mine Safety Appliances Company, August 31, 1925, under Schedule 13.

2. MSA 1 hr oxygen breathing apparatus. Approval BM-1306, issued to Mine Safety Appliances Company, July 28, 1937, under Schedule 13B.

3. Chemox oxygen breathing apparatus (3/4 hr self-contained oxygen-generating breathing apparatus). Approval BM-1307, issued to Mine Safety Appliances Company, October 3, 1946, under Schedule 13C.

4. Scott Air-Pak demand-type apparatus (1/2 hr self-contained compressed air breathing apparatus). Approval BM-1308, issued to Scott Aviation Corporation, October 3, 1946, under Schedule 13C.

5. MSA demand-type oxygen apparatus (1/2 hr self-contained compressed oxygen breathing apparatus). Approval BM-1309, issued to Mine Safety Appliances Company, October 3, 1946, under Schedule 13C.

6. MSA demand-type air apparatus (1/2 hr self-contained compressed air breathing apparatus). Approval BM-1310, issued to Mine Safety Appliances Company, November 26, 1946, under Schedule 13C.

7. McCaa 2 hr oxygen breathing apparatus with life line telephone (full) facepiece. Supplemental approval BM-1303S, issued to Mine Safety Appliances Company, November 20, 1956, under Schedule 13D.

8. Globe Air Guardsman demand-type air apparatus (1/2 hr self-contained compressed air breathing apparatus). Approval BM-13D-11, issued to Globe Industries, Inc., June 30, 1959, under Schedule 13D.

9. Fyr-Fyter Guardsman demand-type air apparatus (1/2 hr self-contained compressed air breathing apparatus). Extension of approval BM-13D-11, issued to The Fyr-Fyter Company, August 6, 1959, under Schedule 13D.

10. U.S. Divers SurviAir demand-type air apparatus (1/2 hr self-contained compressed air breathing apparatus). Approval BM-13D-12, issued to U.S. Divers Company, September 11, 1961, under Schedule 13D.

11. MSA One Hour Chemox oxygen breathing apparatus (self-contained oxygen-generating breathing apparatus). Extension of approval BM-1307, issued to Mine Safety Appliances Company, January 25, 1962, under Schedule 13C.

12. MSA One-Half Hour Chemox oxygen breathing apparatus (self-contained oxygen-generating breathing apparatus). Approval BM-13D-13, issued to Mine Safety Appliances Company, May 2, 1962, under Schedule 13D.

B. Gas Masks Approved under Schedules 14, 14A, 14B, 14C, 14D, 14E, and 14F

1. Type A: Acid Gas Masks

1. MSA hydrocyanic acid gas mask. Approvals BM-1413 (regular size canister) and BM-1414 (supersize canister), issued to Mine Safety Appliances Company, December 9, 1933, under Schedule 14B.

2. Acme chlorine gas mask. Approval BM-1421, issued to Acme Protection Equipment Company, Inc., April 21, 1939, under Schedule 14D.

3. MSA chlorine gas mask. Approval BM-1422, issued to Mine Safety Appliances Company, May 26, 1939, under Schedule 14D.

4. Davis hydrocyanic acid gas mask. Approval BM-1424, issued to Davis Emergency Equipment Company, Inc., December 11, 1939, under Schedule 14D.

5. Davis chlorine gas mask. Approval BM-1427, issued to Davis Emergency Equipment Company, Inc., June 26, 1940, under Schedule 14D.

6. Willson hydrocyanic acid gas mask. Approval BM-1428, issued to Willson Products, Inc., August 30, 1940, under Schedule 14D.

7. Bullard hydrocyanic acid gas mask. Extension of approval BM-1428, issued to E. D. Bullard Company, May 20, 1947, under Schedule 14D.

8. Willson chlorine gas mask. Approval BM-1453, issued to Willson Products, Inc., January 20, 1953, under Schedule 14E.

9. Bullard chlorine gas mask. Extension of approval BM-1453, issued to E. D. Bullard Company, June 28, 1957, under Schedule 14E.

2. Type AE: Acid Gas, Dust, Mist, and Fog Masks

1. MSA industrial gas mask for chlorine, and dusts, mists, and fogs. Approval BM-14F-60, issued to Mine Safety Appliances Company, March 29, 1961, under Schedule 14F.

2. MSA industrial gas mask for hydrocyanic acid gas, and dusts, mists, and fogs. Approval BM-14F-62, issued to Mine Safety Appliances Company, April 7, 1961, under Schedule 14F.

3. MSA gas mask with supersize canister for hydrocyanic acid gas, and dusts, mists, and fogs. Approval BM-14F-63, issued to Mine Safety Appliances Company, April 18, 1961, under Schedule 14F.

3. Type B: Organic Vapor Masks

1. MSA organic vapor mask. Approval BM-1415, issued to Mine Safety Appliances Company, July 28, 1936, under Schedule 14D.

2. Davis organic vapor mask. Approval BM-1417, issued to Davis Emergency Equipment Company, Inc., May 3, 1938, under Schedule 14D.

3. Acme organic vapor mask. Approval BM-1418, issued to Acme Protection Equipment Company, Inc., May 13, 1938, under Schedule 14D.

4. Willson organic vapor mask. Approval BM-1423, issued to Willson Products, Inc., October 6, 1939, under Schedule 14D.

5. Willson organic vapor mask with large canister. Approval BM-1437, issued to Willson Products, Inc., August 5, 1944, under Schedule 14E.

6. MSA organic vapor mask with supersize GMA canister. Approval BM-1441, issued to Mine Safety Appliances Company, August 2, 1946, under Schedule 14E.

7. Bullard organic vapor mask. Extension of approval BM-1423, issued to E. D. Bullard Company, May 20, 1947, under Schedule 14D.

8. Bullard organic vapor mask with large canister. Extension of approval BM-1437, issued to E. D. Bullard Company, May 20, 1947, under Schedule 14E.

4. Type BE: Organic Vapor, Dust, Mist and Fog Masks.

1. MSA industrial gas mask for organic vapors, and dusts, mists, and fogs. Approval BM-14F-56, issued to Mine Safety Appliances Company, February 24, 1961, under Schedule 14F.

2. MSA gas mask with supersize canister for organic vapors, and dusts, mists, and fogs. Approval BM-14F-57, issued to Mine Safety Appliances Company, March 10, 1961, under Schedule 14F.

5. Type BE: Organic Vapor, Toxic Dust, Fume, Mist, and Fog Masks

1. Willson WIG-LG1-G mask for organic vapors, toxic dusts, fumes, mists, and fogs. Approval BM-1446, issued to Willson Products, Inc., April 17, 1950, under Schedule 14E.

6. Type AB: Acid Gas and Organic Vapor Masks

1. Davis acid gas and organic vapor mask. Approval BM-1411, issued to Davis Emergency Equipment Company, Inc., January 19, 1931, under Schedule 14B.

2. MSA hydrogen sulfide and petroleum vapor mask. Approvals BM-1416 and BM-1416A, issued to Mine Safety Appliances Company, June 16, 1937, and July 1, 1937, respectively, under Schedule 14D.

3. Willson hydrogen sulfide and petroleum vapor mask. Approval BM-1444, issued to Willson Products, Inc., April 18, 1949, under Schedule 14E.

4. Willson WIG-LG3 acid gas and organic vapor mask. Approval BM-1450, issued to Willson Products, Inc., March 22, 1951, under Schedule 14E.

5. Bullard hydrogen sulfide and petroleum vapor mask. Extension of approval BM-1444, issued to E. D. Bullard Company, April 15, 1954, under Schedule 14E.

6. Bullard acid gas and organic vapor mask. Extension of approval BM-1450, issued to E. D. Bullard Company, April 15, 1954, under Schedule 14E.

7. Type ABE: Acid Gas, Organic Vapor, Dust, Mist, and Fog Masks

1. MSA gas mask for hydrogen sulfide gas, petroleum vapors, and dusts, mists, and fogs. Approval BM-14F-61, issued to Mine Safety

Appliances Company, March 29, 1961, under Schedule 14F.

2. MSA gas mask for acid gases, organic vapors, and dusts, mists, and fogs. Approval BM-14F-64, issued to Mine Safety Appliances Company April 18, 1961, under Schedule 14F.

8. Type ABE: Acid Gas, Organic Vapor, Toxic Dust, Fume, Mist, and Fog Masks

1. Willson WIG-LG3-G acid gas, organic vapor, toxic dust, fume, mist, and fog mask. Approval BM-1451, issued to Willson Products, Inc., March 22, 1951, under Schedule 14E.

2. Bullard acid gas, organic vapor, toxic dust, fume, mist, and fog mask. Extension of approval BM-1451, issued to E. D. Bullard Company, May 29, 1951, under Schedule 14E.

9. Type C: Ammonia Gas Masks

1. Acme ammonia gas mask. Approval BM-1420, issued to Acme Protection Equipment Company, Inc., March 25, 1939, under Schedule 14D.

2. Willson ammonia gas mask with large canister. Approval BM-1438, issued to Willson Products, Inc., September 22, 1944, under Schedule 14E.

3. MSA ammonia gas mask with supersize GMD canister. Approval BM-1442, issued to Mine Safety Appliances Company, August 29, 1946, under Schedule 14E.

4. Bullard ammonia gas mask with large canister. Extension of approval BM-1438, issued to E. D. Bullard Company, May 20, 1947, under Schedule 14E.

5. MSA ammonia gas mask. Approval BM-1449, issued to Mine Safety Appliances Company, December 19, 1950, under Schedule 14E.

6. LaFrance ammonia gas mask. Extension of approval BM-1449, issued to American-LaFrance-Foamite Corporation, March 9, 1951, under Schedule 14E.

7. Davis ammonia gas mask. Approval BM-1452, issued to Davis Emergency Equipment Company, Inc., March 29, 1951, under Schedule 14E.

8. Willson ammonia gas mask. Approval BM-1454, issued to Willson Products, Inc., November 29, 1955, under Schedule 14F.

9. Acme ammonia gas mask. Approval BM-14F-55, issued to Acme Protection Equipment Company, Inc., May 4, 1959, under Schedule 14F.

10. Type CE: Ammonia, Dust, Mist, and Fog Masks

1. MSA industrial gas mask for ammonia, and dusts, mists, and fogs. Approval BM-14F-58, issued to Mine Safety Appliances Company, March 10, 1961, under Schedule 14F.

2. MSA gas mask with supersize canister for ammonia, and dusts, mists, and fogs. Approval BM-14F-59, issued to Mine Safety Appliances Company, March 16, 1961, under Schedule 14F.

11. Type D: Carbon Monoxide Gas Masks

1. MSA self-rescuer. Approval BM-1447, issued to Mine Safety Appliances Company, April 17, 1950, under Schedule 14E.

12. Type N: Universal Gas Masks

a. Universal Gas Masks with Filters that Afford Respiratory Protection against Smokes from Ordinary Fires and Limited Respiratory Protection against Dusts, Fumes, Mists, and Fogs

1. MSA All-Service gas mask. Approval BM-1405, issued to Mine Safety Appliances Company, August 24, 1928, under Schedule 14A.

2. McDonald All-Service gas mask. Extension of approval BM-1405, issued to B. F. McDonald Company, October 2, 1937, under Schedule 14A.

3. Acme All-Purpose gas mask. Approval BM-1435, issued September 30, 1942, and approval BM-1435A with window indicator canister, issued March 30, 1960, to Acme Protection Equipment Company, Inc., under Schedule 14E.

4. Willson WUG-N1 universal gas mask. Approval BM-1443, issued May 25, 1948, and approval BM-1443A with window indicator canister, issued June 9, 1958, to Willson Products, Inc., under Schedule 14E.

5. Bullard Multigas universal gas mask. Extension of approval BM-1443, issued January 12, 1949, and extension of approval BM-1443A with window indicator canister, issued September 3, 1959, to E. D. Bullard Company, under Schedule 14E.

b. Universal Gas Masks with Filters that Afford Respiratory Protection against Toxic Dusts, Fumes, Mists, Fogs, and Smokes

1. MSA All-Service Model S gas mask. Approval BM-1434, issued September 30, 1942, and approval BM-1434A with window indicator canister, issued June 9, 1958, to Mine Safety Appliances Company, under Schedule 14E.

2. LaFrance Protexall gas mask. Extension of approval BM-1434, issued to American-LaFrance & Foamite Industries, Inc., March 2, 1943, and extension of approval BM-1434A with window indicator canister, issued July 28, 1958, under Schedule 14E.

3. Acme Model FD universal gas mask. Approval BM-1436, issued October 27, 1943, and

approval BM-1436A with window indicator canister, issued June 9, 1958, to Acme Protection Equipment Company, Inc., under Schedule 14E.

4. Willson WUG-N2 universal gas mask. Approval BM-1445, issued June 29, 1949, and approval BM-1445A with window indicator canister, issued October 16, 1958, to Willson Products, Inc., under Schedule 14E.

5. Bullard Smokeater universal gas mask. Extension of approval BM-1445, issued December 7, 1949, and extension of approval BM-1445A with window indicator canister, issued September 3, 1959, to E. D. Bullard Company, under Schedule 14E.

6. Davis universal gas mask. Approval BM-1448, issued August 16, 1950, and approval BM-1448A with window canister, issued October 16, 1958, to Davis Emergency Equipment Company, Inc., under Schedule 14E.

7. MSA All-Service Model S gas mask. Approval BM-14F-66, issued November 13, 1961, and approval BM-14F-66A with window indicator canister, issued November 16, 1961, to Mine Safety Appliances Company under Schedule 14F.

c. Universal Gas Masks with Filters that Afford Respiratory Protection against Dusts, Mists, Fogs, and Smokes

1. MSA All-Service gas mask. Approval BM-14F-65, issued to Mine Safety Appliances Company, May 11, 1961, under Schedule 14F.

C. Supplied-Air Respirators Approved Under Schedules 19, 19A, the Amendment to Schedule 19A, and 19B

1. Type A: Hose Masks with Blowers

The Type A supplied air respirator (hose mask with hand-operated blower) is approved for respiratory protection in any atmosphere provided that enough respirable air is supplied to the wearer by means of the blower.

1. Davis hose mask. Approval BM-1902, issued to Davis Emergency Equipment Company, Inc., March 30, 1931, under Schedule 19.

2. Bullard hose mask. Approval BM-1903, issued to E. D. Bullard Company, April 14, 1933, under Schedule 19.

3. Davis hose mask. Approval BM-1904, issued to Davis Emergency Equipment Company, Inc., October 29, 1934, under Schedule 19.

4. MSA combination hose mask. Approval BM-1905A, issued to Mine Safety Appliances Company, July 2, 1935, under Schedule 19.

5. Davis hose mask. Approval BM-1906, issued to Davis Emergency Equipment Company, Inc., August 2, 1935, under Schedule 19.

6. LaFrance Fresh-Air mask. Extension of approval BM-1905A, issued to American-LaFrance & Foamite Industries, Inc., September 20, 1937, under Schedule 19.

2. Type B: Special Hose Masks without Blowers

The Type B supplied air respirator (special hose mask without blower) is approved for respiratory protection in any atmosphere from which the wearer can escape unharmed without the aid of the respirator.

1. Davis air line mask. Approval BM-1913, issued to Davis Emergency Equipment Company, Inc., March 10, 1939, under Schedule 19A.

2. Bullard Simplex hose mask. Approval BM-1916, issued to E. D. Bullard Company, October 14, 1939, under Schedule 19A.

3. Type C: Air Line Respirators

The Type C supplied air respirator (air line respirator) is approved for respiratory protection in any atmosphere not immediately harmful or from which the wearer can escape without the aid of the respirator.

a. Continuous Flow Air Line Respirators that Supply Air to Interior of Facepiece Continuously at a Set Rate

1. MSA air line respirator. Approval BM-1909, issued to Mine Safety Appliances Company, July 15, 1938, under Schedule 19A.

2. Willson air line respirator, Models GA, GAF, GA2, GB, and GC. Approval BM-1912, issued to Willson Products, Inc., October 7, 1938, under Schedule 19A.

3. Cesco No. 602 Healthguard direct air mask. Approval BM-1917, issued to Chicago Eye Shield Company, August 17, 1940, under Schedule 19A.

4. METCO air line respirator. Extension of approval BM-1920, issued to Metallizing Engineering Company, Inc., December 8, 1948, under Schedule 19A.

5. Cesco No. 600 Healthguard hood. Approval BM-1925, issued to Chicago Eye Shield Company, August 16, 1950, under Schedule 19A.

6. MSA lead hood. Approval BM-1926, issued to Mine Safety Appliances Company, May 9, 1951, under Schedule 19A.

7. McDonald lead hood. Extension of approval BM-1926, issued to B. F. McDonald Company, September 4, 1951, under Schedule 19A.

8. McDonald lead dust helmets Nos. 177A100 and 177A100-1. Approval BM-1927, issued to B. F. McDonald Company, October 3, 1951, under Schedule 19A.

9. McDonald Dustfoe air line respirator.

Approval BM-1928, issued to F. M. McDonald Company, August 9, 1954, under Schedule 19A.

10. MSA Dustfoe air line respirator. Extension of approval BM-1928, issued to Mine Safety Appliances Company, October 4, 1954, under Schedule 19A.

11. Bullard Lite-Weight helmet, Type C supplied air respirator. Approval BM-1929, issued to E. D. Bullard Company, July 29, 1955, under Schedule 19B.

12. Willson GA28 and GAHS air line respirators. Approval BM-19B-30, issued to Willson Products Division, Ray-O-Vac Company, May 29, 1959, under Schedule 19B.

13. Acme CA mask. Approval BM-19B-31, issued to Acme Protection Equipment Company, October 13, 1959, under Schedule 19B.

14. MSA Lead-Foe air line respirator. Approval BM-19B-32, issued to Mine Safety Appliances Company, June 28, 1960, under Schedule 19B.

15. MSA Hyperflo air line respirator. Approval BM-19B-33, issued to Mine Safety Appliances Company, July 18, 1960, under Schedule 19B.

16. MSA Flexi-Flo air line respirator. Approval BM-19B-34, issued to Mine Safety Appliances Company, August 30, 1961, under Schedule 19B.

17. MSA Flexi-Flo air line respiratory with Custom Comfo facepiece for use with a welding helmet. Approval BM-19B-37, issued to Mine Safety Appliances Company, March 12, 1962, under Schedule 19B.

18. MSA Flexi-Flo abrasive mask with full facepiece. Approval BM-19B-38, issued to Mine Safety Appliances Company, May 7, 1962, under Schedule 19B.

19. MSA Hyperflo air line respirator with Custom Comfo facepiece for use with a welding helmet. Approval BM-19B-37A, issued to Mine Safety Appliances Company, May 23, 1962, under Schedule 19B.

20. MSA Hyperflo air line respirator. Approval BM-19B-34A, issued to Mine Safety Appliances Company, June 13, 1962, under Schedule 19B.

21. MSA Hyperflo abrasive mask with full facepiece. Approval BM-19B-38A, issued to Mine Safety Appliances Company, June 14, 1962, under Schedule 19B.

22. Bullard Lite-Weight helmet, Type C supplied air respirator. Approval BM-19B-40, issued to E. D. Bullard Company, April 30, 1962, under Schedule 19B.

b. Demand Air Line Respirators that Supply Air to Interior of Facepiece Only When Wearer Inhales and at a Rate Governed by His Breathing

1. MSA demand-type air line respirator. Approval BM-1922, issued to Mine Safety Appliances Company, May 27, 1949, under Schedule 19A.

2. Scott demand respirator. Approval BM-1924, issued to Scott Aviation Corporation, September 28, 1949, under Schedule 19A.

3. Scott Model 2600 demand respirator. Approval BM-19B-36, issued to Scott Aviation Corporation, February 23, 1962, under Schedule 19B.

4. Type CE: Abrasive Blasting Helmets, Hoods, or Masks

The Type CE supplied air respirator (abrasive blasting helmet, hood, or mask) is approved for respiratory protection during abrasive blasting in any atmosphere not immediately harmful or from which the wearer can escape without the aid of the respirator.

1. MSA abrasive mask. Approval BM-1907, issued to Mine Safety Appliances Company, July 15, 1938, under Schedule 19A.

2. Pangborn blast helmet, Type DD-4. Approval BM-1908, issued to Pangborn Corporation, July 15, 1938, under Schedule 19A.

3. Sly Purair helmet. Approval BM-1911, issued to W. W. Sly Manufacturing Company, July 16, 1938, under Schedule 19A, and July 11, 1957, under Schedule 19B.

4. Willson No. 31 abrasive blasting helmet. Approval BM-1914, issued to Willson Products, Inc., March 10, 1939, under Schedule 19A.

5. Pangborn blast helmet, Type DF-2. Approval BM-1915, issued to Pangborn Corporation, March 23, 1939, under Schedule 19A.

6. Cesco No. 602 Healthguard mask. Approval BM-1918, issued to Chicago Eye Shield Company, January 4, 1941, under Schedule 19A.

7. MSA abrasive mask. Approval BM-1920, issued to Mine Safety Appliances Company, April 30, 1948, under Schedule 19A.

8. METCO abrasive mask. Extension of approval BM-1920, issued to Metallizing Engineering Company, Inc., April 30, 1948, under Schedule 19A.

9. Bullard No. V abrasive blasting helmet. Approval BM-1921, issued to E. D. Bullard Company, September 9, 1948, under Schedule 19A.

10. Willson No. 51 lightweight abrasive blasting helmet. Approval BM-1923, issued to Willson Products, Inc., July 19, 1949, under Schedule 19A.

11. MSA Blastfoe abrasive helmet. Approval BM-1926, issued to Mine Safety Appliances Company, May 9, 1951, under Schedule 19A.

12. McDonald Blastfoe abrasive helmet. Extension of approval BM-1926, issued to B. F. McDonald Company, September 4, 1951, under Schedule 19A.

13. McDonald sandblast helmet No. 177A200 and shotblast helmet No. 177A300. Approval BM-1927, issued to B. F. McDonald Company, October 3, 1951, under Schedule 19A.

14. Bullard Lite-Weight helmet, Type CE supplied air respirator. Extension of approval BM-1929, issued to E. D. Bullard Company, April 24, 1956, under Schedule 19B.

15. Cesco No. 603-RH, RS, RG abrasive blasting hood. Approval BM-19B-35, issued to Chicago Eye Shield Company, January 9, 1962, under Schedule 19B.

16. MSA Flexi-Flo abrasive mask with light- or heavy-weight hood. Approval BM-19B-38, issued to Mine Safety Appliances Company, May 7, 1962, under Schedule 19B.

17. MSA Hyperflo abrasive mask with light- or heavy-weight hood. Approval BM-19B-38A, issued to Mine Safety Appliances Company, June 14, 1962, under Schedule 19B.

18. Bullard Model 37-V abrasive blasting helmet. Approval BM-19B-39, issued to E. D. Bullard Company, April 24, 1962, under Schedule 19B.

19. Bullard Lite-Weight helmet, Type CE supplied-air respirator. Approval BM-19B-40, issued to E. D. Bullard Company, April 30, 1962, under Schedule 19B.

D. Dispersoid (Dust, Fume, and Mist) Respirators Approved under Schedules 21 and 21A

For the purpose of these approvals, the following definitions of terms are used:

Dust. Dispersoids or particulate matter, smaller than 0.1 millimeter (mm) or 100 microns (μ), formed when solid materials are disintegrated by such processes as crushing, grinding, and abrading.

Fume. Solid dispersoids formed when vapors are condensed from heated metals and other substances.

Mist. Liquid dispersoids formed when liquid is disintegrated, as in spray coating and atomizing.

1. Pneumoconiosis-producing and Nuisance Dust Respirators

These respirators are approved only for protection against the inhalation of pneumoconiosis-producing dusts and nuisance dusts, such as free silica, asbestos, aluminum, cellulose, cement, charcoal, coal, coke, flour, gypsum, iron ore, limestone, and wood.

All respirators listed under Section 3 (dust respirators) and some listed under Section 4 (fume respirators) are also approved for protection against inhalation of pneumoconiosis-producing and nuisance dusts.

1. Willson bag respirator No. 400. Approval No. BM-2103, issued to Willson Products, Inc., January 21, 1935, under Schedule 21.

2. Cover No. 24 Dupor respirator. Approval BM-2111, issued to H. S. Cover, September 15, 1936, under Schedule 21.

3. Willson Rotiform respirator No. 200. Approval BM-2118, issued to Willson Products, Inc., December 30, 1937, under Schedule 21.

4. AO R1015 and R2015 respirators. Approval BM-2121, issued to American Optical Company, February 3, 1938, under Schedule 21.

5. Cover Dupor Skin-A-Cat respirator No. 40. Approval BM-2129, issued to H. S. Cover, July 5, 1939, under Schedule 21.

6. McDonald Dustfoe respirator. Approval BM-2132, issued to B. F. McDonald Company, August 23, 1939, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

7. MSA Dustfoe respirator. Extension of approval BM-2132, issued to Mine Safety Appliances Company, August 23, 1939, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

8. AO R9100 respirator. Approval BM-2137, issued to American Optical Company, March 6, 1940, under Schedule 21.

9. McDonald Clear-Vue Dustfoe respirator. Approval BM-2147, issued to B. F. McDonald Company, July 16, 1942, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

10. MSA Clear-Vue Dustfoe respirator. Extension of approval BM-2147, issued to Mine Safety Appliances Company, July 16, 1942, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

11. Cesco respirator No. 94. Approval BM-2153, issued to Chicago Eye Shield Company, March 23, 1945, under Schedule 21.

12. Pulmosan S-600 respirator. Approval BM-2158, issued to Pulmosan Safety Equipment Corporation, March 1, 1949, under Schedule 21.

13. Pulmosan Mn 500 respirator. Approval BM-2159, issued to Pulmosan Safety Equipment Corporation, April 26, 1949, under Schedule 21.

2. Toxic Dust Respirators

These respirators are approved only for protection against the inhalation of toxic dusts that are not significantly more toxic than lead, such as arsenic, cadmium, chromium, lead, manganese, selenium, vanadium, and their compounds.

All respirators listed under Section 3 (dust respirators) and some listed under Section 4 (fume respirators) are also approved for protection against inhalation of toxic dusts.

1. Willson Rotiform respirator No. 200 L. Approval BM-2123, issued to Willson Products, Inc., April 18, 1938, under Schedule 21.

2. AO R1016 and R2016 respirators. Approval BM-2138, issued to American Optical Company, March 16, 1940, under Schedule 21.

3. AO R9100T respirator. Approval BM-2144, issued to American Optical Company, May 19, 1941, under Schedule 21.

3. Dust Respirators

These respirators are approved only for protection against the inhalation of dusts that are not significantly more toxic than lead, such as arsenic, cadmium, chromium, lead, manganese, selenium, vanadium, and their compounds, and pneumoconiosis-producing and nuisance dusts.

Some of the respirators listed under Section 4 (fume respirators) are approved for protection against inhalation of dusts that are not significantly more toxic than lead.

1. Cover Dupor No. 46 respirator. Approval BM-2124, issued to H. S. Cover, October 3, 1938, under Schedule 21.

2. AO R1017 and R2017 respirators (formerly R1000AD). Extension of approval BM-2138, issued to American Optical Company, February 4, 1941, under Schedule 21.

3. Cesco Healthguard No. 94 respirator. Approval BM-2142, issued to Chicago Eye Shield Company, October 3, 1940, under Schedule 21.

4. McDonald Clear-Vue Dustfoe respirator. Approval BM-2148, issued to B. F. McDonald Company, July 21, 1942, under Schedule 21.

5. MSA Clear-Vue Dustfoe respirator. Extension of approval BM-2148, issued to Mine Safety Appliances Company, July 21, 1942, under Schedule 21.

6. Willson respirator No. 750DA. Approval BM-2151, issued to Willson Products, Inc., October 5, 1944, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

7. Willson respirators Nos. 5D and 45D. Approval BM-2152, issued to Willson Products, Inc., October 19, 1944, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

8. AO R2000 respirator. Approval BM-2154, issued to American Optical Company, January 2, 1947, under Schedule 21.

9. AO R5050 and R5050A respirators. Approval BM-2156, issued to American Optical Company, June 23, 1948, under Schedule 21, and August 20, 1957, under Schedule 21A. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

10. Pulmosan L-800 respirator. Extension of approval BM-2160, issued to Pulmosan Safety Equipment Corporation, February 13, 1953, under Schedule 21. (Also approved for protection against inhalation of chromic acid mist.)

11. Willson respirators Nos. 6 and 460. Approval BM-2161, issued to Willson Products, Inc., June 30, 1950, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

12. Willson respirator No. 860. Approval BM-2162, issued to Willson Products, Inc., June 30, 1950, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

13. DeVilbiss MSD-505 respirator. Extension of approval BM-2154, issued to The DeVilbiss Company, November 3, 1950, under Schedule 21.

14. DeVilbiss MSE-501 respirator. Extension of approval BM-2156, issued to The DeVilbiss Company, November 20, 1950, under Schedule 21, and September 18, 1957, under Schedule 21A. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

15. Pulmosan L-3100 pouch-type respirator. Approval BM-2165, issued to Pulmosan Safety Equipment Corporation, December 11, 1950, under Schedule 21.

16. Cesco No. 96 respirator. Approval BM-2167, issued to Chicago Eye Shield Company, October 17, 1952, under Schedule 21.

17. MSA Dustfoe #66 respirator. Extension of approval BM-2166, issued to Mine Safety Appliances Company, October 25, 1955, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

18. McDonald Dustfoe #66 respirator. Extension of approval BM-2166, issued to B. F. McDonald Company, October 25, 1955, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

19. MSA Comfo respirator with Type F filters. Approval BM-2168, issued to Mine Safety Appliances Company, October 13, 1955, under Schedule 21A. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

20. Willson Monomask respirator No. 600. Approval BM-2170, issued to Willson Products, Inc., January 18, 1956, under Schedule 21A. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

21. MSA (Ltd.) Dustfoe #55 respirator. Extension of approval BM-2166, issued to Mine Safety Appliances Company, Ltd., Glasgow, Scotland, March 28, 1956, under Schedule 21. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

22. AO R2090 respirator. Approval BM-2172, issued to American Optical Company, July 11, 1958, under Schedule 21A. (Also approved, August 18, 1958, for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

23. Pulmosan C-264 respirator. Approval BM-2173, issued to Pulmosan Safety Equipment Corporation, August 26, 1958, under Schedule 21A. (Also approved for protection against inhalation of chromic acid mist.)

24. AO R5090 respirator. Approval BM-2174, issued to American Optical Company, August 18, 1958, under Schedule 21A. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

25. Welsh No. 7100 respirator. Approval BM-2175, issued to Welsh Manufacturing Company, August 29, 1958, under Schedule 21A. (Also approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists.)

26. Pulmosan L801 respirator. Approval BM-21A-76, issued to Pulmosan Safety Equipment Corporation, December 11, 1958, under Schedule 21A. (Also approved for protection against chromic acid mist.)

27. Cesco No. 90-F respirator. Extension of approval BM-21A-77, issued to Chicago Eye Shield Company, January 11, 1962, under Schedule 21A. (Also approved for protection against pneumoconiosis-producing, nuisance mists, and chromic acid mist.)

4. Fume Respirators

These respirators are approved for protection against the inhalation of fumes that are not significantly more toxic than lead.

1. Willson respirators Nos. 780A and 880A. Extension of approval BM-2149, issued to Willson Products, Inc., August 7, 1942, under Schedule 21. (Also approved for protection against inhalation of dusts that are not significantly more toxic than lead, and pneumoconiosis-producing, chromic acid, and nuisance mists.)

2. Willson WHG-DFM respirator. Approval BM-2155, issued to Willson Products, Inc., March 1, 1948, under Schedule 21. (Also approved for protection against inhalation of dusts that are not significantly more toxic than lead, and pneumoconiosis-producing, chromic acid, and nuisance mists.)

3. MSA Comfo respirator with Type S filters. Approval BM-2169, issued to Mine Safety Appliances Company, December 8, 1955, under Schedule 21A. (Also approved for protection against inhalation of dusts that are not significantly more toxic than lead, and pneumoconiosis-producing, chromic acid, and nuisance mists.)

4. AO R5056 and R5056F respirators. Extension of approval BM-2163, to cover the use of new filters, issued to American Optical Company, February 28, 1957, under Schedule 21A. (Also approved for protection against inhalation of dusts that are not significantly more toxic than lead, and pneumoconiosis-producing, chromic acid, and nuisance mists.)

5. Pulmosan C-261 respirator. Approval BM-2171, issued to Pulmosan Safety Equipment Corporation, February 28, 1957, under Schedule 21A. (Also approved for protection against inhalation of dusts that are not significantly more toxic than lead, and chromic acid mist.)

5. Mist Respirators

No respirators have been approved for protection against mists only, but several respirators have been approved for mists in combination with other dispersoids.

Respirators that have been approved for protection against inhalation of pneumoconiosis-producing, chromic acid, and nuisance mists are listed as follows: under Section 1 (pneumoconiosis-producing and nuisance dust respirators), items 6, 7, 9, and 10; under Section 3 (dust respirators), items 6, 7, 9, 11, 12, 14, 17-22, 24, and 25; and under Section 4 (fume respirators), items 1-4.

Respirators that have been approved for protection against inhalation of chromic acid mist are listed as follows: under Section 3 (dust respirators), items 10, 23, and 26; and under Section 4 (fume respirators), item 5.

E. Nonemergency Gas Respirators (Chemical Cartridge Respirators) Approved under Schedules 23, 23A, and 23B

1. Type B: Organic Vapor Respirators

These respirators are approved for respiratory protection in atmospheres not immediately dangerous to life or containing not more than 0.1 per cent by volume, of organic vapors.

1. MSA twin cartridge GMA respirator, Approval BM-2301, issued to Mine Safety Appliances Company, June 4, 1945, under Schedule 23.

2. Willson No. 731A chemical cartridge respirator. Approval BM-2303, issued to Willson Products, Inc., July 30, 1946, under Schedule 23.

3. Binks twin cartridge respirator, Type 8. Extension of approval BM-2301, issued to Binks

Manufacturing Company, June 18, 1948, under Schedule 23.

4. Willson No. 801 chemical cartridge respirator. Approval BM-2302, issued to Willson Products, Inc., April 19, 1951, under Schedule 23.

5. AO R5051 chemical cartridge respirator. Approval BM-2304, issued to American Optical Company, July 19, 1949, under Schedule 23, and September 18, 1957, under Schedule 23A.

6. DeVilbiss MSE-502 chemical cartridge respirator. Extension of approval BM-2304, issued to The DeVilbiss Company, October 19, 1950, under Schedule 23, and September 18, 1957, under Schedule 23A.

7. Cesco No. 99 chemical cartridge respirator. Approval BM-2307, issued to Chicago Eye Shield Company, October 16, 1952, under Schedule 23.

8. Pulmosan No. C-256 chemical cartridge respirator. Approval BM-2309, issued to Pulmosan Safety Equipment Corporation, September 3, 1953, under Schedule 23.

9. Willson Nos. 741A and 841 chemical cartridge respirators. Extension of approval BM-2308, issued to Willson Products, Inc., September 3, 1954, under Schedule 23.

10. MSA Gasfoe chemical cartridge respirator. Approval BM-2310, issued to Mine Safety Appliances Company, October 14, 1955, under Schedule 23A.

11. McDonald Gasfoe chemical cartridge respirator. Extension of approval BM-2310, issued to B. F. McDonald Company, December 29, 1955, under Schedule 23A.

2. Type BE: Dispersoid and Organic Vapor Respirators

These respirators are approved for respiratory protection in atmospheres that are not immediately dangerous to life and that contain either dispersoids (type of dispersoid stated for each respirator listed below) not significantly more toxic than lead, or not more than 0.1 per cent, by volume, of organic vapors, or both.

1. AO R5055 chemical cartridge respirator. Approval BM-2305 for dusts and organic vapors, issued to American Optical Company, February 3, 1950, under Schedule 23, and September 18, 1957, under Schedule 23A.

2. MSA Gas-Fume respirator. Approval BM-2306 for fumes and organic vapors, issued to Mine Safety Appliances Company, October 17, 1951, under Schedule 23.

3. Willson Nos. 741AD and 841D chemical cartridge respirators. Approval BM-2308 for dusts and organic vapors, issued to Willson Products, Inc., November 24, 1952, under Schedule 23.

4. MSA Comfo chemical cartridge respirator with Static-Web filter. Extension of approval BM-2301 for toxic dusts and organic vapors, issued to Mine Safety Appliances Company, June 24, 1953, under Schedule 23.

5. Cesco No. 99DF chemical cartridge respirator. Extension of approval BM-2307 for toxic dusts and organic vapors, issued to Chicago Eye Shield Company, April 29, 1955, under Schedule 23.

6. MSA Gasfoe chemical cartridge respirator with Static-Web filter. Extension of approval BM-2310 for toxic dusts and organic vapors, issued to Mine Safety Appliances Company, January 21, 1957, under Schedule 23A.

7. AO R5561 chemical cartridge respirator. Approval BM-2311 for dusts, fumes, mists, and organic vapors, issued to American Optical Company, October 2, 1957, under Schedule 23A.

8. Pulmosan No. C-259 chemical cartridge respirator. Extension of approval BM-2309 for dusts and organic vapors, issued to Pulmosan Safety Equipment Corporation, August 26, 1958, under Schedule 23A

9. MSA Comfo paint spray respirator. Approval BM-23B-12 for organic vapors and paint, lacquer, and enamel mists, issued to Mine Safety Appliances Company, December 23, 1960, under Schedule 23B.

10. Binks paint spray respirator. Extension of approval BM-23B-12 (see item 9), issued to Binks Manufacturing Company, December 23, 1960, under Schedule 23B.

11. AO R5051P respirator. Approval BM-23B-13, for organic vapors, dusts, pneumoconiosis-producing and chromic acid mists, and paint, lacquer, and enamel mists, issued to American Optical Company, December 23, 1960, under Schedule 23B.

12. DeVilbiss MSP-503 respirator. Extension of approval BM-23B-13 (see item 11), issued to The DeVilbiss Company, January 4, 1961, under Schedule 23B.

13. Willson No. 941P paint spray respirator. Approval BM-23B-14, for organic vapors and paint, lacquer, and enamel mists, issued to Willson Products Division, Ray-O-Vac Company, December 23, 1960, under Schedule 23B.

14. AO R5091P respirator. Approval BM-23B-15, for organic vapors, dusts, pneumoconiosis-producing and chromic acid mists, and paint, lacquer, and enamel mists, issued to American Optical Company, December 23, 1960, under Schedule 23B.

15. DeVilbiss MSP-502 respirator. Extension of approval BM-23B-15 (see item 14), issued to The DeVilbiss Company, January 4, 1961, under Schedule 23B.

16. Pulmosan C-251 respirator. Approval

BM-23B-16, for organic vapors, and paint, lacquer, and enamel mists, issued to Pulmosan Safety Equipment Corporation, April 7, 1961, under Schedule 23B.

II. NAMES AND ADDRESSES OF MANUFACTURERS TO WHICH APPROVALS ON CURRENTLY AVAILABLE RESPIRATORY PROTECTIVE DEVICES HAVE BEEN GRANTED

Acme Protection Equipment Company, 1201 Kalamazoo Street, South Haven, Michigan.

American-LaFrance Corporation (formerly American-LaFrance-Foamite Corporation), Elmira, New York.

American Optical Company, Southbridge, Massachusetts.

Binks Manufacturing Company, 3114 Carroll Avenue, Chicago 12, Illinois.

E. D. Bullard Company, 2680 Bridgeway, Sausalito, California.

Chicago Eye Shield Company, 2727 West Roscoe Street, Chicago 18, Illinois.

H. S. Cover, Station A, South Bend, Indiana.

Davis Emergency Equipment Company, Inc., 45 Halleck Street, Newark 4, New Jersey.

The DeVilbiss Company, Toledo, Ohio.

The Fyr-Fyter Company, 221 Crane Street, Dayton 1, Ohio.

Globe Industries, Inc., 125 Sunrise Place, Dayton 7, Ohio.

B. F. McDonald Company, 5721 West 96th Street, Los Angeles 45, California.

Metallizing Engineering Company, Inc., 1101 Prospect Avenue, Westbury, New York.

Mine Safety Appliances Company, Braddock, Thomas, and Meade Streets, Pittsburgh 8, Pennsylvania.

Mine Safety Appliances Company, Ltd., Queenslie Industrial Estate, Glasgow E. 3, Scotland.

Pangborn Corporation, Hagerstown, Maryland.

Pulmosan Safety Equipment Corporation, 644 Pacific Street, Brooklyn 17, New York.

Scott Aviation Corporation, Lancaster, New York.

W. W. Sly Manufacturing Company, 4735 Train Avenue, Cleveland 2, Ohio.

U.S. Divers Company, 3323 West Warner Avenue, Santa Ana, California.

Welsh Manufacturing Company, 9 Magnolia Street, Providence, Rhode Island.

Willson Products Division, Ray-O-Vac Company (formerly Willson Products, Inc.), Reading, Pennsylvania.

REFERENCES

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Chapter 11

SPECIAL APPLICATIONS

I. INTRODUCTION

There are many highly toxic airborne contaminants which require a high degree of reliability in respiratory protective devices. It must be emphasized that the U.S. Bureau of Mines does not approve filter-type respirators for protection against aerosols significantly more toxic than lead, such as (1) radioactive aerosols, (2) beryllium dusts and fumes, and (3) pesticides such as Phosdrin. It is the purpose of this chapter to discuss the problems and developments relating to respiratory protective devices for such highly toxic contaminants. In addition, a unique thermal respirator and household items for emergency respiratory protection are discussed.

Sections II and III discuss respirators for protection against radioactive materials and beryllium. There are many types of respirators currently available that claim to provide protection against these contaminants, but there is no official government agency which evaluates or approves such devices. Although industrial hygienists and health physicists acknowledge the need for a high degree of protection when respirators are used, there is practically no uniformity among the devices recommended and used by these men at different locations. The recommendations made in Sections II and III are intended as interim recommendations until the Bureau of Mines or another government agency tests and approves devices for protection against these contaminants.

Sections IV and V both discuss respirators for protection against pesticides, although these two sections cover different chemicals that are applied for different purposes in different ways. The application of fumigants such as hydrocyanic acid or phosphine (aluminum phosphide) in a closed space creates inhalation hazards that probably are greater than those discussed in Sections II and III or elsewhere in this Manual, since the concentrations are often in the lethal range.

Section V discusses the U.S. Department of Agriculture (USDA) testing program for certain pesticides and its relation to other government agency testing methods. A comparison of the Bureau of Mines test methods discussed in Chapter 9 and the USDA test methods discussed in Section V indicates the need for standardized methods to test respiratory protective devices.

II. RESPIRATORY PROTECTIVE DEVICES FOR RADIOACTIVE AEROSOLS AND GASES

The types of respiratory protective devices that will provide adequate protection against radioactive aerosols have never been delineated, partly because of the broad scope of the problem. Radioactive aerosols include all of the elements in the periodic chart and their compounds. For example, when only 1190 particles of plutonium dioxide, 1 micron (μ) in diameter, constitute a daily tolerance level (see Table 11.1), it obviously is important to determine the exact degree of protection provided by a given respirator. The Bureau of Mines currently is studying this problem, but

TABLE 11.1

ACTIVITIES OF INDIVIDUAL PARTICLES AND DAILY TOLERANCES FOR VARIOUS INSOLUBLE MATERIALS

Isotope	Form	Number of 1μ Particles for Daily Tolerance[a]
Natural uranium	UO_2	3.49×10^8
U^{235}	UO_2	9.35×10^7
U^{233}	UO_2	2.10×10^4
Pu^{239}	PuO_2	1.19×10^3
Po^{210}	Po	0.09
Na^{24}	NaCl	2.53
Sr^{90}	SrO	10.0
Ra^{226}	$RaBr_2$	173
Beryllium	BeO	3.54×10^7
Lead	PbO	4.35×10^8

a. Based on the International Committee on Radiation Protection values in Health Physics, V. 3, pp. 41-84, June 1960. Calculation based on daily air intake of 10 M^3 and volume of 1μ particle equal to 5.22×10^{-13} cm^3.

approval of commercial respirators for such materials cannot be expected for some time.

No official government agency evaluates or approves—for civilian use—respiratory devices for protection against aerosols significantly more toxic than lead, which include most radioactive aerosols. Commercially available devices, however, will protect adequately if they are carefully selected, fitted, used, and maintained. The highest degree of protection against radioactive aerosols and gases is provided by a continuous flow air line respirator or self-contained breathing apparatus that provides a positive pressure in the facepiece. Similar devices, when equipped with a demand value that operates on a reduced pressure in the facepiece, give good protection when the facepiece is properly fitted. Air-purifying respirators that function with a negative pressure in the facepiece and depend on filters and chemical canisters to remove the radioactive contaminants provide good protection under many conditions, when their limitations are understood (see Chapter 6, Section IV).

A. History

A review of the research and development work that has taken place in this field since the advent of atomic energy is interesting.

During the period of the Manhattan District Project, it was recognized that respiratory protective devices would have to be used for uranium compounds and its many highly toxic isotopes. A contract was awarded to the University of Rochester, where commercially available half masks, full face masks, and other devices were tested to determine the degree of protection offered against several uranium compounds. The filters and/or cartridges were tested, the respirators were rated for wearing comfort, and commercially available devices were classified according to the degree of protection provided against uranium and its compounds. This work, conducted in 1942 to 1944, is reported by Dygert.[1]

The information on commercial respirators reported by Dygert provided health and safety personnel with good data to choose the best available respirators for protection against uranium and its compounds during the early years of the Manhattan District Project. When the U.S. Atomic Energy Commission began producing relatively large quantities of plutonium, many realized that a higher degree of respiratory protection was needed; therefore the U.S. Army Chemical Corps was asked to assist.

Respiratory protective devices for protection against radioactive aerosols were provided during the Manhattan District Project by the U.S. Army Chemical Warfare Laboratories. According to

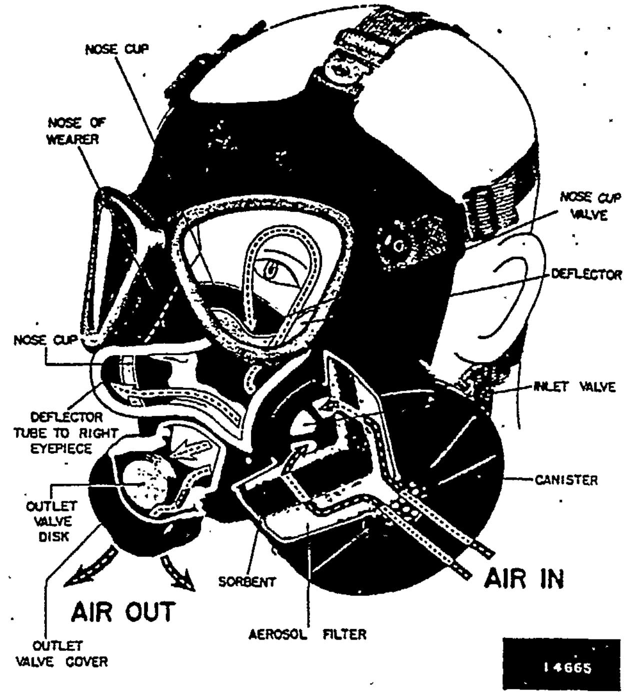


Fig. 11.1. Army Chemical Corps M-9 combat gas mask equipped with the M-11 canister. (Courtesy U.S. Army Chemical Warfare Laboratories, Protective Development Div.)

West,[2] extensive tests conducted with the M-9 gas mask (Fig. 11.1) showed it to be capable of providing protection against radioactive dust. For protection against radioactive aerosols only, the M-11 canister, which contained activated charcoal for gases plus a filter, was replaced by the M-14 gas mask aerosol canister, which contained only a filter (see Fig. 11.2).

Since 1946, the Chemical Corps has manufactured and shipped thousands of the M-14 aerosol canisters to the AEC and its contracting laboratories. Many of the AEC laboratories use the M-9 facepiece with the M-14 aerosol canister or the M-11 canister, which protects against aerosols and gases.

Extensive efforts were made by the Chemical Corps to design the mask as a whole, including facepiece, valves, and filters, to give a high degree of protection. Each aerosol canister is individually tested against dioctyl phthalate (DOP) to meet the Army specifications,[3] which require that it allow no more than 1 in 100,000 parts of DOP particles to pass. The M-9 gas mask facepiece is provided in three sizes in an attempt to give

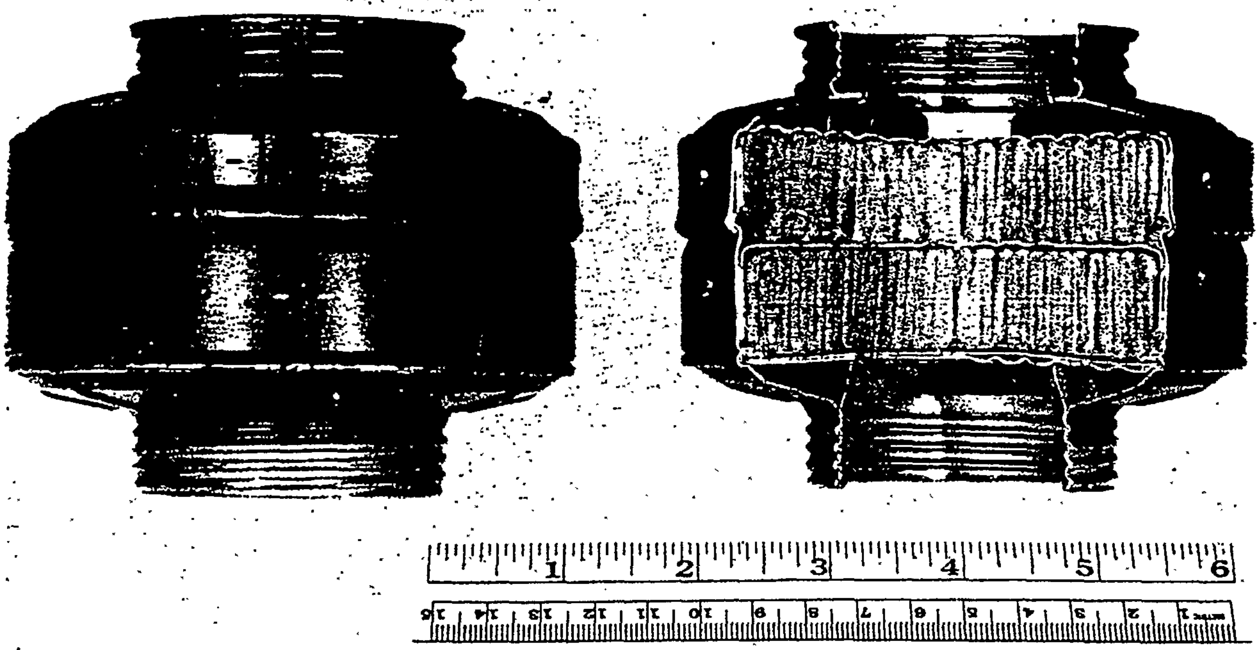


Fig. 11.2. U.S. Army Chemical Corps M-14 mask aerosol filter.
(Courtesy U.S. Army Chemical Warfare Laboratories, Protective Development Div.)

proper fit on the faces of adult males.

For work in areas containing an appreciable quantity of highly toxic radioactive particles, personnel can be provided with a hood that is an accessory to the M-9 field protective mask. The M-3 toxicological agents gas mask hood[4] is made of impermeable fabric and prevents the deposition of particulates in the hair and in the head harness of the mask, where they could be disturbed and shaken off to become a secondary respiratory hazard when the mask is removed. As described by West,[2] the hood covers the entire mask except the eye lenses and canister inlet. It serves as a reservoir to hold the purified air which is exhaled through the outlet valve of the mask. Thus, the entire face-fitting surface of the mask is enveloped in a curtain of uncontaminated air, and should minor leaks in the face seal result from facial irregularities, only uncontaminated air would enter the mask. Such a hood is generally used as a component of the M-3 impermeable protective outfit shown in Fig. 11.3. When the worker emerges from the contaminated area, he may be showered down with water before removing the hood and mask to remove any contaminated materials.

When the Hanford Works started producing plutonium, they realized that they needed superior respiratory protection against this radionuclide. The M-9 mask was one of the early respirators used at this site. Before commercial respirators were used by General Electric in the Hanford Works, extensive tests of filter media efficiency were made by Adley et al.[5] with uranium aerosols.

In 1958, Adley[6] described a "respirator tester" (Fig. 11.4) that measured filter efficiencies and leakage caused by the fit of the facepiece and that indicated some of the characteristics of the individual respirators. In Fig. 11.4, the respirator tester has the panels removed to show the mechanism. The breather pump system (A and B) was designed to simulate human respiration. A respirator is tested by mounting it on a manikin head (C) built up of latex that "has the resiliency and texture of human tissue." An inhalation tube passes from the mouth through the head and out the rear, where a high efficiency sampling filter (D) is located. A synthetic test aerosol can be introduced into the chamber inlet (E), or the apparatus can be moved to the site of a questionable atmosphere, which may be radioactive or inert. The

Fig. 11.3. U.S. Army Chemical Corps M-3 impermeable protective outfit. (Courtesy U.S. Army Chemical Warfare Laboratories, Protective Development Div.)

results obtained with this apparatus have proven useful in providing data for the establishment of mask limits so that each type of respiratory device can be used with greater understanding of its characteristics and limitations. It is recognized that there is a limitation on testing face fit when only one head size of manikin is used. Additional tests made by General Electric at the Hanford Works include those by Gill[7] on the penetration of respiratory protective devices by ruthenium.

Morgan and Buchanan[8] of the AEC Isotopes Division in Oak Ridge in 1952 prepared a booklet on air contamination and respiratory protection in radioisotope work. Although it contained many good recommendations, it emphasized filter efficiency primarily. The safety and health physics personnel[9] at the Union Carbide Nuclear Corp. purchased commercial respirators and performed their own tests to determine the degree of protection provided against several uranium compounds, fluorine, hydrogen fluoride, and certain other contaminants. After extensive testing, they developed what they called the ORGDP universal respirator.

Canada's atomic energy project at Chalk River, because of the NRX reactor accident of December 1952, was uniquely dependent on respirators to protect large crews of men dismantling and rebuilding the damaged reactor. Tait and Byington[10] have reported the development of an excellent respirator program, resulting in new, improved respirators and full face masks, consequent on the lessons they learned. Interestingly, they found that the best respirator alone was not the answer. Since then, the authors report, they have had a "respirator officer" whose sole duty is to make certain that each worker has the right respirator and knows how to wear it and that the respirator is maintained properly.

In 1958, a second accident at Chalk River, involving the NRU reactor, provided additional information on the effectiveness of respirators for protection against radioactive aerosols and gases. The Canadian Army antigas respirator, which was worn in the reactor hall during decontamination, is described by White.[11] This respirator was believed to give adequate protection against all radioactive aerosols and to be effective against many gases, such as radioactive iodine. A modified commercial half mask respirator, previously described by Tait and Byington[10] as the "modified oro-nasal respirator," was worn when workers entered the area outside the reactor hall. White reports that internal contamination of personnel occurred. He also reports that a careful study showed that many individuals who had received internal contamination had not worn their masks properly. Some men under the stress of the moment lifted the respirators from their faces in order to speak to fellow workers. Others held them away from their faces in order to relieve respiratory distress after rapidly climbing stairs.

B. Current AEC Activities

In 1955, several of the AEC contractors realized that a cooperative and uniform respiratory protective development project for the AEC was needed. The AEC organized a meeting of plutonium-using AEC contractors, at the Bureau of Mines, Pittsburgh, in February 1956. As a result of this meeting, the Division of Biology and Medicine of the AEC appointed a Respirator Committee from the various contractors, with instructions to investigate and recommend respiratory protective devices. In 1960, this committee prepared and distributed design specifications for air-purifying respirators (full face and half mask) for protection against radioactive aerosols (see Appendix C).

In 1959, the Division of Biology and Medicine

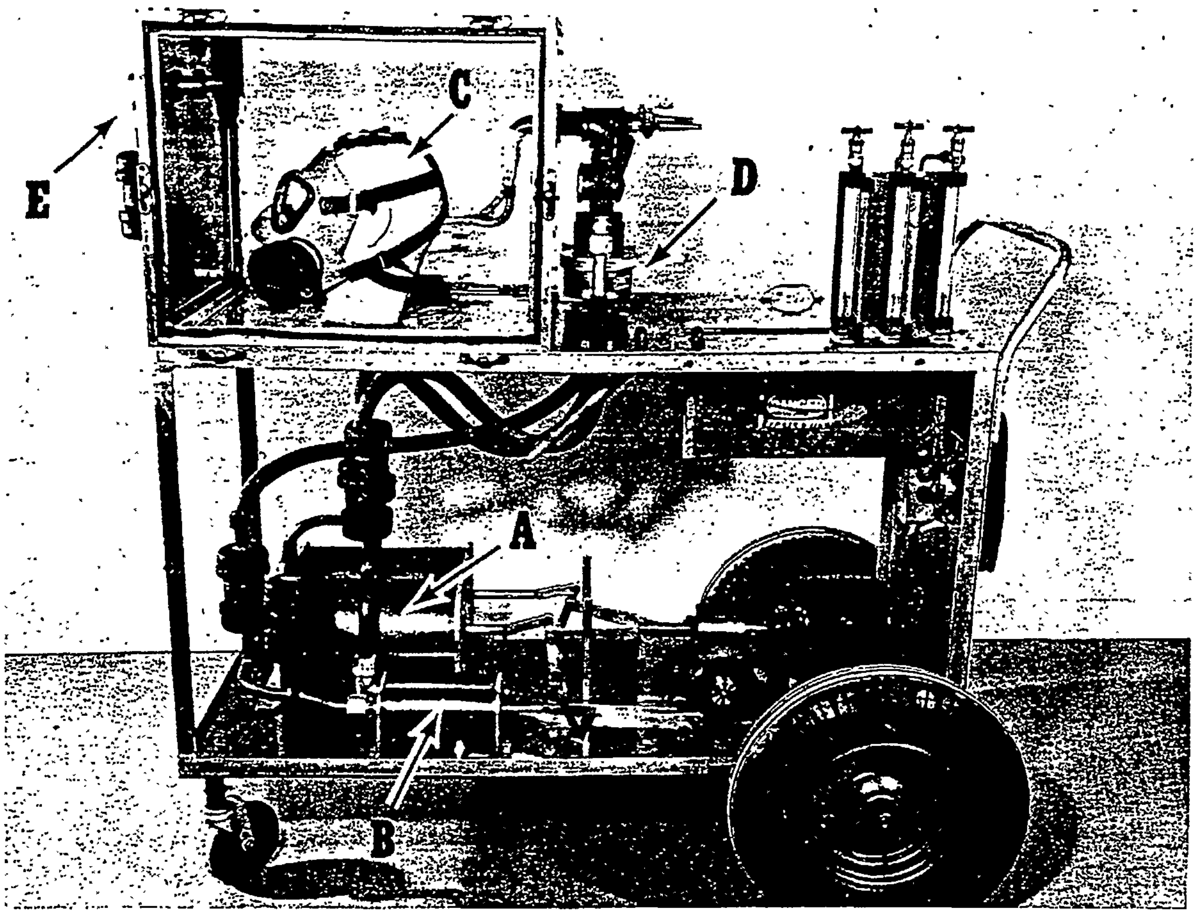


Fig. 11.4. Respirator tester.

contracted with the Harvard School of Public Health to study and evaluate existing devices and to modify them or develop new devices for respiratory protection against highly toxic radioactive aerosols encountered in the nuclear industry. In the first progress report on this respiratory evaluation project, Silverman[12] lists the following items of principal concern in the achievement of the major objective:

1. A study should be made of the factors influencing the performance of respirators or protective breathing devices. These factors include pulsating air flow, facial seal, valve leakage and sealing, comfort, filter media factors, resistance, visual field, and interference with performance.

2. Initially, there should be developed an evaluation procedure for rating and qualifying personal protective equipment on wearers in order to determine the performance of such devices under conditions comparable to exposure to highly toxic radioactive materials such as plutonium and nonradioactive materials such as beryllium.

3. An evaluation of existing types of respiratory protective equipment must be conducted in the light of AEC requirements.

4. The development and evaluation of a satisfactory maximum comfort, minimum effort respiratory protective device for 8 hour (hr) daily use must be considered.

In the first progress report, Silverman discusses: (1) development of a test method to evaluate respiratory protective equipment; (2) evaluation of the effectiveness of some examples of existing equipment; (3) development of devices for respiratory protection, and (4) coordination of research efforts with other interested and responsible agencies. A new technique for evaluating respirator performance, developed during the project, has been reported by Silverman.[12]

The technique described by Silverman is based on a comparison of coincidental air samples taken in the exposure environment and in the respirator dead space during the inhalation phase of a test subject's respiratory cycle. Uranine was used as the test aerosol because it has low toxicity and is detectable in micro quantities. The following procedure was used:

A uranine aerosol with a geometric mean size (by count) of 0.20μ and a geometric standard deviation of 2 was continuously generated into an exposure helmet chamber of unique design which permits dynamic exposure of the subject in any location to aerosol concentrations of less than 4 milligrams per cubic meter (mg/M^3). The chamber design permits complete mobility of the subject. The uranine aerosol was collected inside and outside the respirator by sampling with membrane filters, using a lightweight miniature filter holder. A respirator sampling director, which directs continuous sampling outside the respirator, as well as sampling during either inhalation or exhalation inside the respirator, was developed.

Uranine analysis was conducted with commercially available equipment having a minimum detection sensitivity of 0.1 microgram per milliliter (μg/ml). This sensitivity permits the evaluation of respirator penetration as low as 0.05 per cent in a 10 minute (min) study with an exposure concentration of 3 mg/M^3 of uranine. Total penetration can be determined from the concentration of the aerosol inside the respirator and the respiratory minute volume of the subject. The respiratory minute volume is determined with a soap film spirometer technique.

C. Commercial Devices

Many respirator manufacturers meet the need for protection against radioactive and highly toxic aerosols by manufacturing high efficiency filters. The development of respirator filters has advanced so that adequate filters are now available for most specific uses. Most manufacturers individually test each high efficiency filter against a DOP aerosol with a geometric mean size (by count) of 0.3μ, with an allowable penetration of less than 0.05 per cent.

The possibility of leakage around the facepiece is the main disadvantage of the half mask respirator and, to some extent, of the full face mask. One solution to such leakage is a positive pressure mask.

Steps have been taken to help solve the problems often related to leakage: speech transmission and the wearing of corrective eyeglasses with a full facepiece.

Voice transmission diaphragms, as well as facepiece microphones used in conjunction with battery-operated amplifiers, are now available for certain types of facepieces (see Chapter 3, Section III). At least three methods of mounting corrective eyeglass lenses inside full face masks have been developed, eliminating the need for temple bars, which cause leakage (see Chapter 3, Section III).

Current development projects give promise of devices that will afford a higher degree of protection against radioactive aerosols under various conditions and that will be more comfortable for the wearer.

Some AEC contractors currently are fitting in a gas chamber all men who must work with radioactive aerosols. The mask providing the best face fit with maximum comfort is chosen from several commercial half and full face masks, thereby assuring acceptance by the workmen.

D. Scope of the Problem

As emphasized throughout this Manual, respirators should never be substituted for adequate engineering and ventilation control measures. However, there will always be unusual, temporary, or emergency situations in which the other control measures will be inapplicable, impractical, or ineffective, and in which respirators must therefore be used. Industrial and laboratory operations employing radioisotopes encompass practically every conventional industrial operation. In addition there are unusual problems related to reactor work, bomb tests, operation and servicing of marine nuclear engines, nuclear rocket engines, and many other specialized applications.

Exposures to radioactive aerosols range from routine maintenance work to emergency situations, such as fires or explosions with pyrophoric radioactive metals, ruptured reactor fuel elements, reactor explosions, and radioactive source leaks. Radioactive contaminants may be in the air as dusts, fumes, mists, or gases, often in conjunction with nonradioactive toxic chemicals. It is logical to consider respirators for radioactive airborne contamination by classification according to the type of contaminant and the degree of toxicity, as in the following section.

E. Interim Recommendations for Respirators to Provide Protection Against Radioactive Aerosols and Gases

1. Dusts and Fumes of Extreme Toxicity

For dusts and fumes of such extreme toxicity as plutonium-239, polonium-210, and strontium-90, the minimum protection is a well designed full face mask with high efficiency filter. The men wearing these devices must be carefully trained in their use after they have been fitted and the need for the respirator has been explained to them. Health and safety personnel of AEC contractors have adopted a full face mask with a high efficiency filter as minimum protection against plutonium aerosols. A full face respirator with high efficiency filter is recommended as the minimum protection that should be used for extremely toxic radioactive aerosols in air concentrations up to 50 times the threshold limit value (TLV). Above 50 times TLV, supplied air masks and suits, or self-contained breathing apparatus that provide a positive pressure in the facepiece, should be used. (Fifty times TLV has been calculated as the best interim recommendation. The upper limit for a full face mask currently used by AEC contractors varies from 20 to 100 times TLV).

2. Dusts and Fumes of Moderate Toxicity

For dusts and fumes that are significantly more toxic than lead but several orders of magnitude less toxic than plutonium—such as enriched uranium and fission products—the following interim recommendations are made. They are consistent with those made by an AEC contractor[13] in 1958.

1. The upper limit of airborne contamination against which the half mask respirator offers suitable protection should be five times TLV. Because any given model of a half mask respirator is made in one size only, certain individuals with extreme or unusual facial contours obviously cannot be fitted perfectly with a half mask respirator. Although a perfectly fitted respirator with tight straps and a high efficiency filter or cartridge has a moderately low penetration of contaminant (generally less than 5 per cent and possibly 1 per cent), it is impossible to give one figure defining the effectiveness of a half mask respirator for all workmen under varying conditions. Therefore, an upper limit of the contaminant concentration in which half mask respirators may be worn should be established. Before a qualified individual issues half mask respirators, he should assure himself that the possibility of the level of airborne contamination exceeding five times TLV is extremely remote. If there is any doubt about this level, full face masks or supplied air equipment should be provided.

2. Full face masks should be used only when the concentration of the atmospheric contaminant is under 50 times TLV, although full facepieces may be worn safely in higher concentrations if they are expertly fitted (by individual leakage test) and if the wearer cares more for his safety than for his comfort.

3. For air concentrations of radioactive contaminants above 50 times TLV, supplied air respirators or self-contained breathing apparatus should be worn. For maximum protection, a type providing a positive pressure in the facepiece should be used.

3. Radioactive Gases

Tritium or hydrogen-3 as a gas cannot be removed by any of the air-purifying devices on the market. For adequate protection against tritium, only supplied air respirators or suits, and/or self-contained breathing apparatus, should be used. Because tritium water vapor in high concentrations can be absorbed readily through intact skin, only a supplied air plastic suit gives adequate protection. The integrity of vinyl plastic suits in tritium atmospheres has been discussed by Butler and Van Wyck.[14]

One of the more common radioactive gases is radioactive iodine. Adams and Browning[15] have shown that iodine can be absorbed or removed by an activated charcoal filter with an efficiency up to 99.99 per cent. The life expectancy of the activated charcoal cartridge, related to quantity of sorbent and concentration of iodine, must be considered.

The maximum permissible concentrations of the noble gases argon, krypton, and xenon are based on the dose delivered to the whole body when submerged in air containing this concentration. Hence, respiratory protection against these gases is of no value. Such gases dissipate rapidly and are unlikely to be present in excessive quantities in an atmosphere containing mixed fission products.

4. Fission Products

Fission products include dusts, fumes, and gases and are usually associated with nuclear accidents or with bomb tests. They may be present, of course, during routine reactor operations such as removing spent fuel elements and chemical processing of spent fuel elements. It is recognized that no air-purifying device will completely remove mixed fission products including gases; however, supplied air respirators or the Army M-9 masks with the M-11 canister (or equivalent) are considered satisfactory protection for routine exposures. For emergency situations, only self-contained breathing apparatus should be used.

During many recovery operations following bomb detonations, a full face mask with a high efficiency filter has proven effective because the gaseous fission products have dissipated with the bomb cloud. No internal contamination has been detected for personnel involved.

Minimum personal respiratory protection during the handling and processing of spent fuel elements should be a full face mask equipped with a combination high efficiency filter and activated charcoal canister to remove particulates and iodine. This type of device is satisfactory for decontamination following a reactor accident, provided the personnel have been properly fitted and instructed in use of the respirator. To be worn properly under stress, the respirator must have moderately low resistance to inhalation and it should be equipped with a speaking diaphragm.

F. Information Service

If any questions about the selection, use, or care of respiratory devices for protection against radioactive aerosols are not covered in the Manual, they should be referred to the Division of Operational Safety of the AEC in Washington, D.C.

III. RESPIRATORY PROTECTIVE DEVICES FOR BERYLLIUM

A. Background Information

Respiratory protective devices for beryllium are especially important because of beryllium's high toxicity. The Bureau of Mines has not approved any device for respiratory protection against any particulate contaminants significantly more toxic than lead, and beryllium and its compounds are many times more toxic than lead. Commercially available devices, however, provide reliable respiratory protection if they are carefully selected, fitted, used, and maintained.

The control necessary for beryllium and its compounds is best emphasized by the permissible level of beryllium concentration in air. In 1949, the AEC Advisory Committee on Beryllium Intoxication proposed the following concentration limits for beryllium:

1. The in-plant daily weighted average exposure to atmospheric beryllium should not exceed 2 micrograms per cubic meter ($\mu g/M^3$) average concentration throughout an 8 hr day.

2. Even when the daily weighted average is within the above limit, no person should be exposed to a concentration greater than 25 $\mu g/M^3$ for any period of time, however short.

The permissible level of 2 $\mu g/M^3$ was adopted as a threshold limit value in 1956 by the ACGIH but the short term tolerance was not. The AEC Advisory Committee's setting of a short term tolerance level is unique in industrial hygiene practice and has caused considerable misunderstanding regarding the type of respiratory protective device to use. Breslin and Harris[16] note that occupational disease at facilities operated under contract to the AEC has been avoided by adhering to the exposure criteria set in 1949. A few mild acute occupational respiratory cases (chemical tracheitis) have occurred where the limits were exceeded temporarily. The limitations and pitfalls of respirators for protection against beryllium are discussed by Breslin and Harris, who recommend that their use be held to a minimum and carefully regulated.

Breslin and Harris describe some unusual problems encountered in a beryllium processing plant. Some soluble beryllium salts, such as beryllium fluoride and ammonium beryllium fluoride, are recognized skin irritants, and dust deposited on the skin from a heavy suspension in the air provokes a skin reaction. Material accumulated where the respirator contacts the face also causes dermatitis, and respirators worn in irritant dust atmospheres must be washed daily. Some manufacturers supply respirator coverlets, cotton cloths that fit around the facial contact surface of the respirator, but they are not recommended because they prevent an airtight seal at the periphery of the facepiece.

B. Interim Recommendations for Respirators to Protect against Beryllium and Its Compounds

The following interim recommendations for the selection of respiratory devices for protection against beryllium and its compounds are made until the Bureau of Mines tests and approves such devices and the devices become available commercially.

1. Half Mask Respirators (Air-purifying Type)

A maximum air concentration should be set, which should not be exceeded when a half mask respirator is worn, because such a mask provides only limited protection. A half mask respirator with high efficiency filter can be used safely when the atmospheric concentration of beryllium does not exceed 25 $\mu g/M^3$, provided the facepiece is fitted to give an airtight seal. The original recommendation (see Appendix B) that use of a half mask respirator be restricted to a concentration of 10 times TLV places the upper limit at 20 $\mu g/M^3$. For beryllium, it is more practical to use 25 $\mu g/M^3$, because this is the short time tolerance level recommended by the AEC Advisory Committee and is a convenient guide line.

Estimating this tolerance level each time a worker enters a beryllium processing area is difficult; therefore the following selection guide is suggested. A half mask respirator equipped with a high efficiency filter may be used during short exposures (less than 4 hr) for protection in unventilated operations if high concentrations of airborne particulates (greater than 25 $\mu g/M^3$) are judged improbable.

Note: Some manufacturers assert, in writing, that certain commercial half mask respirators with high efficiency filters protect against beryllium. The manufacturers make this claim for the complete respirator when actually the degree of efficiency for removing particulates applies only to the filter itself. Because of leakages around the facepiece and other factors, the efficiency of a respirator in actual use may be far less than the efficiency of its filter under test conditions.

Half mask respirators should be used with the understanding that they are not currently approved by the Bureau of Mines for protection against beryllium and should be selected only by qualified industrial hygienists experienced in this field.

2. Full Face Respirators (Air-purifying Type)

Although leakage around the face is possible with the full face mask, a good fit can be achieved in a higher per cent of cases than with the half mask respirator because the full face type is fitted to a portion of the face where there is less individual variation. Less than 0.1 per cent over-all penetration may be obtained with a properly fitted full face respirator. However, because of the difficulty in fitting all types of faces with commercial masks in a single size, full face masks should be restricted to atmospheric concentrations where the contaminant does not exceed 100 $\mu g/M^3$. If the individual selecting the device does not have a high degree of confidence that a level of 100 $\mu g/M^3$ will not be exceeded, he should select a supplied air respirator rather than a full face mask.

3. Supplied Air (Air Line) Respirators

Two types of supplied air respirators are available commercially: demand and continuous flow. The constant flow air line respirator approved by the Bureau of Mines (for all atmospheres except oxygen deficiency) gives greater protection, although similar devices of the demand type may be worn safely if the workmen are properly trained in their use and expertly fitted so that there is a gas-tight seal. A competent individual should supervise both the selection and the use of air line respirators and periodically should retrain workers who use such respirators. A positive supply of pure air through the respirator is vital (this problem is discussed in more detail in Chapter 7).

4. Self-contained Breathing Apparatus

Respirators for normal or nonemergency use are discussed in general above. In emergencies, or when a brief exposure to a high concentration may be hazardous or even potentially lethal, only self-contained breathing apparatus approved by the Bureau of Mines should be used, and thorough training should be given to the expected users of these devices (see Chapter 13 for a discussion of this training).

IV. RESPIRATORS FOR PROTECTION DURING FUMIGATION

A. Defining the Problem

Fumigation is the process of disinfesting by dispersing a pesticide (in the form of a vapor, gas or solid) into a closed space, as opposed to the spraying of pesticide aerosols in open areas. Hydrogen cyanide, the most widely used fumigant in the past, is the standard to which all other fumigant gases are compared.

Respirators for protection against fumigants are now (1962) included in the U.S. Department of Agriculture's project of testing and recommending respiratory protective devices for protection against pesticides (see Section V). The USDA tests respirators only against such pesticides as Systox, Parathion, TEPP, Phosdrin, Aldrin, Chlordane, and Dieldrin—chemicals which usually are prepared with carrier substances no more toxic than xylene. The Bureau of Mines is the only government agency which tests and approves respiratory equipment for protection against hydrogen cyanide, methyl bromide, carbon disulfide, and carbon tetrachloride, which are commonly used as fumigants.

This difference is emphasized because illnesses and even fatalities have resulted from misunderstanding by some fumigant manufacturers and fumigators about the selection and use of respirators for protection against this type of pesticide. The confusion in the term "pesticide" obviously accounts for some of the trouble.

According to deOng,[17] all chemicals used as pest control agents are officially termed "pesticides," including insecticides, repellents, fungicides, seed protectants, herbicides (weed killers), and rodenticides. Obviously, then, one cannot select and use a respirator for protection against "pesticides" in general; one must know the chemical name, the method of dispersing, and the physical and toxicological properties of the individual pesticide. The respiratory devices for protection against pesticide fumigants, used for fumigating buildings and stored grain, are discussed in this section.

B. Current Practice

A typical fumigant (Fumigant No. 3, used in the fumigation of stored, shelled corn) is described by Paulus.[18] It consists of 80 per cent carbon tetrachloride and 20 per cent carbon disulfide. He reports that the total vapor concentration in the breathing zone of the fumigator while fumigating 18 ft cylindrical bins of corn during an industrial hygiene survey was over 20,000 parts per million (ppm) for carbon disulfide and carbon tetrachloride. The respiratory protective equipment used during the fumigation with this mixture was a full face mask with organic vapor canister. Paulus notes that such a canister as approved by the Bureau of Mines is effective in atmosphere containing up to 2 per cent (20,000 ppm) organic solvent vapor for a period of 30 min at this concentration, or for an equivalent time—concentration value.

When fumigating a storage bin, a man stands on a ladder at the top of the bin and sprays with liquid fumigant through an open hatch. Paulus reports that for corn about 18 gal of fumigant is sprayed into the 18 ft diameter bin at a rate of from 3 to 4-1/2 gallons per minute (gal/min). At these concentrations the vapor stream often is concentrated enough to impart a cooling sensation to parts of the body which it contacts.

Paulus makes a series of recommendations for the safe fumigation of shelled corn, which include the following for the selection and use of respiratory devices:

1. Each member of the fumigation crew should be provided with a Bureau of Mines approved full face gas mask and organic vapor canister. The mask should be donned and checked for leaks before fumigation starts and should not be removed until the crew member leaves the area of high vapor concentration. If the crew member detects the odor of solvent while wearing the mask, he should leave the area immediately.

2. Bureau of Mines approved devices with the gas mask canister worn on the fumigator's back rather than on his chest are preferable, because they keep the canister out of the heaviest vapor concentration and increase its useful life.

3. After fumigation the bins should not be entered without a mask for at least seven days.

4. Under no circumstances should a half mask, chemical cartridge respirator be used during fumigation.

Although these recommendations are made for the fumigation of shelled corn with a mixture of carbon disulfide and carbon tetrachloride, they are applicable to the fumigation of any grain with any chlorinated hydrocarbon. There should be a stand-by man when the operator is fumigating.

McCollister[19] reports on the comparative inhalation toxicity of fumigant mixtures known as Dowfume 75, EB-5, and EB-15, which contain ethylene dichloride, carbon tetrachloride, and ethylene dibromide in varying percentages. He recommends that exposures to Dowfume 75 should not exceed 100 ppm for a 7 hr exposure. Adams,[20] during an industrial hygiene survey of flour mills and bakeries, found concentrations of the fumigant mixture EB-15 up to 200 ppm 30 min to 12 hr after application of the fumigant; however, all the values were below 75 ppm when work was resumed the next day. Certainly, very high concentrations of fumigant exist during fumigation, and adequate respiratory protective devices should be used.

Phosphine is used in grain fumigation under the name of Phostoxin. It is introduced (in pellet form as aluminum phosphide) through probes forced into the grain. Phostoxin releases poisonous gas when moist. The claim is made that no mask equipment is needed because the evolution of phosphine is within the stored grain and because phosphine is heavier than air and should settle to the bottom. However, due to the high toxicity of phosphine, anyone entering into an area which has had the gas in it and which has not been thoroughly ventilated should wear a universal canister.

In a U.S. Department of Labor bulletin, Johnson[21] describes the mass attack on grain fumigation deaths by the Kansas State Board of Health and the Kansas State Department of Labor, after six deaths and 17 cases of illness in five years from fumigants. The program was sparked by the death of a 26 year old grain worker on his wedding eve. Johnson emphasizes the cooperation of the many state agencies, the federal agencies, and the grain handlers themselves toward achieving a good health and safety program for the protection of workmen handling fumigants.

At a Kansas State University conference[22] to encourage safe use of fumigants, Dr. W. F. von Oettingen (consultant, U.S. Public Health Service) warned that some persons lose awareness of an odor after smelling it for a short while. He also emphasized that some fumigants are virtually odorless, and some are absorbed through the skin, paralleling inhalation as a mode of poisoning. At the same conference S. J. Pearce (Bureau of Mines) discussed common errors in the use of gas masks, including the wearing of a dust mask during fumigation, the use of a mask which either is no longer effective or is the wrong kind for a particular fumigant, and the wearing of an old mask which leaks or does not fit. Pearce warned also against the danger of entering a gas concentration higher than the protective limits of any gas mask. These limits are discussed in Chapters 5 and 6. A similar conference was held in Texas in 1961.

Mayes[23] comments on the death of a fumigator who was wearing a commercial respirator which had been tested and accepted by the USDA for protection against pesticides. The USDA releases on respiratory devices specifically state: "Respirators [chemical cartridge respirators] do not provide needed protection from inhalation of pesticide dust, mist, and vapors for use by (1) Those formulating or mixing pesticides in closed or inadequately ventilated spaces. (2) Those applying pesticides, including aerosols, in greenhouses. Fullface gas masks equipped with tested canisters should be worn under these conditions."

The important safety fact in this case is that, although the respirator was approved by a government agency, the user did not know that the fumigant he was using (containing more than 70 per cent carbon tetrachloride) was not among those pesticides for which the respirator was approved or accepted. Moreover, the supplier of the fumigant also had supplied this type of respirator—a very sorry situation, indeed.

Mayes states that the problem of protecting fumigators is aggravated further by the reported distribution in Kansas of inadequate World War II surplus gas masks. A warning bulletin (Fig. 11.5) was distributed throughout the state, with an appropriate news release for all newspapers in the state, cautioning against the use of the surplus masks. Even after one near fatality at a grain storage house, involving one of the war surplus masks illustrated in that bulletin, a chemical company still advertised a sales package, aimed primarily at the farm market, in which one of the war surplus masks was given free with each purchase of liquid fumigant.

In March, 1960, the Kansas State Department of Labor issued a bulletin [24] establishing standards of safety and health protection procedures in fumigation operations. The standards for the use of respiratory protective devices state: "Approved personal protective equipment shall be furnished by the employer, that will provide adequate protection against the specific hazards involved in the particular fumigation operation. Approved personal protective equipment shall be only that equipment approved (and marked as approved) by the U.S. Bureau of Mines for the particular chemical or hazard for which it is to be used."

The standards of the Kansas Department of Labor also include a section on training which requires that each employer shall conduct training and education programs sufficient to provide suitable instruction to all employees who will be handling and using fumigating chemicals. Whenever possible, employees shall have on-the-job instruction and training with the actual chemical and with the protective devices and personal protective equipment which they will use in their fumigating operations.

A California occupational health bulletin[25] recommends that employees who dispense or test methyl bromide be equipped with approved (Bureau of Mines) respiratory protection, either supplied air respirators or canister masks specifically approved for methyl bromide. (The Bureau of Mines has not approved any gas masks specifically for methyl bromide.) If gas masks with canisters are used, the bulletin notes the following precautions: (1) no canister will protect against concentrations of methyl bromide over 5 lb per 1,000 ft^3 (2 per cent); and (2) a regular size, organic vapor canister used in a methyl bromide concentration of 3 lb per 1,000 ft^3 (1.2 per cent) affords protection for only 15 min. The capacity of activated charcoal for methyl bromide is much less than for CCl_4, which is the reason for the suggested time limit precaution.

In his book,[17] deOng recognizes the importance of proper respiratory protective equipment during fumigation and recommends that only Bureau of Mines approved devices be used. In his discussion of gas masks, he states that carefully fitted masks should be insisted upon for anyone exposed to even moderate concentrations of hydrogen cyanide, chloropicrin, cyanogen chloride, and other quick-acting fumigants. He also advises the wearing of masks when subjected to higher concentrations or long exposure to nicotine fumes, ethylene oxide, methyl bromide, methyl formate, ethylene dichloride, carbon disulfide, carbon tetrachloride, and other organic fumigants.

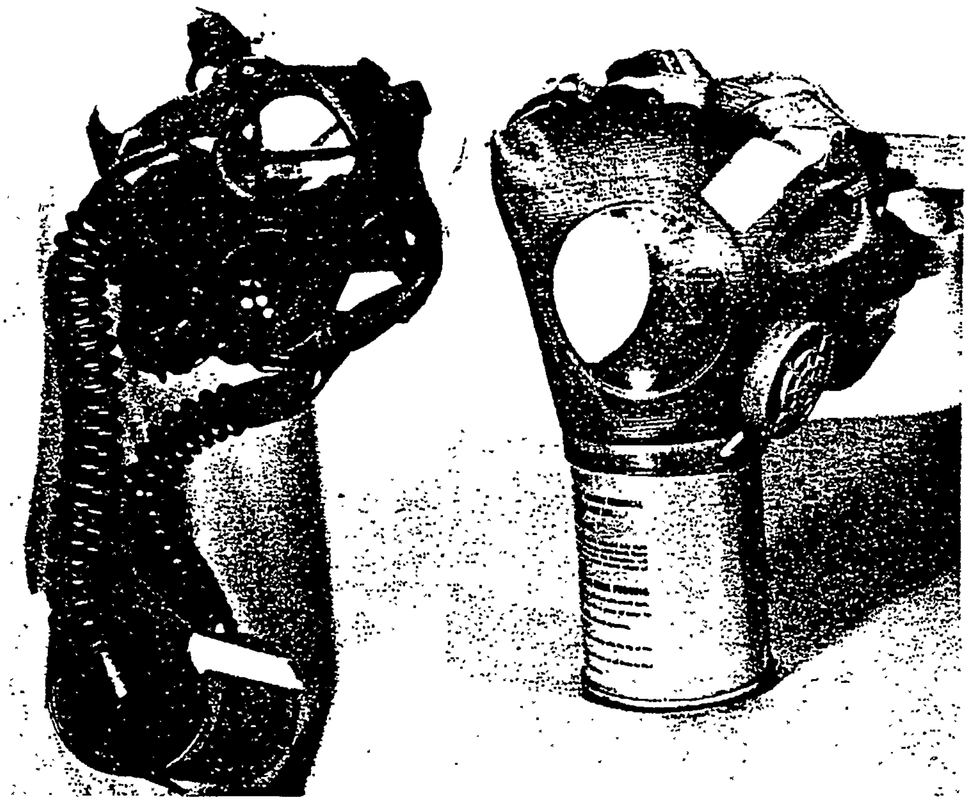
Determining when a canister is no longer effective against a gas is a most serious problem, especially when a gas or vapor has few or no warning properties. Many gases warn of impending failure of a canister by their odor, taste, or irritating effect on eyes, nose, or throat. For example, a person who has been wearing a gas mask for some time in an ammonia gas–air atmosphere knows, when he detects the odor of the gas, that the canister is exhausted and he should return to fresh air immediately to replace the canister. However, gases like methyl bromide and hydrogen cyanide give no such warning. There have been several instances in which workers wore gas masks while fumigating with methyl bromide, and yet, unaware that any gas was coming through the exhausted canister, breathed enough methyl bromide to affect them seriously or fatally.

There are available on the market mixtures of methyl bromide with chloropicrin. It has been found that chloropicrin is absorbed by organic materials at a greater rate than is methyl bromide, making it entirely possible to lose the warning properties from these mixtures during use.

A second problem is the use of canisters in vapors and gases which cannot clearly be detected by odor. An example is hydrocyanic acid. This material may be easily detected by odor at low concentrations by some individuals, but the odor is not reliable to warn the user that the canister is exhausted because of olfactory fatigue. Most men become used to the odor, and the odor threshold will effectively move up the scale by some unknown factor as the exposure continues. It is likely that the user will fail to detect concentrations which may be harmful even in a short period of time.

Many of the fumigants, such as hydrocyanic acid and acrylonitrile, may be absorbed through the skin in toxic quantities. Also, many of the

WARNING



BEWARE OF THESE GAS MASKS

The gas masks pictured above are reportedly being distributed in Kansas. Beware of them! They can be potential killers!

NOT SAFE FOR USE WHILE FUMIGATING GRAIN IN CONFINED AREAS

SMALL CANISTER EFFECTIVE ONLY A FEW MINUTES

USE MASKS, BUT ONLY THOSE APPROVED BY THE U. S. BUREAU OF MINES AND IN GOOD CONDITION

IF IN DOUBT AS TO THE SAFETY OF A MASK CONTACT ANY OF THE AGENCIES LISTED BELOW:

Kansas State Board of Agriculture
Kansas State Board of Health
Kansas State Safety Council
Kansas State Department of Labor

Fig. 11.5. Warning bulletin on dangers of using surplus military masks.

fumigants are skin irritants, especially in high concentrations. These irritants also are severely hazardous to the eye, and eye protection should always be provided during fumigation.

Several of the fumigants are potential fire and explosive hazards. Benzene and carbon disulfide are well-known fire hazards. Fumigant manufacturers have used chlorinated hydrocarbons to reduce this type of hazard.

Many fumigators insist that fresh canisters be used when either methyl bromide or hydrogen cyanide is being applied. Then these canisters must be discarded and fresh canisters attached to the masks before workmen re-enter a fumigated area to air it out. In this enlightened attitude no attempt is made to squeeze the last bit of life out of a canister, with resultant possible injury or even death to the wearer.

The problems and hazards encountered during fumigation are summarized here for clarity. It is emphasized that highly toxic and volatile chemicals are used to fumigate closed spaces such as buildings and grain storage bins. The concern in regard to these chemicals is due to the fact that they (1) are encountered in exceedingly high concentrations, (2) may be odorless or cause olfactory fatigue, (3) may be absorbed through the skin, (4) may affect the eyes and require eye protection, and (5) could create fire and explosive hazards.

There has been confusion regarding the term "pesticide," especially in the selection and use of respiratory protective devices. It is very important to identify the chemical or chemicals used as fumigants to permit the proper selection of a gas mask canister. The Bureau of Mines tests and approves gas masks specifically for respiratory protection against hydrocyanic acid gas and ammonia gas and generally for respiratory protection against gases or vapors classed as organic vapors or acid gases. See Table 11.2 for type of gas mask to be used for respiratory protection against specific fumigants.

The U.S. Department of Agriculture tests canisters only against specific organic compounds used as insecticides for open field spraying and aerosols for use in greenhouses and non-ventilated areas.

New chemicals that present special problems are being introduced as fumigants before there has been time to test and approve canisters to protect against them. An example is Vikane (sulfuryl fluoride), a new fumigant recently released by Dow. It was first thought that an acid gas—organic vapor canister might have an adequate absorptive capacity, but this was not the case. The Dow Chemical Company has tested various canisters submitted by manufacturers and found only specific ones to be effective. In order to be sure that fumigators could be provided with adequate gas mask canisters to protect against Vikane, Dow has listed on the fumigant label those canisters found effective.

For advice on respiratory protective devices for new or unusual fumigants, consult a responsible respirator manufacturer, the basic supplier of the chemical, or the Bureau of Mines and the USDA.

A vital factor in respiratory protection is the length of time that a canister can be safely used. There are many varying factors that determine the life of a canister, including concentration of the contaminant, quantity and type of sorbent, humidity, and breathing rate. These factors are discussed in detail in Chapters 5, 6 and 9. The Bureau of Mines tests organic vapor canisters against vapors and requires a minimum 30 min life when canisters are worn by men performing a prescribed schedule of exercises. An increase in relative humidity may decrease the life of the sorbent (see Chapter 5, Section III).

Surplus military gas masks should not be used for protection during fumigation (see discussion of surplus respirators in Chapter 1).

C. Recommendations for Respiratory Protective Devices for Protection during Fumigation

It is strongly recommended that only approved Bureau of Mines personal protective devices of the full face type be used for protection during fumigation. Each device should be specifically approved by the Bureau of Mines for the particular chemical or hazard for which it is to be used, noting, first, that the Bureau of Mines tests and approval restrict the organic vapor canisters to use in a maximum gas concentration of 2 per cent (20,000 ppm), and, second, that at this maximum concentration, the canister life is approximately thirty minutes. If the air concentration of fumigant is known or estimated to exceed 2 per cent, a self-contained breathing apparatus is recommended.

A fresh canister should be used when hydrogen cyanide, methyl bromide, or ethylene dichloride is applied. Before workmen re-enter a fumigated area to air it out, the canister used to fumigate should be discarded and a fresh canister attached to the mask. It is good practice to check the air concentration to see if it is safe to enter, especially when using hydrogen cyanide. Reliable chemical detectors are available from several safety equipment manufacturers.

Because of the complex nature of the hazards involved in fumigation, all fumigators should consult the USDA, or their State Industrial Hygiene Department, and follow their advice on application and hazards involved. For information on the

TABLE 11.2

TYPES AND COLORS OF GAS MASK CANISTERS TO BE USED FOR RESPIRATORY PROTECTION AGAINST SPECIFIC FUMIGANTS[a]

Fumigant	Odor[b]	Type of Canister[c]	Color of Canister[d]
Acrylonitrile	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Ammonia	Good	Ammonia	Green
Benzene	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Carbon dioxide	None	None	--
Carbon disulfide	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Carbon monoxide	None	Universal	Red
Carbon tetrachloride	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Chloroform	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Chloropicrin	Good	Organic vapor Acid gas and organic vapor	Black Yellow
Ethylene bromide	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Ethylene dichloride	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Ethylene oxide	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Hydrocyanic acid	NR	Hydrocyanic acid Acid gas and organic vapor	White with green stripe Yellow
Methyl bromide	None	Organic vapor Acid gas and organic vapor	Black Yellow
Methylene chloride	NR	Organic vapor Acid gas and organic vapor	Black Yellow
Phosgene	Good	Acid gas and organic vapor	Yellow
Phosphine	NR	Universal	Red
Sulfur dioxide	Good	Acid gas and organic vapor	Yellow
Sulfuryl fluoride	None	Specific canister[e]	--
Trichloroethylene	NR	Organic vapor Acid gas and organic vapor	Black Yellow

a. The universal gas mask canister will remove all of these fumigants (except sulfuryl fluoride) but would not be the canister of choice except in the two instances indicated.
b. "NR" indicates odor not reliable to determine when canister is exhausted.
c. Standard canister volume for organic vapors is 1,000 cm^3; super canister contains 2,000 cm^3. Standard canister for acid gas and organic vapors contains 1,500 cm^3.
d. The primary method of identifying canisters is to read the label. A secondary method is the color code.
e. Use only canisters specifically recommended against sulfuryl fluoride.

correct selection, use, and care of respiratory protective devices, fumigators should contact the Branch of Health Research of the U.S. Bureau of Mines, the USDA, or a responsible respirator manufacturer.

The proper canisters for respiratory protection against specific fumigants are listed in Table 11.2. It should be noted that several of the fumigants listed may cause eye irritation and require eye protection. Such protection is provided by full facepiece devices. Also, some of the fumigants are fire and explosive hazards. The volume of sorbent used for some canisters is noted. The standard organic vapor canister (1000 cm^3) will provide protection the same length of time as the super size acid gas—organic vapor canister (2000 cm^3) against the same concentration of carbon tetrachloride.

V. RESPIRATORS FOR PROTECTION AGAINST INSECTICIDES

A. Background Information

The U.S. Department of Agriculture is the only government agency that has tested and found satisfactory commercially available respirators and gas masks as being effective for protection against the following classes of pesticides: insecticides, fungicides, and nematocides.

Fulton and Smith[26] note that in 1947, when the first organic phosphorus insecticides were tested, none of the respiratory protective devices commercially available had been proved to afford protection to the operator. In 1946, Schulte[27] reported on the misuse of "dust" type respirators for protection against the volatile organic mercury compounds used in seed treating.

In 1949, several government agencies that were concerned over the inhalation hazard to operators applying dusts, sprays, and aerosols of parathion called a conference[28] which resulted in a co-operative program for the development of respirators and gas masks. Manufacturers of insecticides and respirators worked with the former Bureau of Entomology and Plant Quarantine of the USDA, which developed tests for determining the effectiveness of experimental filters and sorbents against insecticides. In 1950, Fulton[29] listed commercially available respirators and canisters for protection against dusts, mists, and low vapor concentrations of parathion.

As new insecticides were introduced, the USDA continued to release lists of commercial respirators tested and found effective against specific insecticides, fungicides, and nematocides. A current release[30] (ARS-33-76) from the USDA Agricultural Research Service (Sept. 1962) is reproduced in Appendix D.

B. USDA Respirator Program

The USDA respirator filter and cartridge testing program has been described by Fulton.[26,28] The USDA tests the filter and sorbent and in 1962 the complete respirator. The Bureau of Mines tests and approvals also (see Chapter 9) take cognizance of the performance of a completely assembled device.

The USDA began respirator testing to meet an immediate need, and their efforts have protected many workers against specific pesticides. Since Chapter 9 contains a detailed discussion of the Bureau of Mines test procedures, it is obviously necessary to acquaint the industrial hygienist with the USDA test procedures also. It should be noted that the manufacturers or packagers of pesticides are required by law (1956 Federal Pesticides Act) to have an adequate precautionary label on the package, including a direction on the label such as "use a mask or respirator passed by the USDA for (parathion, endrin, etc.) protection."

1. Test Methods

The chemical analytical procedures for insecticide aerosols which pass a filter or sorbent are rather involved, except those for malathion and parathion. These are the only organic phosphates tested by chemical analysis. The chlorinated hydrocarbon insecticides are analyzed by published methods of the Association of Official Agricultural Chemists. Filters and sorbents against fungicides and nematocides which are discussed by Fulton and McClelland[31] and classified as (1) carbamates, (2) mercury compounds, (3) halogenated hydrocarbons, (4) copper compounds, and (5) phenoxy compounds are tested by published chemical analytical procedures.

Except for parathion, which may be tested either by a chemical or a bioassay method, and malathion, most organic phosphates are checked only by bioassay, because there are no satisfactory chemical procedures for determining the amount of organic phosphate insecticides in the air passing through a filter. Aphids and mites react rapidly to most organic phosphorus compounds; therefore, the insects are used to detect these compounds in the air within a few minutes after the aerosol has passed through the filter. The filter's effectiveness is determined by counting the live and dead aphids and spider mites from colonies of known susceptibility in the insect exposure chamber after a 30 to 60 min exposure. Fulton[26] discusses the bioassay method in detail.

2. Test Apparatus

The apparatus used for biological or chemical testing of respirator cartridges consists of the following: (1) dusting or spraying chamber, (2) a cartridge or canister holder, (3) a chamber for exposing the test insects, (4) a flowmeter to determine air flow through the unit, (5) a manometer to determine the resistance to the air flow, and (6) a sampling unit for withdrawing air for chemical analysis. Air is drawn through the apparatus by a vacuum pump at a rate of 16, 32, or 64 liters per minute (l/min). This apparatus is described in detail in Fulton's article,[26] and several drawings of the equipment are given.

An apparatus to produce concentrated vapors for testing the efficiency of gas mask canisters also is described in Fulton's article and illustrated in detail. Its sampling unit and insect exposure chamber are the same as for the cartridge tests. To control the vapor pressure of the insecticide, the entire unit is placed in a large constant temperature box maintained at 85°F. All the tests are made with the insecticide concentration recommended by the chemical manufacturer and the concentration of the insecticide in the air ahead of the filter is determined. The same type of apparatus is used to test against fungicides and nematocides.

3. Results of Tests

The USDA has based their bioassay tests on known strains of insects. Fulton notes that the filters must remove all the particles in the wide range of sizes of insecticide formulations, which are classified according to particle size in Table 11.3.

TABLE 11.3

PARTICLE SIZE CLASSIFICATION FOR PESTICIDES

Classification	Size, μ
Coarse sprays	400 and larger
Fine sprays	100 to 400
Mists	50 to 100
Aerosols and fogs	50 and smaller
Coarse dusts	175 and larger
Medium dusts	45 to 175
Fine dusts	44 and smaller

For adequate protection against organic phosphorus compounds, Fulton ultimately had to use high efficiency filters, with a sorbent to remove odors from impurities. The first tests made in 1949 were with parathion, in which "dust filters" reduced the amount of parathion passing the filter to less than 0.5 ppm. When HETP and TEPP were tested, a high percentage passed through dust filters persumably satisfactory for parathion. "Fume filters" were effective in removing HETP and TEPP. When Demeton was tested, it was necessary to use the best fume filter available, plus a sorbent to remove nuisance odors from impurities. The filter—cartridge combinations developed for demeton were effective against all the previously tested organic phosphorus compounds, and against all the newer ones except Phosdrin. To remove Phosdrin, a high efficiency filter (99.95 per cent efficient for 0.3μ DOP) was required.

Fulton's work in 1949 indicated that the halogenated insecticides were removed quantitatively by activated charcoal, but not by filtration, since they produced vapors. The most satisfactory arrangement for chlorinated insecticides is a combination of a filter to remove the particles and a chemical cartridge to remove vapor. The filter also prolongs the life of the cartridge. According to Fulton's data,[28] the concentrations of dieldrin and aldrin passing through the combination of a sorbent and a filter were in excess (TLV to two times TLV) of the ACGIH threshold limit value for these pesticides. The TLV for several pesticides are given in Table 11.4. This table groups all the pesticides listed in the USDA release by chemical class.

4. USDA Recommended Respirators

The 1962 USDA release concerning recommended respiratory devices for protection against inhalation hazards of dusts, mists, and low vapor concentrations of certain pesticides is in Appendix D. This release contains a table listing certain pesticides with "respirators" and "gas mask canisters" that have been tested and found acceptable. The USDA classifies respiratory protective devices according to the size of the sorbent container. Therefore, the respirators tested may have a half mask facepiece (respirator A, for example) or a full facepiece (respirator G) with a small sorbent cartridge (50 to 200 cm^3 volume). Larger sorbent containers ($>$ 350 cm^3) are classified as gas mask canisters. Canisters tested range in volume from 350 to 1,000 cm^3 of sorbent. It should be noted that the USDA classification of respiratory protective devices differs from the system used by this Manual and the Bureau of Mines.

The USDA release contains several good recommendations for the field use and care of respirators.

TABLE 11.4

CHEMICAL CLASSIFICATION OF PESTICIDES[a] AND THEIR THRESHOLD LIMIT VALUES

Class	Insecticide	TLV,[b] mg/M^3
Halogenated hydrocarbons	Aldrin[c]	0.25
	Chlordane	2.0
	D-D	--
	Dieldrin[c]	0.25
	Endrin	0.25[d]
	Ethylene dibromide	190.0
	Terrachlor	--
	Thiodan	--
Organic phosphates	DDVP	1.0[d]
	Delnav	--
	Demeton (Systox)	0.2[d]
	Diazinon	--
	Dibrom (emulsion)	--
	Dibrom (xylene solution)	--
	Dimethoate	--
	Di-syston	--
	EPN[c]	0.5
	Ethion	--
	Malathion[c]	15.0
	Methyl parathion	--
	Methyl trithion	--
	Parathion[c]	0.1
	Phorate	--
	Phosdrin	0.1[d]
	Phostex	--
	Ronnel	--
	Schradan	--
	TEPP[c]	0.05
	Trithion	--
	Dicapton	--
	Shell SD-3562	--
Carbamates	Ferbam	15.0
	Sevin	--
	Vapam	--
	Zineb	--
Copper compounds	Calcium copper chloride	--
Mercury compounds	Ceresan	0.01[e]
	Panogen	0.01[e]
Miscellaneous	Nicotine[c]	0.5

a. See 1962 release in Appendix D.
b. All threshold limit values based on ACGIH values for 1961.
c. The liquid compound can penetrate the skin to cause systemic effects.
d. Tentative e. As mercury.

C. Air-purifying Respirators for Insecticides

Air-purifying respirators depend on the use of efficient filters in combination with activated charcoal for adequate protection against agricultural pesticides. The only effective way to remove organic phosphates is by the use of an efficient filter. The phosphates are not removed with common absorbing agents such as activated charcoal or soda lime. The chlorinated hydrocarbon insecticides show the properties of a true vapor, and they are removed quantitatively by activated charcoal. The life of the unit is prolonged by the use of an efficient filter.

The toxicity of the organic phosphate insecticides is entirely too great to chance the minimum protection afforded by chemical cartridge respirators. Malathion is the only known exception. The limitation of chemical cartridge respirators (half mask facepiece with sorbent cartridge) is discussed in Chapter 5, Section VI. Because of the small sorbent volume used in half mask cartridges and the difficulty of obtaining a reliable gas-tight seal on the face, it is emphasized that there are several insecticide vapors (for example, dieldrin and Ceresan) too toxic to chance the minimum protection afforded by chemical cartridge respirators. In Table 5.3, Chapter 5, sorbents for specific gases and vapors in the 1961 ACGIH threshold limit values are given. Sorbents for insecticide vapors were not listed, but activated charcoal or impregnated activated charcoal is generally the sorbent of choice. For mercury compounds, a mercury vapor sorbent plus filter is necessary.

For maximum protection against the highly toxic insecticides, it is recommended that only a well-fitting full facepiece gas mask equipped with an organic vapor canister (standard or extra large size) plus a high efficiency filter be selected. Befor the individual is permitted to apply insecticides, he should be properly trained in the use of the device (see Chapter 13). The gas mask described above is commercially available and will provide protection against organic phosphates, halogenated hydrocarbons, carbamates and nicotine (see Table 11.4). For mercury compounds, the Type N universal gas mask contains hopcalite, which is effective against mercury vapors.

Minimum protection is provided by half mask facepieces equipped with an organic vapor cartridge plus high efficiency filters. The Bureau of Mines approves chemical cartridge respirators for protection against a maximum concentration of organic vapors of 0.1 per cent (1,000 ppm). The insecticide concentration recommended by the manufacturer may exceed this limit. Chemical cartridge respirators plus a filter will provide adequate protection only when the wearer obtains a gas-tight face seal, when the insecticide aerosol concentration is low (< 0.1 per cent), and when the exposure time is short.

Warning: Chemical cartridge respirators should never be used for protection during fumigation with any pesticide. The USDA release in Appendix D warns that respirators are advised for protection only against the pesticides listed by them. It also warns that only full facepiece gas masks give adequate protection to those formulating or mixing pesticides in closed or inadequately ventilated spaces and to those applying pesticides, including aerosols, in greenhouses.

D. Protection against Skin Absorption

Many of the pesticides listed in Table 11.4 are known to produce toxic systemic effects when absorbed through the intact skin and are so designated. It should be noted that several other pesticides listed in Table 11.4 may produce the same effect; they are not so designated because of the lack of specific toxicological data. In the USDA release in Appendix D, it is emphasized that the use of respirators is not a substitute for essential precautions. This refers to personal protective clothing and personal cleanliness, to prevent skin absorption of the pesticide. The USDA notes that the gas mask should be worn with proper protective clothing when a workman is applying pesticides in greenhouses or other enclosed spaces.

In addition to using proper respiratory protective devices and proper protective clothing (impervious gloves, etc.), the workmen must be provided with adequate washing facilities and instructed to wash themselves and their respirators at frequent intervals. The USDA respirator maintenance and washing instructions are similar to those given in this Manual (see Chapter 12) and should be followed diligently.

VI. THERMAL PROTECTIVE RESPIRATOR

A. Background Information

Industrial situations frequently require the exposure of personnel to inordinately high atmospheric temperatures for a short time, as during repair, inspection, and cleaning inside dryers, ovens, furnaces, and kilns. Excessive temperatures may affect personnel psychologically, physiologically, or psycho-physiologically. The effects, in order of increasing severity, are discomfort, irritation, reduced work capacity, increased errors, increased accidents, imbalance of water and salt in the body, heart and circulatory system strain, acute exhaustion, and death.

Clothing which protects the head (including the eyes) and the body against excessive temperatures is used extensively in industry, with respiratory protection against hot environmental air obtained by use of a mask to which cool, respirable air is supplied through an insulated hose, or by use of a mask connected to a tank of compressed air carried on the body and insulated from the hot environmental air. These two solutions to the respiratory problem have the disadvantage that they severely limit the freedom of motion of personnel.

Frederik[32] and associates have developed a respirator, now obtainable commercially, which protects the respiratory system against hot atmospheres up to about 300°F. This compact, lightweight, self-contained thermal respirator consists of a half mask facepiece to which a simple heat exchange cartridge is attached. The respirator may be used alone for conditions of low thermal stress, or it may be worn with an aluminized asbestos hood and suit for full body protection against environments producing high thermal stress.

B. Operating Principle

The respirator described by Frederik is based on the principle of heat exchange. Because the heat capacity of a solid is much greater than that of a gas, a small mass of solid in a heat exchange cartridge can absorb and retain the heat from a relatively large volume of air. Metallic fibers in the respirator cartridge act as the heat exchanger and remove heat from the incoming air so the wearer inhales cool air. The heat, stored temporarily in the fibers, then is forced out of the cartridge when the user exhales, thus returning the cartridge to its original temperature. The heat exchange cycle is repeated each time the user breathes.

C. Construction

The cartridge is constructed so that it can be attached easily to a half mask respirator by screwing it into a holder mounted in the lightweight facepiece of the respirator. The complete respirator weighs only 6 ounces (oz) and offers a breathing resistance of only 0.2 inches (in.) of water for 85 l/min of air flow. See Fig. 11.6.

The cartridge, 3 in. in diameter and 2-3/8 in. long, consists of a number of metallic screens isolated from hot environmental air by a thermal insulating shell (molded of a low density, closed cell polyurethane foam plastic which has a very small coefficient of thermal conductivity and can withstand very high temperatures). The metallic screens which are the actual heat exchange medium are of aluminum, which is relatively corrosion resistant and has a large heat capacity compared to that of air. In addition to a high density of heat-absorbing medium per unit volume of cartridge, the metal screens have a very low resistance to the inflow of air.

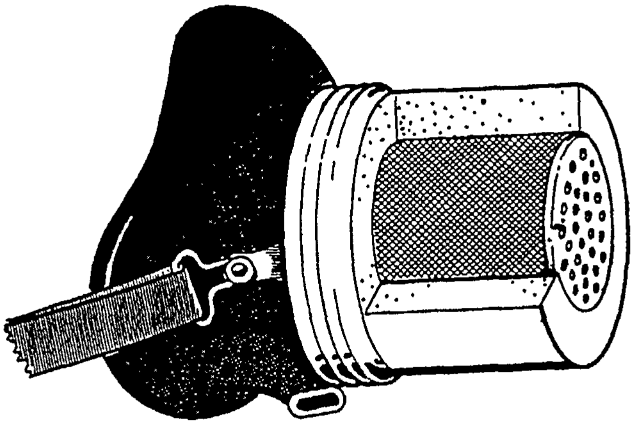


Fig. 11.6. Thermal Protective Respirator. Cross section illustrating Metallic screens (Heat exchanger) mounted in foam plastic shell of cartridge. The exhalation valve is plugged.

D. Applications

Laboratory investigation showed that the heat exchange cartridge maintained a temperature difference of 198°F after an 8 hr exposure to an environmental temperature of 300°F, for a pulsating air flow with an average flow rate of 85 l/min and 35 pulses per minute, approximately the respiration conditions of a person working at the rate of 8,000 foot-pounds per minute (ft-lb/min).

Some typical applications of the thermal protective respirator include use by technicians who must periodically inspect materials in drying ovens in the plant of a building materials manufacturer; employment in a glass manufacturing plant by maintenance men who must repair furnaces in an environment of 150°F; and use by power house workers in a factory in which boilers are repaired at 250°F.

When the respirator is used in dusty operations, a dust filter attached to the heat exchange cartridge provides respiratory protection against both dust and hot environmental air.

The respirator also is effective in low temperatures, as in walk-in freezer lockers. The temperature of the incoming frigid air is raised almost to body temperature. In this application the heat exchange cartridge usually is warmed before use.

VII. HOUSEHOLD ITEMS FOR EMERGENCY USE IN CIVILIAN DEFENSE

In case the civilian population of all ages should ever need emergency respiratory protection against aerosols resulting from radiological, biological, or chemical attack, it is worthwhile to include a discussion of an evaluation of eight common household and personal items for emergency use as respiratory protective expedients. This evaluation, reported by Guyton and Anton,[33] was made by personnel from the biological warfare laboratories of the U.S. Army Chemical Corps at Fort Detrick, Maryland, at the request of the Division of Biology and Medicine of the AEC.

Eighteen variations of eight household and personal items were evaluated to determine their potential utilization as emergency respiratory protection expedients in the event of a radiological or biological attack. Military enlisted men used these materials as respiratory protective devices in an atmosphere containing spores of a nonpathogenic bacteria. The mass median diameter of particles in the aerosol was 2.1μ, with 95 per cent of the particulates between 1.0 and 5.0μ.

The respiratory protective expedients tested possessed no mechanical means such as a strap or harness to maintain an effective peripheral seal. It was realized that a limitation of the test would be the reliability of the seal, which would depend solely upon the care taken by the subjects themselves to ensure a good peripheral seal. Experience in designing tests utilizing human subjects indicated that a minimum of 30 replicate observations would be necessary for each item evaluated. The results of these tests are given in Table 11.5.

It will be noted that five variations of these items had a filtration efficiency greater than 85 per cent. They are: man's cotton handkerchief, folded to a thickness of 16 layers, also when folded to a thickness of eight layers, and when placed over the mouth and nose in a crumpled state; a commercially available toilet paper when used in the thickness of three sheets; and a turkish bath towel when folded in two layers.

An important factor to consider in deciding which of these items would be superior for use as a respiratory protective expedient is the resistance to breathing offered by each. The evaluation of the respiratory protective items included asking the subjects if the item exhibited too great a resistance for normal breathing. Based on the unanimous agreement of the subjects and the recommendations of the Chemical Warfare Laboratory personnel, it was concluded that those items with a resistance of 36 millimeters (mm) of water or greater would be limited in their use as respiratory protective expedients. Although no data were available, the Chemical Warfare Laboratory personnel expressed doubt that women and children could tolerate any resistance greater than about 20 mm of water for an indefinite period.

In considering the resistance criteria, a 36 mm resistance of the man's handkerchief (16 fold)

TABLE 11.5

RESPIRATORY PROTECTION PROVIDED BY COMMON HOUSEHOLD AND PERSONAL ITEMS AGAINST AEROSOLS OF 1 TO 5μ PARTICLE SIZE

Item	Number of Thicknesses	Resistance, mm of H_2O	Number of Observations	Geometric Mean Efficiency, %	95% Confidence Limits for Mean, % Lower	95% Confidence Limits for Mean, % Upper
Handkerchief, man's cotton	16	36	32	94.2	92.6	95.5
Toilet paper	3	13	32	91.4	89.8	92.8
Handkerchief, man's cotton	8	18	32	88.9	85.5	91.6
Handkerchief, man's cotton	Crumpled	--	32	88.1	85.1	90.5
Bath towel, turkish	2	11	32	85.1	83.3	86.8
Bath towel, turkish	1	5	30	73.9	70.7	76.8
Bed sheet, muslin	1	22	32	72.0	68.8	74.9
Bath towel, turkish	1 (wet)	3	31	70.2	68.0	72.3
Shirt, cotton	1 (wet)	>150[a]	15	65.9	57.9	72.3
Shirt, cotton	2	7	30	65.5	60.8	69.6
Handkerchief, woman's cotton	4 (wet)	84[a]	32	63.0	57.3	67.9
Handkerchief, man's cotton	1 (wet)	98[a]	30	62.6	57.0	67.5
Dress material, cotton	1 (wet)	180[a]	31	56.3	49.6	62.0
Handkerchief, woman's cotton	4	2	32	55.5	52.2	58.7
Slip, rayon	1	6	32	50.0	46.2	53.6
Dress material, cotton	1	5	31	47.6	41.4	53.2
Shirt, cotton	1	3	32	34.6	29.0	39.9
Handkerchief man's cotton	1	2	32	27.5	22.0	32.5

a. Resistance obtained when checked immediately after hand wringing. This resistance began to decrease after about one minute when the material started to dry.

would limit the use of this item as an expedient. Because of its obvious variability, no resistance data were obtained for the man's handkerchief in a crumpled state. However, it can be assumed that the resistance approximates that of the 16-fold handkerchief.

There were divided opinions concerning the muslin bed sheet, which had a resistance of 22 mm.

A three-layer thickness of toilet paper exhibited the highest efficiency of the items whose resistance is less than 20 mm. However, accumulated moisture from the breath could cause this material to tear easily, which would preclude its use for any long period of time. The two remaining items, bath towel in two layers and man's handkerchief in eight layers, do not appear to have any serious limitations.

Prior to these tests, there was considerable discussion concerning the aerosol filtration efficiency of wet versus dry materials. Consequently, it was decided to evaluate all the cloth items after they had been saturated with water and then hand wrung. However, two of these items, the muslin bed sheet and rayon slip, could not be evaluated since they exhibited intolerable resistance to human breathing. Two of the remaining five wet items, woman's handkerchief (four layers) and cotton dress material (one layer), showed a slight increase in filtration efficiency. Efficiencies of the cotton shirt material (one layer) and the man's handkerchief (one layer) increased about twofold. The other item tested after wetting, the bath towel (one layer), gave slightly less protection when wet than when dry. This difference, however, is not statistically significant. The results demonstrate that the protection of 70.2 per cent provided by the best of the five wet items, the bath towel, is still inferior to that of seven dry items. The resistance to breathing produced by these wet items, with the exception of the bath towel, was extremely high. In general, therefore, the use of such wet items as respiratory protective expedients is not practical.

Caution: The reader should be cautioned, if considering the use of two layers of a common household bath towel or of eight layers of a man's handkerchief, that the indicated efficiencies were obtained by trained military personnel who were conscientiously making every effort to obtain a good fit on the face. It must be assumed that a small child could not be counted upon to obtain a reliable seal while holding one of these items over the nose and mouth. Also, it should be stressed that these items were tested against aerosols and under no circumstances will they provide protection against gases or vapors.

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Chapter 12

MAINTENANCE, CARE, AND STORAGE

Maintenance is an important phase of any control procedure, and this is as true for respirators as it is for ventilation equipment. No matter how well a respirator is designed or how good its performance, it cannot give satisfactory protection unless it is maintained in good condition. This, one of the most important factors in the use of these devices, is yet the most frequently neglected, particularly with nonemergency respirators in which the results of such neglect are not so readily evident. In addition to providing adequate protection, proper attention to maintenance of respirators in use has a definite economic value. Well-maintained equipment lasts longer and requires less frequent replacement.

The operations of a maintenance program—frequent and periodic inspections, cleaning, replacing or repairing worn or deteriorated parts, and storage—should be centralized wherever possible. They should also be supervised carefully by a responsible and capable person, because proper care and maintenance require a thorough knowledge of the device.

I. INSPECTION

All routinely used respirators should be inspected frequently.

Emergency respirators should be inspected at least every 30 days because, though they may stand unused for a considerable time, they must be available in first-class condition at a moment's notice. The tightness of connections should be checked, as well as the condition of the facepiece, headbands, exhalation and inhalation valves, connecting tube, and canister. The rubber parts of emergency equipment should receive particular attention to assure that they show no signs of deterioration. Unused rubber parts should be kept pliable and flexible, and prevented from taking a set during periods of disuse by working, stretching, and manipulating with a massaging action during the inspection. If the sides of the exhalation valve gap even slightly, a new valve should replace the old.

Emergency devices should be cleaned after each use. After the device is dry, an antifogging compound should be placed on the inside of the lens. Damaged lenses in some masks can be replaced by maintenance personnel, whereas others must be replaced by the manufacturer. The carrying cases for emergency devices are designed to protect facepieces but the device must be properly placed to prevent crimping or pinching. The storage place should be cool and dry, because high temperatures shorten the useful life of rubber parts.

Self-contained breathing apparatus, either demand- or recirculating-type, must be inspected monthly. The air or oxygen cylinder must be fully charged to 1,980 pounds per square inch (1,800 psi plus 10 per cent at 70°F, as allowed by the Interstate Commerce Commission), and the regulator must function properly. No attempt should be made to repair or adjust either the reducing or admission valve mechanism or the safety valve of the regulator. If the regulator is not operating properly, it should be returned to the manufacturer for adjustment or repair. It is extremely dangerous for anyone other than a highly trained mechanic, who thoroughly understands the construction, operation, and adjustment of a regulator to attempt to repair or adjust the regulator.

II. CLEANING

Routinely used respirators also should be cleaned after each use, and they should be collected at a central point at the end of each shift for cleaning and inspection. Each person's respirator should bear some sort of identification, such as his initials or employment number. When a worker recevies a respirator, he should be briefed on the cleaning procedure and assured that he will always get the same device. If the respirators are serviced between shifts, only one respirator per workman is needed. If the cleaning is done during a work shift, each worker requires two respirators. When not in use (for example, during the lunch period), the respirators should be stored in clean cabinets at convenient locations in the work area.

It is generally accepted that washing with a good detergent in warm water, by hand brushing or agitation in a washing machine, is a sound basic cleaning procedure. According to Drinker and Hatch,[1] "there is no reason to require special sterilizing . . . . Scrubbing with warm water and soap, rinsing, and air drying in a clean place is entirely adequate."

There are a number of procedures currently in use for cleaning respirators. When a respirator is used by only one individual, a practical method of cleaning is as follows:

1. Remove the filter or cartridge and discard.
2. Wash in good detergent or soap in warm water (120°F).
3. Rinse completely in clean, warm water.
4. Air dry the device in a clean area.
5. Inspect the valves, headstraps, and other parts; replace with new parts if defective.
6. Insert new filters or cartridges; make sure the seal is tight.
7. Place in a plastic bag for storage.

For complete decontamination against phosphate pesticides on respirators, following washing with alkaline soap, it should be rinsed with 50% alcohol (ethyl or iso propyl).

Several respirator manufacturers currently sell a cleaner sanitizer that effectively cleans the respirator and contains a bactercidal agent. This bactercidal agent is generally a quaternary ammonia compound. One manufacturer marketing a combination detergent and quarternary ammonia salt recommends immersing the respirator in the solution, rinsing in clean, warm (120°F) water, and air drying.

When the same respirators are used by different individuals, a good public health policy is to disinfect them before they are re-issued. The literature[2-5] lists a variety of chemicals and methods for disinfecting respirators. A number of the procedures are unsatisfactory. For example, formaldehyde not only is a poor disinfectant, but it is absorbed on the rubber and may cause dermatitis. Soaking a respirator in a 70 per cent solution of ethyl alcohol for 1 hr may be partially effective. Live steam or very hot water (170°F), organic solvents, and ultraviolet light should not be used because of their injurious effects, particularly on the rubber parts.

The compounds generally considered to be the most reliable for disinfecting respirators are: (1) a hypochlorite solution (50 parts per million (ppm) of chlorine; immersion time, 2 min), or (2) an alcoholic solution of iodine (50 ppm iodine; 2 min immersion). A concentration of 200 ppm of quaternary ammonia compounds in water with less than 500 ppm total hardness is generally an effective disinfecting solution. The disadvantages of the quaternary ammonia compounds are: (1) different concentrations of salts are required to achieve a disinfecting solution with waters of varying composition, and (2) the possibility of dermatitis if the quarternary ammonia salts are not completely rinsed from the respirator.

If cleaning and inspection reveal parts which should be replaced or repaired, this should be done only by experienced personnel with parts specifically designed for the particular device. Filters or chemical cartridges also can be replaced at this time. Whether such replacements are made after each use or after some definite period of time will depend upon the conditions under which the device is used and upon past experience. In general, if the conditions are not relatively constant and well-known, replacement after each use is recommended, particularly for cartridges and canisters using sorbents.

III. STORAGE

After cleaning, inspection, and necessary repair, the equipment should be stored properly, in essentially dustproof containers, away from sunlight, heat (not near radiators or steam pipes), extreme cold, and excessive moisture. Most devices come in cartons or cases which are suitable for storage; however, if devices are placed at stations and work areas for emergency use, special compartments may be necessary to protect the devices even in their original containers. Routinely used devices, such as dust respirators, may be placed in plastic bags. The devices should never be stored in such places as clothes lockers or tool boxes unless they are in their carrying cases or cartons.

Respirators should be packed or stored so that the rubber facepiece and exhalation valve will rest in a normal position and function will not be impaired by the rubber setting in a bent or twisted position.

Instructions for the proper storage of emergency devices, such as universal gas masks and self-contained breathing apparatus, are on the "instructions for use and care" bulletin mounted on the inside of their carrying case lid.

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Chapter 13

TRAINING

I. INTRODUCTION

A very important, but often neglected, phase of respiratory protection is adequate training of those who are expected to use such protection. It is a common misconception that training is needed only for the self-contained breathing apparatus. Training is necessary for supervisors, such as foremen who are to supervise the use of any type of respiratory protective device, as well as for those who are to wear it, if a device is to be used intelligently, confidently, and safely. Obviously, the more complicated the apparatus or the more hazardous the atmosphere in which it is to be used, the more extensive and intensive the training must be. Such training should be given by a qualified person, such as an industrial hygienist, a safety engineer, or respirator manufacturer's representative.

Training in the use of any respirator should cover the following:

1. Discussion of the airborne contaminants against which the wearer is to be protected, including information on their physical properties, possible concentrations or changes thereof, mode of physiological action, toxicity, and means of detection.
2. Discussion of the reasons for using the respirator.
3. Description of its construction, operating principles, and limitations.
4. Instruction in procedures for assuring that it is in proper working condition.
5. Instruction in fitting the respirator properly and checking for the adequacy of fit.
6. Instruction in the proper use and maintenance of the respirator.
7. Discussion of the importance of careful reading of labels on the respirator and on its container and of the manufacturer's instructions for its use and care.

An important by-product of training is the sense of confidence that the trainee should develop in his ability to use the respirator properly. If something suspicious should happen to the respirator, or to the atmospheric conditions, he would act rationally rather than panic.

To conserve space and avoid repetition, only those items of the foregoing list that require special emphasis will be included in the discussion of specific training for the various types of respirators. However, <u>all</u> of the items should be covered adequately in the training program.

II. SPECIFIC TRAINING FOR VARIOUS TYPES OF RESPIRATORS

Supervisory personnel should be trained to select the proper type of respirator for the job. A choice from several makes of the proper type and design of respirator might be left up to those who are to wear them. Such a procedure tends to lessen the workers' apparent inborn resistance to wearing a respirator.

Since the maintenance of respirators is discussed in Chapter 12, no specific instructions on this matter will be given here. However, instruction in proper maintenance of respirators is a very important part of any training program.

A. Particulate-removing Respirators

The particulate-removing (mechanical filter) respirator is the simplest type, yet there have been many instances of misuse because of inadequate training. These misuses have included such practices as wearing the respirator upside down, wearing it without filters or without exhalation valve, and discarding the entire respirator because the filter "plugged up." Trained persons would not have committed these blunders.

Since the main field of use of particulate-removing respirators is for respiratory protection against contaminants that have no immediate unpleasant effects, the worker usually must be convinced that it is necessary for him to wear the respirator. This can be accomplished in a factual manner without undue "scare" tactics.

Instruct the trainee how to check the respirator to be sure that it is in good wearing condition. Then allow him to actually check a respirator as follows:

1. Check the exhalation and inhalation valves to see that they are in place and not misshapen, and that no dirt or lint is on the valve or valve seating surfaces.
2. Check the body of the facepiece to see that the face-contacting periphery is clean and has not been unduly softened by body oils, distorted, or hardened.
3. Check for the presence and condition of gaskets and special spacers, if any.

4. Check to see that the filter seating surface is not damaged.

5. Check to see that the filter designated for the intended use is present and is properly assembled with the respirator.

6. Replace missing parts, and repair or replace damaged or defective parts.

Instruct the trainee how to wear the respirator properly. Since the most important part of this phase of training is to fit the respirator to his face, show him how to test for proper face fit, then remove the respirator from his face, and have him go through the procedure several times by himself until he is confident that he can do it properly. Stress the importance of maintaining a proper face fit. A convenient means for testing the face fit is to close off the exhalation valve and exhale gently into the facepiece. The face fit is satisfactory if a slight positive pressure can be built up in the facepiece without any evidence of outward leakage of air at the periphery.

Instruct in the need to change the filter and the procedure for changing it. Train in the proper maintenance of the respirator, particularly if a centralized system for respirator maintenance is not used.

B. Gas- and Vapor-removing Respirators

1. Chemical Cartridge Respirator

Discuss the following limitations of the chemical cartridge respirator: It is for use only against the type of contaminant listed on the cartridge label, in concentrations not exceeding the maximum given on the cartridge label. It will not afford respiratory protection against particulates unless a particulate-removing filter is indicated and present.

Instruction and training in checking and fitting the respirator should be the same as described for particulate respirators except that the trainee should check the cartridge (and particulate-removing filter, if used) to see that it is of the proper type, is in good physical condition, and is seated securely against its gasket. It is desirable that the trainee check the fit of the facepiece by actually wearing the respirator, equipped with organic vapor cartridges, in an atmosphere containing approximately 100 parts per million (ppm) of isoamyl acetate vapor (banana oil). Before this test is made, an organic vapor cartridge should be affixed to the respirator in lieu of any other type of cartridge.

A special test chamber is not needed for this training since such a concentration can be built up in any room, without damage to its contents, by evaporating 17.3 milliliters (ml) of isoamyl acetate for each 1,000 cubic feet (ft^3) of room volume. Isoamyl acetate can be detected by odor in very low vapor concentrations. If the person wearing the respirator can enter and remain in the test atmosphere for a minute or two without detecting the odor of isoamyl acetate, the respirator is properly fitted. If he detects the odor of isoamyl acetate, he should retreat to fresh air, readjust the facepiece, and then repeat the test. If leakage is still noted, he should retreat to fresh air and recheck the respirator, as previously. If the respirator is to be worn in air containing contaminants other than organic vapors, replace the organic vapor cartridges with cartridges of the appropriate type, after a satisfactory face fit test.

There are many occasions when it is necessary to conduct fitting tests in the field. A field check is illustrated in Fig. 13.1. The reliability of the face fit is checked by pouring a few drops of isoamyl acetate onto a piece of cotton and waving it gently near the periphery of the facepiece while the wearer breathes normally. The concentration is likely to be above 100 ppm, but it does serve to check the face fit and is commonly used in the field.

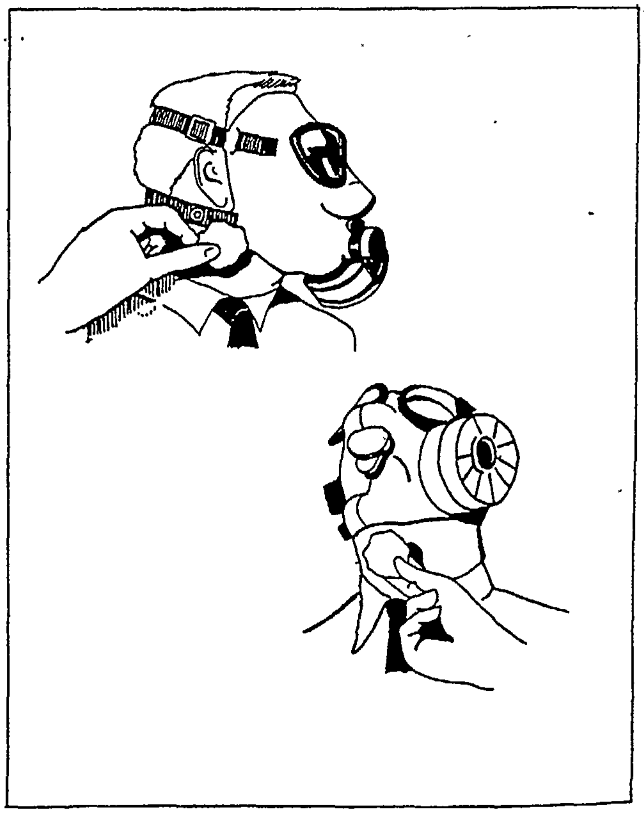

Fig. 13.1. Field test of face fit of respirators using isoamyl acetate.

2. Gas Mask

Explain the operating principle of the gas mask and its limitations (see Chapter 6, Section III). Instruct the trainee how to check the gas mask to be sure that it is in good wearing condition. Then allow him to check a gas mask as follows:

a. Check the canister to see that it is in the proper type for its intended use and that its expiration date has not passed.

b. Check the canister for dents and signs of external corrosion, for the presence of closures on the inlet and outlet openings if a new canister is to be installed (all canisters should be stored sealed), and for malformations of the canister neck.

c. If the canister has a window-indicator, check to see that there is good contrast between the indicator and reference portions of the indicator and that either the external or internal check valve is present and in good operating condition.

d. Check the canister harness to see that it is in proper condition to hold the canister securely in place on the wearer's body.

e. Check the facepiece for cracked or discolored eyepieces, dirty or misshapen exhalation valves, lack of elasticity of rubber or elastomer and missing tabs, or checked appearance of head harness. Check the face-contacting periphery of the facepiece to see that it is clean and has not been unduly softened by body oils or distorted. Apply antifogging material to interior of eyepieces.

f. Check the corrugated breathing tube to see that it is flexible, that it has no visible holes in it, that it is securely fastened to the facepiece, and that the inlet end is not distorted. If a threaded canister adaptor is to be used, be sure that the inlet end of corrugated tube is securely attached and that the adaptor gasket is in place.

Instruct the trainee how to don and adjust the mask properly.

The adjustment of the neck or shoulder strap of the canister controls the "repose" position of the breathing tube. Adjust this strap so that, when the mask is being worn, there is a slight bow in the breathing tube when the wearer's head is in the normal forward position. Adjust the belt strap of the canister harness so that the canister is held securely against the wearer's body, but not tight enough to interfere with his breathing or other body movements.

The most important part of this phase of training is to fit the facepiece to his face, show him how to test for proper face fit, and have him go through the procedure several times by himself until he is confident that he can do it properly. Stress the importance of maintaining a proper face fit. There are two means for testing for the gas-tightness of fit of the complete gas mask, as follows:

1. Negative pressure test. Close off the inlet opening of the canister by covering it with the palm of the hand or by replacing the tape seal, inhale so that the facepiece collapses slightly, and hold the breath for 10 sec. If the facepiece remains in its slightly collapsed condition and no inward leakage of air is detected, the gas-tightness of the gas mask—as worn—is satisfactory.

2. Positive pressure test. Close off the exhalation valve and exhale gently so that a slight positive pressure is built up in the facepiece. If no outward leakage of air is detected at the periphery of the facepiece, the face fit is satisfactory.

If leakage that is not attributable to a poor face fit is detected, check for unsoldered joints in the canister, recheck for the presence of and condition of the gasket in the threaded breathing tube connector, tighten the breathing tube clamp, and repeat the negative pressure test. If leakage is still detected, recheck the facepiece and breathing tube as described previously, and repeat the pressure test.

It is desirable for the trainee to check the fit of the facepiece by actually wearing the gas mask, equipped with a canister that will remove organic vapors, in an atmosphere containing approximately 1,000 ppm of isoamyl acetate vapor. Information regarding the test atmosphere is given in the preceding section on the chemical cartridge respirator.

Warn the trainee to enter a contaminated atmosphere wearing a gas mask only (1) if he is certain that there is sufficient oxygen to support life, (2) if he has knowledge that the canister is of the proper type, and (3) if he has thoroughly checked the gas mask and the face fit thereof.

Instruct the trainee to enter the contaminated area cautiously, and if the odor of the contaminant is noted, to return to fresh air immediately and ascertain the cause of the leakage.

Encourage the trainee to attach a fresh, properly dated, canister before entering an extremely hazardous atmosphere, particularly one containing a gas or vapor (such as methyl bromide) which cannot be detected by odor even in harmful concentrations.

Instruct the trainee to assemble the complete gas mask, to replace missing or damaged parts and to repair defective parts.

Information and instruction to develop confidence should supplement a trainee's practice in the use of masks. The following factors are important and should be explained to the user.

a. Heat felt on a canister, or in the effluent air which is breathed in, indicates that the canister is giving protection. The lower part of a single layer canister will feel hot shortly after the wearer enters the toxic atmosphere, and the heat will progress upward until it is almost entirely in the upper one or two inches of the canister, at which time the break point may be expected. The amount of heat varies with each gas and its concentration. In general, the effluent air temperature will reach the limit the person can be expected to tolerate only after several minutes' use at the upper recommended concentration. This is an indication of impending exhaustion of the canister.

b. In pits or confined spaces with no ventilation, contaminants of high vapor density will remain in the lower portion of the space. Extremely high concentrations may prevail if the heavy contaminant is being released at or near the floor.

c. Contaminants with low boiling point and high vapor pressure are usually released most rapidly, producing high concentrations.

d. Air movement is the most important factor in spreading a contaminant throughout an area, producing a rise in contaminant concentration in areas downwind and a decrease near the source. If fresh air is brought into the area, the total concentration will be reduced. The mask user should be trained to recognize any change from the expected conditions so that appropriate action may be taken.

e. Every canister has some initial resistance to breathing which increases with increased exertion. As a result, those who have not been properly trained are tempted to take off their masks, calling them "no good." Instruction in the mechanics of the mask and the reasons for the anticipated resistance will bolster the user's confidence and help assure proper use of the equipment.

f. Fogged lenses, which interfere with vision, may be caused by any of several conditions, including canister storage or previous use, excessive atmospheric humidity, and improper mask design.

An old canister which has been exposed to high humidity atmospheres or excessive use may cause fogging (see Chapter 5, Section VI, a). The absorption of certain gases produces moisture; if the canister contents are saturated with moisture the excess will come through with the effluent air and fog the mask facepiece lenses. Such a canister should be replaced.

Excessively high atmospheric humidity, combined with the water produced by absorption of a high concentration of certain gases, can cause fogging even with a new canister. A larger canister is needed to correct this condition.

An improperly designed mask which does not circulate incoming air over the eyepieces will also produce fogging.

3. Mouthpiece Respirator (Self-rescue Respirator)

Since the use of the mouthpiece respirator is primarily for escape from a suddenly contaminated atmosphere, instruct the trainee to carry the respirator with him at all times when in an area where it might be needed. (In coal mining operations, carbon monoxide self-rescuers are carried on the belt by those required to move from location to location in the mine. A sufficient number of these self-rescuers for those men working in one place are stored in caches near the working place. These caches are moved forward as the working place advances.)

Instruct the trainee how to check the respirator to be sure that it is in good wearing condition, then allow him to check the respirator. Follow appropriate instructions in Sections B, 1 and B, 2.

Instruct the trainee as to how to wear the respirator. Stress the importance of using the nose clip to prevent accidental inhalation of the contaminated atmosphere through the nose. Instruct him to remove any gum, tobacco, or food from his mouth. Such solid material could lodge in the exhalation valve and cause the valve to stick in the open position and thus leak.

C. Supplied Air Respirators

As explained in Chapter 7, there are two degrees of protection afforded by supplied air respirators. The hose mask with blower will afford respiratory protection in any atmosphere, whereas the hose mask without blower, the air line respirator, and the abrasive blasting respirator afford respiratory protection only in atmospheres that are not immediately hazardous to life and from which the wearer can escape unharmed without the aid of the respirator. Hence, more training is needed for the use of the hose mask with blower than for the other types.

1. Hose Mask with Blower

Since an operator is required at the blower at all times when the hose mask with blower is used, the man who is to operate the blower and the man who is to use the respirator must be trained as a team.

Explain the operating principle of the hose mask with blower (see Chapter 7, Section I). Instruct the trainees as to how to check the respirator to be sure that it is in good wearing condition. Then allow them to actually check the respirator as follows:

a. Check the blower to see that it operates properly. Cap any unused blower outlets.

b. Check the hose to see that all gaskets are in place and in good condition.

c. Check the gasket seating surface of each hose coupling to see that it is smooth.

d. Check the hose for worn covering and for resiliency. The resiliency may be determined as follows: Grasp the hose with the hands, palms down, about six inches apart and bend it by bringing the knuckles of the hands together and holding for 30 sec. If visible cracking of the covering occurs, the hose is definitely unsatisfactory. If audible crackling is noted, the hose fabric is deteriorating and the hose should be subjected to the following additional test: attach one end of the hose section to a stationary object, such as the blower in the trunk, make a single tight loop in the hose and attach a spring scale to the free end. The trunk should be anchored securely. Apply a slow steady pull of 90 lb to the spring scale while the loop is kept from unwinding by having another man place his hand on it. The hose should not deform or break at the kink so formed.

e. Check the body harness for cracks or tears and for "pulled" belt buckle holes. Attach a section of the hose to the body harness and check the security of the attachment.

f. Check the facepiece for cracked eyepieces, dirty or misshapen exhalation valves, lack of elasticity of the rubber or elastomer and missing tabs, or checked appearance of head harness. Also, check the face-contacting periphery of the facepiece to see that it is clean and has not been unduly softened by body oils or distorted.

g. Check the interior of the trunk for loose dirt, and remove any that may be present.

h. Check for foreign material in the blower and hose by attaching the hose to the blower and operating the blower at high speed for 2 or 3 min.

i. Check the life line to see that it is in good condition and is fastened securely to the D-ring on the body harness.

j. Replace missing parts, and repair or replace damaged or defective parts.

Show the trainees how to don the body harness and facepiece and how to test for proper fit of the facepiece. There are two means for testing for the gas-tightness of fit of the facepiece, as follows:

a. Negative pressure test. Close off the inlet tube or tubes by hand pressure, inhale so that the facepiece collapses slightly, hold the breath for 10 sec. If the facepiece remains in its slightly collapsed condition and no inward leakage of air is detected, the face fit is satisfactory.

b. Positive pressure test. Close off the exhalation valve (the inlet tubes will be closed by the inhalation valve) and exhale gently so that a slight positive pressure is built up in the facepiece. If no outward leakage of air is detected at the periphery of the facepiece, the face fit is satisfactory.

A set of signals based on the number of pulls on the life line should be prearranged and practiced by the blower operator and the user of the respirator.

Instruct the blower operator to locate the blower in respirable air, to operate the blower at a steady rate, to be alert to signals from the wearer of the respirator, and to warn the wearer to return to fresh air if the intake air of the blower becomes contaminated.

Instruct the wearer of the respirator to avoid fouling or exerting extreme pull upon the hose, to be alert to signals from the blower operator, to return to fresh air immediately if the forced flow of air to the facepiece stops or if he detects contaminated air in the facepiece, and to be certaitain that he is in respirable air before he removes the facepiece.

Stress proper maintenance of the respirator.

2. Hose Mask without Blower

Explain the operating principles and limitations of the hose mask without blower (see Chapter 7, Section I). Instruct the trainee as to how to check the respirator to be sure that it is in good wearing condition. Then allow him to actually check a respirator as follows:

a. Follow instructions for items 2, 3, 4, 5, 6, 7, and 10 as given in the preceding section on the hose mask with blower.

b. Check for foreign material in the hose by blowing compressed air through it. The compressed air should be clean, that is, free from oil, water, and solid matter.

Show the trainee how to don the body harness and facepiece, and how to test for proper fit of the facepiece using either the negative or positive pressure test as described in the preceding section on hose mask with blower.

Instruct the trainee to anchor the inlet end of the hose, with screen attached, securely in an assured source of respirable air, to avoid fouling or exerting extreme pull on the hose, and to return to fresh air immediately if he detects contaminant odor.

3. Air Line Respirator

Explain the operating principles and limitations of the air line respirator (see Chapter 7, Section II). Explain the necessity for a supply of respirable air and the means for obtaining it (see Chapter 7, Section VI). Emphasize the fact that the air pressure applied to the inlet end of the air supply hose must be within the pressure range given on the approval plate of the respirator to maintain the proper rate of flow of air to the breathing zone of the wearer. Stress the importance of using the proper length of the air supply hose specified by the respirator manufacturer.

The rate of flow of air through two hoses which are outwardly similar in appearance may be markedly different.

Instruct the trainee as to how to check the respirator to be sure that it is in good wearing condition. Then allow him to actually check a respirator as follows:

a. Check the air issuing from the air supply line for droplets of water, particulate matter, and objectionable odors. These should be removed by a properly maintained air line filter. If in doubt concerning the presence of carbon monoxide, check the air issuing from the air supply line by means of a colorimetric tube type carbon monoxide detector or other method of equivalent sensitivity and specificity (see Chapter 7, Section VI).

b. Check the air supply line to see that it is of the proper type, that it is not twisted or kinked, and that it has not been worn through to the fabric.

c. Check the detachable coupling at the respirator end of the hose to see that it can be detached quickly and easily, and that it does not leak.

d. Check for the presence of and condition of the filter cartridge which is used on many air line respirators as a secondary filter for the removal of odors and large particles from the air flowing to the wearer.

e. Check the facepiece, helmet, or hood for obvious defects, such as missing or dirty exhalation valves, cracked or dirty eyepieces, broken or inelastic head harnesses, and defective flexible breathing tubes.

f. Check the helmets or hoods of abrasive blasting respirators for the general condition of their exteriors, for the presence of the safety glass or plastic eyepiece, and for the protective screen or perforated metal cover for the eyepiece.

g. Replace missing parts, and repair or replace damaged or defective parts.

If the air line respirator is of the continuous flow class, instruct the user in the proper method of donning the complete respirator and if of the flow control type, of adjusting the rate of flow of air to the interior of the facepiece, helmet, or hood. Allow him to practice uncoupling the detachable coupling so that he could free himself of the encumbrance of the air supply hose quickly in an emergency.

If the air line respirator is of the demand flow class, instruct the user in the proper method of donning the complete respirator, including a test for facepiece fit. This test may be made by either the positive pressure or the negative pressure method, as described in the section on the hose mask with blower. Instruct him to set the pressure at the inlet to the air supply hose within the range shown on the approval label.

4. Supplied Air Hoods

The supplied air hood (see Chapter 7, Section IV) is an air line respirator of the continuous flow class. However, the supplied air device described in Chapter 7, Section IV, has a flexible, clear plastic hood which distinguishes it from the abrasive blasting respirator.

Instruct the user in the proper method of donning the hood, which is generally mounted on an adjustable head band. Demonstrate how the flexible plastic hood may be closed at the bottom with a drawstring or may be tucked inside protective clothing, such as coveralls, when the hood is used for protection against airborne radioactive contaminants or irritant chemicals.

Follow appropriate instructions for air line respirator listed in the preceding section.

Caution the user that contamination on the outside of the hood may be transferred to the wearer or create an inhalation hazard when removed. For example, when the device has been worn in high concentrations of radioactive contaminants, an assistant (wearing a respirator) should remove the hood and immediately fit the wearer with an air purifying respirator. Explain that the plastic hood is relatively cheap and may be disposed of after use.

5. Supplied Air Suits

It is imperative that the individuals being trained learn the operating principles and the limitations of supplied air suits (see Chapter 7, Section V). One cannot obtain performance standards from the usual source, the U.S. Bureau of Mines, because the Bureau has not set up a schedule yet for testing and approving supplied air suits.

A supplied air suit never should be worn in an environment which is immediately hazardous to life. The wearer of the suit is dependent solely upon the attached air hose for his supply of breathing air, so that his activity is limited to a predetermined area. Moreover, should his air supply fail, he would have only two to three minutes to escape from the suit. Consequently, the environment in which the wearer is working must have both enough oxygen to support life and an immediate means of egress. A supplied air suit, in fact, always should be used with a team of two men—one to wear the suit and the second to act as a safety man, governing the air supply and continuously observing the main in the suit.

The following fundamentals should be demonstrated and explained to trainees:

a. How air is distributed to the helmet for breathing and to the legs and arms for dissipating heat and perspiration.

b. How the exhaust valves function, their location, any position or situation which may close them, and the importance of each in ensuring comfortable working conditions.

c. How and why the suits are examined and checked for leaks, cracks, and excessive wear, and how the line which supplies air to the suit is tested for safe working condition.

d. How the suits are donned without creating leaks which would permit contamination to enter and lessen the efficiency of the suit.

e. How the suit is partly decontaminated before removal, and how the wearer should be helped. If contaminated by radioactivity, or by such things as beryllium or hydrogen fluoride, the wearer should, if possible, pass from the work area into a shower before removing the suit, to wash off gross contamination. An assistant (wearing a respirator) should remove the suit because it is both difficult and impractical for the wearer to remove the suit himself, unassisted. With radioactive contamination, care must be taken to prevent contamination on the outside of the suit from being transferred to the wearer or to his clothing.

f. How the suit is cleaned, and decontaminated if necessary, after use and before storage. These procedures will vary with the type and amount of contamination; see Chapter 12.

The pressure in, and air flow to, the suit are most important. Too great air flow creates excessive pressure within the suit, ballooning the suit and hampering the operator's dexterity, as well as impairing his comfort while he performs his duties. Conversely, an inadequate air supply makes the suit difficult to wear because then the suit clings to the body and does not properly dissipate body heat and perspiration. In an extreme case, inadequate air supply could create a safety hazard for the wearer by causing an oxygen deficiency and carbon dioxide build-up. The air flow will vary between 6 and 15 cubic feet per minute (ft^3/min), depending on the individual's personal comfort preference, the duties to be performed, and the size and number of exhaust valves in the suit, but the air flow never should be less than 6 ft^3/min.

Regulating this air flow and constantly observing the wearer of the suit are the primary duties of the wearer's partner. The wearer and his partner must establish a set of hand signals as a means of communication, because the air supplied to the suit creates a nuisance noise which prevents hearing even very loud conversation. Other communication systems are discussed in Chapter 3, Section III.

D. Self-contained Breathing Apparatus

The self-contained breathing apparatus is the most complicated respiratory protective device and is worn in the most hazardous atmospheres, often under trying physical conditions. Hence, training should be most thorough, and the trainee should be physically fit. The Bureau of Mines has a formal training course for users or self-contained breathing apparatus and issues certificates to the trainees upon completion of the course. Refresher courses are given from time to time.

Space limitations of this Manual do not permit a complete discussion of the training procedures for self-contained breathing apparatus. They are described in a Bureau of Mines handbook.[1] In general, the training consists of instructing the prospective user in the construction, testing, use, care, and limitations of the apparatus. The following points are stressed:

Make certain that the apparatus is in good operating condition with fully charged oxygen or air cylinder, or fresh oxygen-generating canister.

Adjust the apparatus securely to the wearer's body and test for gas-tightness.

Attach a life line to the wearer's body if he is to enter a confined space containing a highly toxic atmosphere. Two men should tend this life line, which serves as a means of transmitting prearranged signals between the wearer and the safety men. At least one of these men should wear a similar apparatus. The life line also serves as a means of guiding the apparatus wearer to the exit and as an aid in rescue operations in case he gets into trouble.

Enter the contaminated area cautiously and return to fresh air immediately if the contaminant is detected by odor, taste, or nose and throat irritation, or if the apparatus is not functioning properly.

If entry is successful, remember the time limitations of the apparatus and allow sufficient time to return to fresh air. Do not remove the facepiece, or mouthpiece and nose clip, until after return to respirable air.

REFERENCE

1. Morrow, A. E., Demkowicz, W. M., and Chastain, G. W.: Mine Rescue Apparatus and Auxiliary Equipment, A Handbook for Miners, U.S. Bureau of Mines; Washington, D.C., 1961, 287 pp.

Appendix A

DEFINITIONS

To standardize the terms used in the respiratory protective field, Section I of Appendix A lists the American Standards Association (ASA) definitions. Because many other terms, not listed by ASA, are used in the manual and should be defined, Section II contains supplementary definitions prepared specifically for this manual. Some of these definitions are common to many scientific fields, but others are used only in respiratory protective work, and their definition is formulated from common usage.

I. AMERICAN STANDARDS ASSOCIATION DEFINITIONS*

Abrasive-Blasting Respirator: See Respirator.

Aerosol: A suspension of fine, solid, or liquid particles in air as dust, fume, mist, smoke, or fog.

Air-Line Respirator: See Respirator.

Air-Regulating Valve: An adjustable valve between the air-supply line and the breathing tube of an air-line respirator or an abrasive-blasting respirator whereby the flow of air to the facepiece, helmet, or hood may be regulated.

Air-Supply Device: A hand- or motor-operated blower for the hose mask or a source of respirable compressed air for the air-line respirator and for the abrasive-blasting respirator.

Air-Supply Line: A hose to conduct respirable air from the air-supply device to that portion of a supplied-air respirator carried on the wearer's person.

Breathing Tube: A flexible tube through which air or oxygen flows to the facepiece of a respirator.

Canister: A detachable container filled with granular materials that remove gases or vapors from the air that is drawn through the unit; it may also contain mechanical filters to remove dust, mist, and smoke particles.

Cartridge: A small canister.

Cartridge-Type Respirator: See Respirator.

Contaminant: A harmful material that is foreign to the normal atmosphere.

Demand Respirator: See Respirator.

Detachable Coupling: A device by means of which the wearer of an air-line respirator may quickly detach the air-supply line from that part of the respirator worn on the person.

Disinfection: The act or process of destroying organisms that cause disease.

Dispersoid: A colloidal or finely divided substance.

Dust: Finely divided solid particles generated by processing (including handling, crushing, grinding, or pulverizing) materials such as rock, ore, metal, coal, wood, and grain.

Eyepiece: A gastight transparent window in a gas-mask facepiece through which the wearer may see.

Exhalation Valve: A device that allows exhaled air to leave a respirator and prevents outside air from entering it.

Facepiece: That portion of a respirator that covers the wearer's nose and mouth and makes a gastight or dust-tight fit with his face; the head harness or headbands and the breathing tube are usually included in the facepiece assembly.

Filter: A device that removes contaminants from air drawn through it or that converts those contaminants into less harmful compounds.

Filter Respirator: See Respirator.

Fog: Small liquid particles, condensed from the vapor phase, suspended in a gas such as air.

Full Facepiece: A facepiece that covers the wearer's nose, mouth, eyes, and face and makes a gastight or dust-tight fit with his face. It includes eyepieces, the head harness, and breathing tube.

Fume: Solid dispersoids formed by condensation of vapors, such as those from heated metals.

Gas Mask: See Respirator.

Half-Mask Facepiece: A facepiece that covers the wearer's nose and mouth but not his eyes, and makes a gastight or dust-tight fit with his face; the headbands are included in the half-mask assembly.

Head Harness (of Gas Mask): A device for holding the facepiece securely in place on the wearer's face.

Hood: A device that completely covers the head, neck, and portions of the shoulders.

Hose Mask with Blower: See Respirator.

Hose Mask without Blower: See Respirator.

Inhalation Valve: A device that allows

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respirable air to enter the facepiece and prevents exhaled air from leaving the facepiece through the intake opening.

Irrespirable: Unfit for breathing.

Mist: Suspended liquid droplets generated by breaking up a liquid into a dispersed state.

Particulate Matter: Matter occurring in the form of minute separate particles, such as dust, fume, mist, and fog: a dispersoid.

Prefilter: A low-resistance filter pad placed in front of and in series with a regular dispersoid filter to lessen the dust load on the latter by removing the larger dispersoids from the air drawn through it.

Resistance: Opposition to the passage of air, as through a filter or orifice.

Respirable: Fit to be breathed.

Respirator: A device to protect the wearer from the inhalation of irrespirable atmospheres.

Abrasive-Blasting Respirator: A supplied-air respirator, similar in principle to the air-line respirator, providing respiratory protection for the head and neck of the wearer against impact and abrasion by rebounding material during abrasive blasting operations.

Air-Line Respirator: A supplied-air respirator designed to be connected by a small-diameter hose to a supply of respirable air under positive pressure sufficient to deliver an adequate flow of air to a half-mask facepiece, full facepiece, helmet, or hood.

Chemical-Cartridge Respirator: A non-emergency chemical-filter respirator usually having a half-mask facepiece and one or more cartridges to remove contaminants from the air drawn through them; it is designed for respiratory protection against low concentrations of gases and vapors or a combination of dispersoids, gases, and vapors.

Demand Respirator: An atmosphere-supplying respirator in which air or oxygen is admitted to the facepiece only when the wearer inhales, and in quantities governed automatically by his breathing.

Filter Respirator: A device designed for the wearer to inhale the surrounding atmosphere after it has passed through a filtering medium to remove contaminants. The filtering medium may chemically absorb or mechanically retain or obstruct the impurities.

Gas Mask: A filter respirator having a full facepiece, a canister containing the suitable granular material with or without dispersoid filter, and a canister-carrying harness; it is designed for respiratory protection against gases or vapors or a combination of dispersoids and gases and vapors.

Helmet, Respirator: A rigid device that completely covers the head, neck, and portions of the shoulders of the wearer, and is provided with an air inlet and eyepiece.

Hood, Respirator: A loose-fitting device that covers the head and neck of the wearer. It may be a nonrigid or a combination of a rigid head covering and a nonrigid skirt for the head covering.

Hose Mask with Blower: A supplied-air respirator having a full facepiece to which respirable air is forced through a large diameter hose by a hand- or motor-operated blower, and through which the wearer can inhale whether or not the blower is operated.

Hose Mask without Blower: A supplied-air respirator having a full facepiece to which the supply of air is drawn from an inlet in respirable air through a large diameter hose by the wearer's breathing effort.

Self-Contained Breathing Apparatus: A respirator in which the supply of air, oxygen, or oxygen-generating material is carried by the wearer.

Supplied-Air Respirator: A respirator that makes respirable air available to the wearer through a hose connected to a source of respirable air.

Self-Contained Breathing Apparatus: See Respirator.

Supplied-Air Respirator: See Respirator.

Timer: A device, operated by the wearer's respirations, that indicates the approximate length of time that a universal gas mask has been worn.

Toxic Dust: Dust that may be harmful to the respiratory tract or to other parts of the body through passing from the respiratory tract into the blood stream.

Valve: A device that permits the passage of air through it in one direction only.

II. SUPPLEMENTARY DEFINITIONS

Absorption: The incorporation of a gas or vapor by chemical action within the pores of a solid.

Activity: The capacity of a sorbent to sorb a particular gas or vapor under specified conditions.

Adsorption: The adhesion of a gas or vapor to a solid surface due to molecular attraction.

Air-Purifying Respirator: A respirator to remove gaseous and/or particulate contaminants.

All Service Canister: Trade name for universal canister.

Anthropometric: Pertaining to measurements of the human body.

Bizygomatic Diameter: Greatest breadth across zygomatic arches (bone between cheek and ear).

Break Concentration: Concentration of contaminant which will saturate canister sorbent within a specified time period.

Canister Sizes: Supersize: trade name for large canister (approximately 2000 cc. sorbent). Industrial: fill volume (750 to 100 cc.) affording good protection for a single gas or vapor. Facepiece Attached: (280 to 500 cc.) for limited use in low concentration.

Capacity: The total amount of gas or vapor which can be removed from an air stream by the sorbent under specified conditions. This is expressed as the ratio of the weight of sorbed substance to the weight of sorbent.

Catalysis: Acceleration of a chemical reaction produced by a substance (catalyst), which is unchanged at the end of the reaction.

Chemical Filter Respirator: Same as gas and vapor removing respirator.

Critical Bed Depth: Minimum depth of a sorbent required to remove a specific gas or vapor concentration from an air stream under specified test conditions.

Desorption: The evolution of gases or vapors that have been adsorbed within a sorbent. The reverse of adsorption.

Diffusion: The intermixing movement of extremely small particles due to molecular motion.

Direct Interception: The deposition of a particle from a streamline onto a filter fibre due to the streamline's passing the fibre within a distance equal to or less than the radius of the particle.

Dispersoid-Removing Respirator: A filter respirator that removes particulate contaminants such as dusts, fumes, and mists.

Electrostatic Attraction: Force tending to move charged particles towards an oppositely charged surface while passing through an electric field. Charge may be carried or induced.

Eyepiece: A gas tight transparent window in a respirator facepiece through which the wearer may see.

Gas- and Vapor-Removing Respirator: A respirator designed for the removal of gases and vapors.

GMA Canister: Trade name.

GMD Canister: Trade name.

Inertial Impaction: Deposition of particles on a filter due to inertial effects produced by particle mass and velocity.

Loading (of filter): Deposition of particles on the filter, thereby reducing pore size and increasing efficiency and resistance.

Mandible Height: Distance from midpoint of inferior border of mandible to the superior point of the gum between the two central lower incisors.

Mechanical Filter Respirator: Same as Dispersoid removing respirator.

Nares: The external openings of the nose.

Nasion-Menton: Face height; distance between Nasion (the middle of the naso-frontal suture) to the midpoint of the inferior border of the mandible.

Nonemergency Respirator: A device designed to provide protection against atmospheres which are not immediately dangerous to life and from which the wearer can escape without the aid of the respirator.

Nuisance Dust: Nontoxic and nonfibrosis-producing particles that dissolve and pass directly into the blood stream or remain in the lungs producing neither local nor systemic effects.

Pneumoconiosis-Producing Dust: Particles which remain in the lungs and may cause significant pulmonary impairment.

Recirculating Self-Contained Breathing Apparatus: A self-contained breathing apparatus that removes carbon dioxide and moisture from the exhaled air and adds oxygen to the exhaled air for rebreathing by the wearer.

Retentivity: The total amount of gas or vapor which once sorbed will be retained by the sorbent under specified conditions. This is expressed as the ratio of the weight of sorbed substance to the weight of sorbent. It is always less than the capacity.

Reynolds Number: A dimensionless number describing flow conditions. Below a Reynolds Number of 2000, laminar or viscous flow exists. Above a Reynolds Number of 3000, turbulent flow exists.

SCUBA: Self-contained underwater breathing apparatus.

Sorbate: That which is adsorbed or absorbed.

Sorbent: A substance which has the capability of retaining gases or vapors by the adsorption or absorption mechanism.

Standard Deviation (σ_g): A statistical measure of spread of a mathematical distribution.

Threshold Limit Value: The time average atmospheric concentration of a contaminant to which workers can be repeatedly exposed, for an eight hour work day without adverse effect.

Universal Canister: U. S. B. M. type N canister, designed to remove acid gases, organic vapors, ammonia, carbon monoxide, and dispersoids.

Viscous Flow: Laminar or streamline flow; flow at low Reynolds Number.

Window-Indicator Universal Canister: A universal canister with a small window on one side which gives a visual indication of the canister's ability to remove carbon monoxide and indicates the end of useful service life of the universal canister against carbon monoxide.

Appendix B

RECOMMENDATIONS REGARDING RESPIRATORY PROTECTION AGAINST HIGHLY TOXIC AEROSOLS*

The U.S. Bureau of Mines is carrying out a program that will eventually lead to the preparation of performance requirements for respiratory protective equipment designed to protect the wearer against the inhalation of highly toxic aerosols. The Joint AIHA-ACGIH Committee on Respiratory Protective Equipment believes that some performance criteria are necessary to cover the interim before the advent of formal approval procedures.

For the interim, the Joint Committee recommends the following approach to the protection of personnel against the inhalation of highly toxic aerosols:

A. Highly Toxic Aerosols of Unknown Concentration

Use respirators that provide a positive pressure at all times in the breathing zone of the wearer. Such respirators include certain types of supplied-air respirators and self-contained breathing apparatus.

B. Highly Toxic Aerosols in Known Concentration**

For exposures to concentrations that are less than 10 times the threshold limit value (TLV), use a half mask with "high efficiency" filter.

For exposures to concentrations that are less than 100 times TLV, use a full facepiece with "high efficiency" filter.

The wearers should be instructed in the proper method of fitting and using the respiratory protective equipment, and the equipment should be maintained in good operating condition.

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*Prepared by the Joint AIHA-ACGIH Committee on Respiratory Protective Equipment. A footnote to the title of the recommendations reads: "For the purpose of this recommendation, 'highly toxic aerosols' are defined as solid or liquid particles of materials which are significantly more toxic than lead but which present no inhalation hazard due to vapors of the materials at temperatures less than 100°F."

**The term "known concentration," as used in this statement, implies a knowledge of the concentration based on actual measurements prior to exposure, sufficient previous evaluation of the operation, or the careful evaluation of the operation and a conservative estimate of the concentration by a trained observer.

Appendix C

PROTECTIVE AGAINST PARTICULATES SIGNIFICANTLY MORE TOXIC THAN LEAD

AD HOC AEC COMMITTEE ON RESPIRATORY PROTECTIVE EQUIPMENT REPORT OF THE SUB-COMMITTEE ON REQUIREMENTS

SUGGESTED REQUIREMENTS FOR RESPIRATORY PROTECTIVE EQUIPMENT FOR USE AS PROTECTION AGAINST ATMOSPHERES CONTAINING PARTICULATES SIGNIFICANTLY MORE TOXIC THAN LEAD*

The AEC Ad Hoc Committee on Respiratory Protective Equipment has herein synthesized certain objective requirements for respiratory protective devices to assist users, vendors, and manufacturers in understanding what characteristics and features are desired in such equipment to meet customer requirements for safe, comfortable, and functional equipment. The specifications that follow do not set forth the complete requirements but are intended to accentuate certain features that warrant special consideration. In compiling these specifications, the opinions and experience of industrial health personnél of 23 AEC contractors were weighed. It is possible that subsequent experience in the development and use of devices incorporating the features outlined herein will indicate modifications to these requirements that may be desirable in the future.

I. MASKS AND RESPIRATORS - MECHANICAL FILTER

A. FULL-FACE MASKS

1. Performance (1): Overall penetration (2) of the device shall be less than 0.1% averaged over the inhalation and exhalation cycle. Any specific device (or a size series thereof) shall provide a fit that will assure no greater than the stated penetration for at least 95% of the normal adult population (3). The 5% not achieving the stated protection shall be identifiable by some criterion.
2. Comfort:
   a. Maximum initial resistance to airflow, at 85 liters per minute; inhalation = 1.25" H_2O, exhalation = 0.75" H_2O.
   b. Maximum weight of complete facepiece, including cartridges, etc. = 1.25 lbs. Center of gravity should be as close to the face as possible to minimize neck fatigue.
   c. Device should be capable of being worn for two 4-hour periods daily without objectionable discomfort, such as "pain spots," etc.
   d. Cartridges, canisters, and other projections should be so located that unrestricted freedom of head movement is provided.
   e. The facepiece should incorporate features to minimize movement of the mask relative to the face.
   f. The device should incorporate features that will permit utilization of corrective spectacles without increasing penetration beyond the permissible maximum or adversely affecting the other stated criteria.
3. Vision:
   a. Use of the device shall not restrict normal binocular vision more than

*The following specifications pertain to the components of the respiratory equipment that actually provide respiratory protection; viz., mask and respirator facepieces, etc., but do not include the requirements for supplementary components such as bottled gas supplies, air-supply piping systems, pumps, etc.

(1) Based on tests performed with a gas and/or a standardized homogeneous particulate aerosol in the size range 0.1 μ - 0.5 μ diameter and with pulsating airflows.

(2) Overall penetration implies the combined penetration from all sources such as the filter medium, face seal leakage, leakage by valves, speaking diaphragms, etc.

(3) Based on the definition of normal U.S. adult population as reported by the U.S. Army Chemical Corps and the Federal Civil Defense Agency as a result of a study to determine the fit of gas masks.

3. Vision (cont.)

30%. Evaluation of this requirement shall be based on actual vision tests performed on individuals that represent the extreme facial characteristics of the group that the device is supposed to fit.

b. Where the use requires beta radiation protection, the lens should have a minimum thickness of 2 mm.
c. The lens should meet approved standards for safety lens material issued by the American Standards Association.
d. Air inlets should reduce lens fogging.

4. Exhalation and Inhalation Valves:
   a. Check valve(s) shall be present for inhalation and exhalation airflow control.
   b. All check valves should be adequately guarded.
5. Decontamination:
   a. Device must be capable of being decontaminated 50 times by being washed in mild soap for 15 minutes at 120°F. without functional impairment.
   b. The device should be capable of being disassembled and assembled using a minimum of common hand tools or special tools provided by the manufacturer.
   c. The device should have a smooth interior and exterior finish, incorporating design features which eliminate cracks, wrinkles, pits, and overlapping parts. Canvas or other absorbent materials should not be used.
6. Standardization:
   Where possible, facepiece components for any manufacturer's device should be standardized to permit interchangeable use of filters, cartridges, canisters or supplied air.

B. RESPIRATORS AND HALF-MASKS

1. Performance: (1) Overall penetration (2) of the device shall be less than 1.0%. Any specific device (or a size series thereof) shall provide a fit that will assure no greater than the stated penetration for at least 95% of the normal adult population (3). The 5% not achieving the stated protection shall be identified by some criterion.
2. Comfort:
   a. Maximum initial resistance to airflow, at 85 liters per minute; inhalation = 1.25'' H_2O, exhalation = 0.75'' H_2O.
   b. Device should be capable of being worn for two 4-hour periods daily without objectionable discomfort, such as "pain spots," etc.
   c. Cartridges, canisters, and other projections should be so located that unrestricted freedom of head movement is provided.
   d. The device should incorporate features that will permit utilization of corrective spectacles without increasing penetration beyond the permissible maximum or adversely affecting the other stated criteria.
   e. The facepiece should incorporate features to minimize movement of the mask.
3. Exhalation and Inhalation Valves:
   a. Check valve(s) shall be present for inhalation and exhalation airflow control.
   b. All check valves should be adequately guarded.
4. Decontamination:
   a. Device must be capable of being decontaminated 50 times by being washed in mild soap for 15 minutes at 120°F. without functional impairment.
   b. The device should be capable of being disassembled and assembled using a minimum of common hand tools or special tools provided by the manufacturer.
   c. The device should have a smooth interior and exterior finish, incorporating design features which eliminate cracks, wrinkles, pits, and overlapping parts. Canvas or other absorbent materials should not be used.
5. Standardization:
   Where possible, facepiece components for any manufacturer's device should be standardized to permit interchangeable use of filters, cartridges, or canisters.

(1) Ibid.
(2) Ibid.
(3) Ibid.

Appendix D

This U.S. Department of Agriculture release became available after the text of the Manual was completed and therefore is included as an Appendix.

September 1962 ARS-33-76

United States Department of Agriculture
Agricultural Research Service

RESPIRATORY DEVICES FOR PROTECTION AGAINST CERTAIN PESTICIDES[1]

by R. A. Fulton, Floyd F. Smith, and Ruth L. Busbey
Entomology Research Division

Increased interest in respiratory protective devices for operators handling pesticides began in 1947 and 1948, when parathion and other extremely dangerous phosphorus compounds were found highly effective in controlling insects in greenhouses and on agricultural crops. The former U.S. Bureau of Entomology and Plant Quarantine initiated an investigation of such devices. On June 22, 1949, it issued a statement on minimum safeguards to be observed in filling greenhouse aerosols containing parathion, other organic phosphorus chemicals, and methyl chloride produced under license agreements issued under U.S. Patent 2,321,023 (a public-service patent assigned to the Secretary of Agriculture). In this statement were mentioned three commercially available gas-mask canisters that had been found to give adequate protection against these insecticides. Also included were other precautionary measures to be observed.

No suitable, fully effective respirators were found to be available for protecting operators in the field from inhalation of dusts or mists of parathion and related phosphorus insecticides. The Interdepartmental Committee on Pest Control sponsored an informal meeting on September 30, 1949. Representatives of the government agencies concerned with the use of pesticides or with respiratory protection met to consider the need for such protective devices against the many new pesticides that were coming into use. As a result of this meeting, two conferences were held by representatives of these agencies and manufacturers of respiratory protective equipment. The manufacturers were invited to submit devices that might provide suitable protection. These were evaluated by the Bureau of Entomology and Plant Quarantine. On May 4, 1950, the Interdepartmental Committee issued a list of five respirators that had been found to give a high degree of protection from dusts, mists, and low vapor concentrations of parathion in field use. Subsequently, lists of respirators and gas-mask canisters found to give adequate protection against other pesticides were issued by the Bureau on August 24, 1951, and May 1, 1952; and by the Agricultural Research Service on July 12, 1954 (revised August 9, 1954); June 27, 1955; April 29, 1957; July 22, 1957; and March 20, 1961.

In November 1951, Fulton and coworkers in the Bureau (1)[2] described test methods for determining the protective efficiency of respirator cartridges and gas-mask canisters. In August 1955, Fulton et al. (4) reported on testing methods used and respiratory protective devices for insecticides in agricultural use. In January 1957, Fulton and McClellan (2) reported on respirators and gas-mask canisters found effective against several representative fungicides and nematocides. In August and September 1958, Fulton and Smith (3) described in detail the methods used in testing respiratory devices against pesticides, and they tabulated all the information obtained up to that time. In brief, the methods usually comprised

1. This publication contains all information available as of August 31, 1962 and supersedes all releases and publications on this subject by the Department.
2. Numbers in parentheses after the authors' names refer to Literature Cited at the end of this report.

drawing pesticide-laden air through the cartridge or canister into a chamber containing insects (aphids and spider mites) of known age on plants. By observing the rate of fall of the insects from the plants, for most insecticides, the effectiveness of the device under test in removing the pesticides from the air stream could be determined in a few minutes. In the case of fungicides, the air after passage through the cartridge or canister was analyzed by methods cited by Fulton and McClellan (2).

TYPES OF RESPIRATORY DEVICES

Two kinds of respiratory protective devices are in general use—chemical cartridge respirators (hereinafter referred to as respirators) and gas masks. Most respirators are designed as half-face masks that cover the nose and mouth but do not protect the eyes (Figs. 1, 2). They have one or two cartridges attached to the facepiece by a clamp or secured in a holder. The respirator facepieces are equipped with one-way valves, which allow the inhaled air to pass through the cartridges but prevent the exhaled moist breath from passing through the cartridges. Gas masks usually are made to cover the entire face (Fig. 3). Their facepieces are made to hold a canister directly or to connect to the canister by means of a flexible hose. The canister of the hose type is carried on the chest or back by means of straps.

Fig. 1. Commercially available respirator adequate for protection against pesticides.

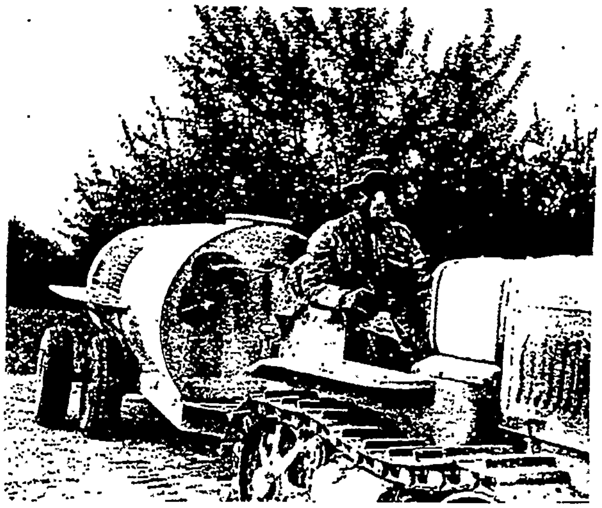

Fig. 2. Wearing respirator during power spraying.

Fig. 3. Gas mask, showing proper adjustment of facepiece.

Respirator cartridges usually contain an absorbing material such as activated charcoal. All the respirators listed in this report also have very efficient filters, which remove dust and spray particles and thus prolong the life of the absorbing material. Gas-mask canisters always contain more absorbing material and longer life filters than respirator cartridges. The volume of chemical absorbing cartridges and gas-mask canisters varies from 50 to 100 ml. (usually the latter) for cartridges, 180 to 500 ml. for chin-style canisters, and 750 to 1,800 ml. for chest-type canisters. Cartridges and chin-style canisters have a shorter useful life than regular canisters because of the smaller volume of sorbent material in them.

U.S. Bureau of Mines requirements stipulate a gas-mask canister life of one-half hour when the device is worn by men performing moderate exercise in gas concentrations up to 2 percent. The life of the canister will vary according to the concentrations encountered, e.g., 1 hour for 1 percent. The life of chemical absorbing cartridges or canisters will also be affected by humidity, temperature, and volume of breathing. High humidity shortens the life of cartridges and canisters in use and in storage. Mist, sprays of water, and rain reduce the effective period of the units. Our tests have shown that cartridges and canisters in storage will gradually lose their effectiveness because of the exchange of air within the unit due to changes in temperature and atmospheric pressure.

An interesting supplied-air respirator (Fig. 4) has a combination blower-filter with a breathing hose leading to a hood worn by the operator. It incorporates both a safety helmet and a face shield. The unit supplies purified air which has passed through filters for removing dust or spray particles and insecticide vapors. Units for mounting on tractors or application equipment (Fig. 5) are obtainable for operation on 6- to 24-volt direct or 115-volt alternating current.

Because of the difference in their protective capacity, gas masks, not respirators, must be worn when pesticides are formulated or mixed in close or inadequately ventilated spaces or when operators are exposed directly to concentrated

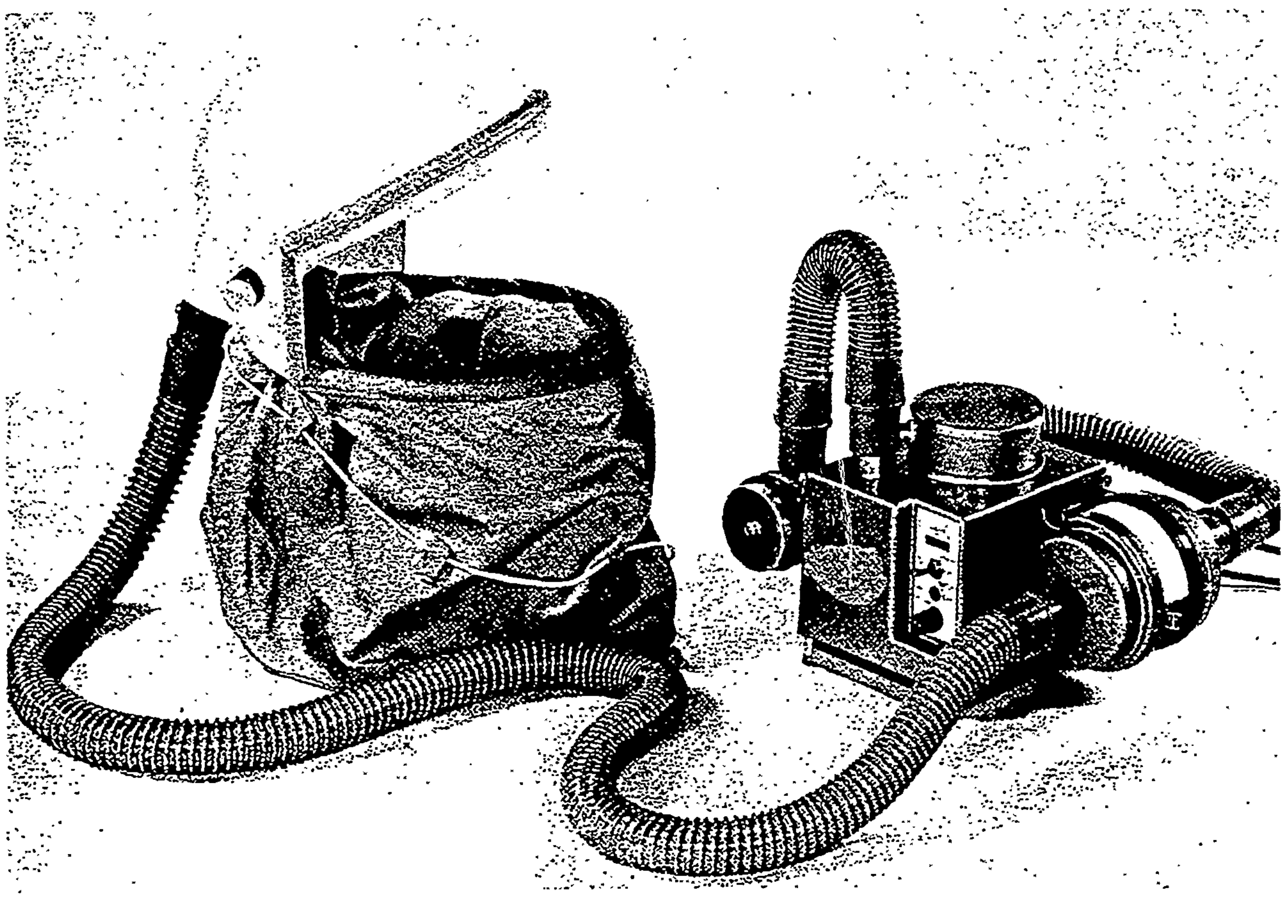

Fig. 4. Supplied-air respirator with blower-filter and hood.

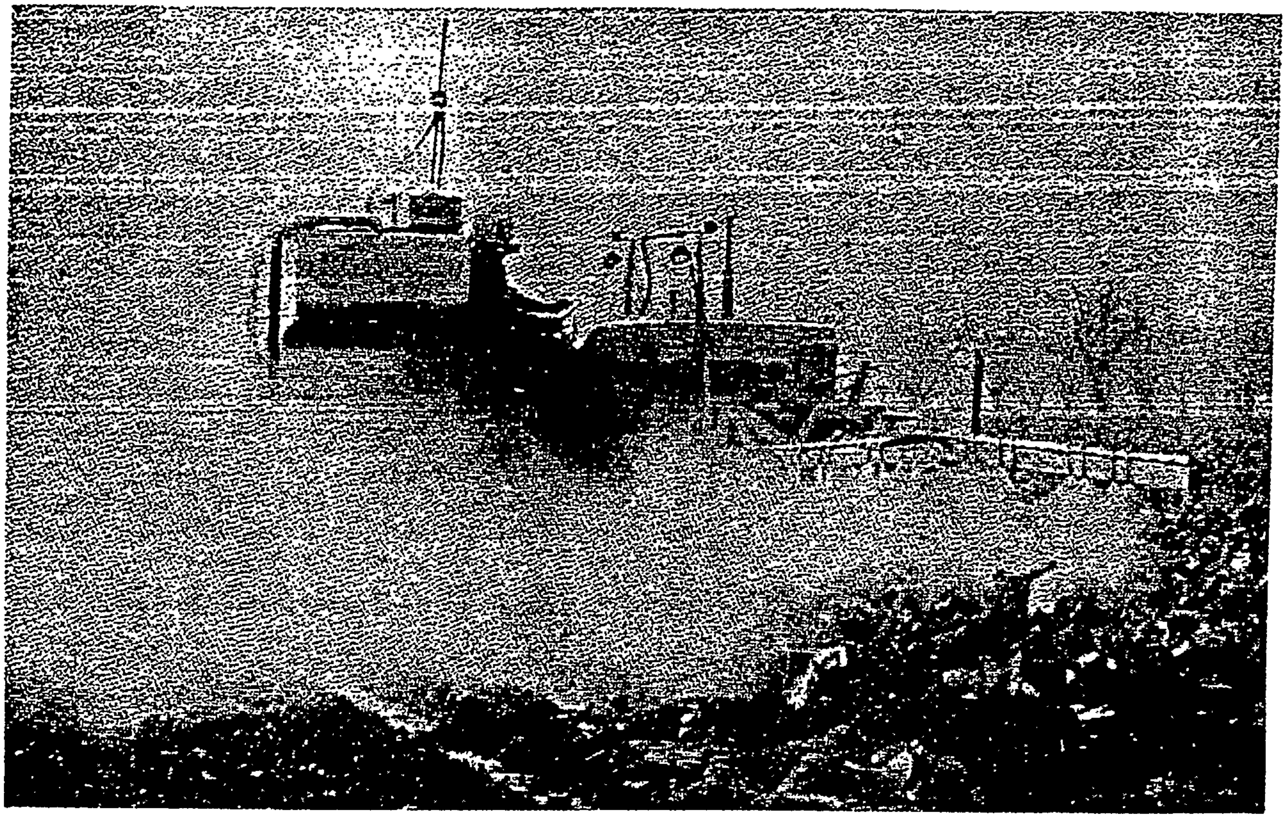

Fig. 5. Supplied-air respirator mounted on sprayer.

dusts, sprays, or aerosols, as in greenhouses, indoors, or at the rear of a power-drawn rig. For special operations, such as dusting or spraying under tobacco shade cloth or in citrus groves on hot days, a half-mask facepiece with a regular gas-mask canister is available. To protect the eyes under these conditions nonfogging goggles are desirable. These can be purchased wherever welding supplies or underwater and diving equipment is sold.

For fumigation workers in ship holds and below the surface in grain elevators, where low oxygen content may be encountered, a hose mask with blower or a self-contained air-supply unit must be used. The hose mask is connected to an air source free of the toxic material. Demand-type masks connected to a compressed-air cylinder also can be used for short periods. These cylinders are available in various sizes—the most common size contains 22 cubic feet of air, enough for 15 to 20 minutes' service. The use of an oxygen mask is not favored by some authorities where heavy work is involved, because this type of mask requires a period for the lungs to adjust to normal breathing.

USE AND CARE OF RESPIRATORS

The use of respirators is advised for protection from dusts or mists during field handling of the pesticides listed in Table 1. Instructions given on pesticide labels concerning respiratory protection should be carefully observed. The use of respirators is not a substitute for essential precautions. Protective equipment herein discussed is indicated for use when mixing or handling all pesticides in poorly ventilated areas or at high temperatures. Under open field conditions, protective equipment may not be required while applying dilute dusts or water sprays of naled, Sevin, malathion, and ronnel.[3]

It is necessary that respirators be used in handling pesticides during the loading of distribution equipment (Fig. 6), when containers are being disposed of, and whenever operators are exposed

3. The mention of proprietary products does not constitute their endorsement by the U.S. Department of Agriculture.

Fig. 6. Wearing respirator while loading spraying equipment with insecticide concentrate.

to obvious amounts of dusts or mists of the more dangerous pesticides. Field operators who may be exposed continuously during the day or for successive days to small amounts of toxic pesticides—even those not readily detectable—should faithfully use respirators as a precaution.

Respirators will give adequate protection to airplane pilots during normal dusting or spraying operations, but gas masks are necessary when there is exposure to high concentrations of the more toxic pesticides. Pilots should take care to select and wear goggles that give a tight seal with the respirator around the nosepiece.

When respirators are used, the following practices are necessary:

(1) Change filters twice a day or oftener if breathing becomes difficult.
(2) Change cartridges after 8 hours of actual use or oftener if any odor of the pesticide is detected.
(3) Remove filters and cartridges and wash the facepiece with soap and warm water after use. After washing, rinse it thoroughly to remove all traces of soap. Dry the facepiece with a clean cloth that is not contaminated with the pesticide. Place the facepiece in a well-ventilated area to dry.
(4) Store the respirator, filters, and cartridges in a clean, dry place—preferably in a tightly closed paper or plastic bag.

The respirator should be fitted properly on the face, not too high on the nose, with the narrow part over the bridge of the nose, and the chin cup contacting the underside of the chin. Headbands should be adjusted just tightly enough to insure a good seal (Fig. 3). Manufacturers can supply special facepieces if the standard one does not fit.

CONDITIONS REQUIRING GAS MASKS

Respirators do not provide needed protection from inhalation of pesticide dusts, mists, and vapors for operators formulating or mixing pesticides in closed or inadequately ventilated spaces. Full-face gas masks equipped with tested canisters are worn under these conditions. In addition, proper protective clothing as specified on the pesticide-container label should be worn when applying pesticides in greenhouses or other enclosed spaces (Fig. 7).

When applying grain fumigants, recommendations of the fumigant manufacturer should be followed closely. In some situations, as when pouring concentrated fumigating material directly on the surface of grains, there may be very high concentrations of gas close to the air inlet of the gas-mask canister. The concentration of the gas in the intake air may be reduced by mounting the canister on the back (Fig. 8).

OTHER ESSENTIAL PRECAUTIONS

The use of respiratory protective devices does not eliminate the need for other precautions in handling toxic pesticides. Provide for adequate ventilation of the area where pesticides are loaded or mixed. Always wear well-constructed natural-rubber latex gloves when handling concentrated materials. Check the condition of the gloves frequently and discard them if they develop pinholes or breaks. If any of the organic phosphorus insecticides are spilled on the skin or clothing, wash immediately with laundry soap. Never wear clothes that have been contaminated with pesticides until they have been washed. If at any time the concentrated pesticide is spilled, cover it

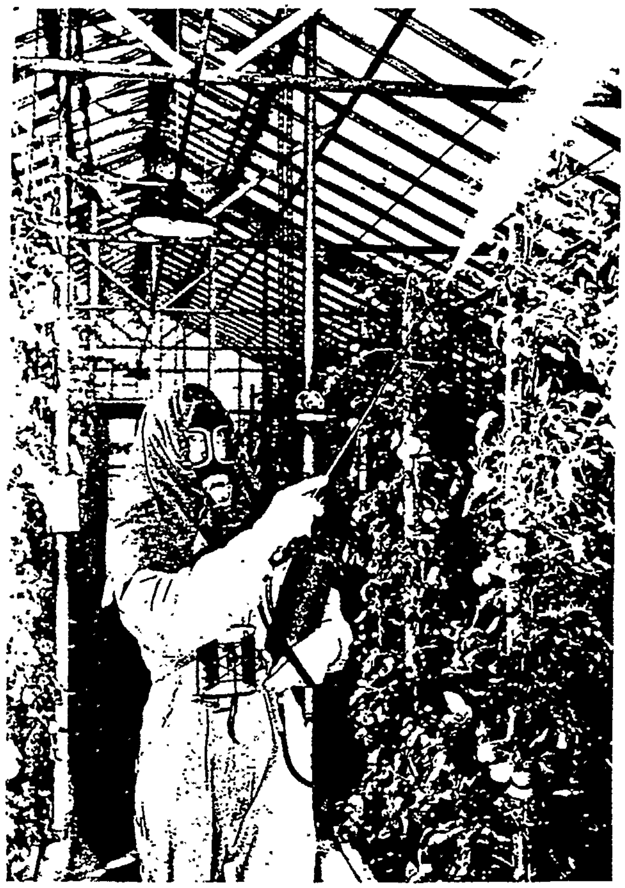

Fig. 7. Gas mask and protective clothing used during aerosol treatment in greenhouse.

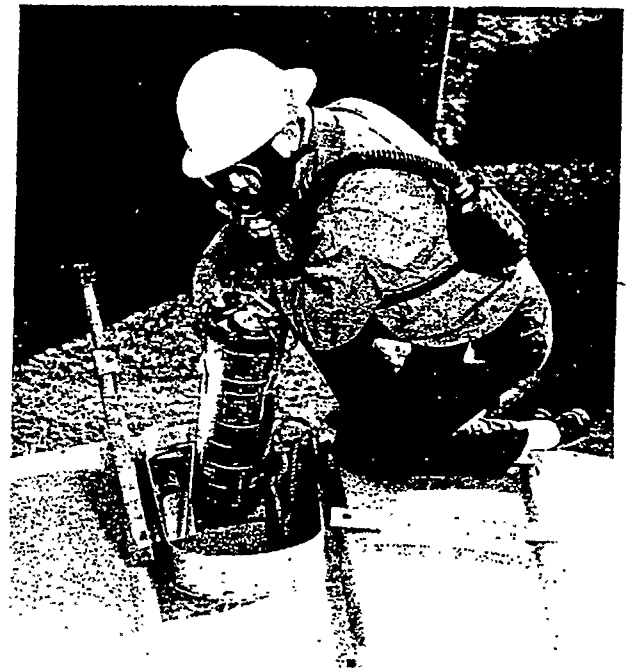

Fig. 8. Gas mask with canister mounted on back of operator to reduce concentration of gas in intake air while applying grain fumigant.

immediately with dirt, clay, or sand. Then cover the contaminated area with washing soda or lime.

If an operator shows any sign of dizziness or nausea, he should immediately be removed from the area and placed in the care of a physician before he returns to work.

LIST OF RESPIRATORS AND GAS-MASK CANISTERS

The commercially available respirators and gas-mask canisters that have been tested and found to give adequate protection against dusts, mists, and low vapor concentrations of certain pesticides are listed below. In developing and testing new designs for respiratory protective equipment, we have tested each device against the pesticides for which it actually will be used. Following the list is a table showing the particular pesticides against which each respirator or canister will give protection. It should be noted that some of the devices are limited in their range of effectiveness. Cartridges and canisters that protect against individual pesticides do not always give adequate protection against mixtures of the same pesticides. Before a facepiece, cartridge, or canister is purchased, its range of usefulness should be checked.

Respirators with Face-Mounted Cartridges

A. Respirator No. 5055, equipped with R-55 filter and cartridge unit. Two units attached to facepiece. (American Optical Co., Safety Division)
B. Healthguard Respirator style 95, equipped with Code B cartridge and filter 1000 or 1001. One unit attached to facepiece. (Chicago Eye Shield Co.)
C. DCA 6100 Respirator, with Para-A cartridge and DC 6100-7 felt filter. (Pulmosan Safety Equipment Corp.)
D. Agrisol Dust and Vapor Respirator, equipped with R-414 filter and 11-A cartridge. Two

units attached to facepiece. (Ray-O-Vac Co., Willson Products Division)

E. Respirator No. 5561, equipped with filter cartridge combination R-561. (American Optical Co., Safety Division)

F. Farm Spray Respirator No. CR-72183, equipped with cartridge No. CR-49293 and filter No. 73488. (Mine Safety Appliances Co.)

G. All Vision Chemical Cartridge Respirator No. CR-74910, equipped with inner cartridge No. CR-73841 and outer cartridge No. 73927. (Mine Safety Appliances Co.)

H. Agritox Respirator, equipped with cartridge No. 11A (new type) and filter No. R490. (Ray-O-Vac Co., Willson Products Division)

I. Respirator No. 5058, with filter-cartridge combination R-58. (American Optical Co., Safety Division)

J. C-241 Respirator, with CMP cartridge and C-241-7 filter. (Pulmosan Safety Equipment Corp.)

K. Gasfoe Respirator No. CM-86007, equipped with cartridge No. CM-76883 and mineral-wool filter No. CM-79786. (Mine Safety Appliances Co.)

Supplied-Air Respirators

a. Whitecap Model SU-1 with No. 901 rubberized shroud, No. 301 cartridge, and No. 101 filter element. (Jamieson Laboratories, Inc.)

b. Same as L, except with extra fine No. 102 filter element. (Jamieson Laboratories, Inc.)

Gas-Mask Canisters

1. Chin Style (282-OVAG-F) Insecticide Canister. (Acme Protection Equipment Co.)
2. Canister GMC-1. (Mine Safety Appliances Co.)
3. Canister G3FD. (Ray-O-Vac Co., Willson Products Division)
4. Universal-type canister of any manufacturer. Type N, bearing Bureau of Mines approval.
5. Military Canister No. 084-Military. (Acme Protection Equipment Co.)
6. Canister No. H-3, equipped with facepiece filter holder and throwaway filter No. R361 or R393. Can be obtained with either a full-face gas mask or a half-mask facepiece. The half-mask facepiece should not be used when mixing or handling insecticides in enclosed spaces or applying aerosols in greenhouses, but is suitable for field use. (Ray-O-Vac Co., Willson Products Division)
7. Canister No. 3235 Type C-40. (Davis Emergency Equipment Co.)

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The addresses of the companies supplying these respirators and gas masks are given below.[4] Respirators are also available from pesticide distributors and mail-order houses.

Acme Protection Equipment Co., 1201 Kalamazoo St., South Haven, Mich.

American Optical Co., Safety Division, Southbridge, Mass.

Chicago Eye Shield Co., 2300 Warren Blvd., Chicago, Ill.

Davis Emergency Equipment Co., 45-57 Halleck St., Newark 4, N.J.

Jamieson Laboratories, Inc., 7900 Haskell Ave., Van Nuys, Calif.

Mine Safety Appliances Co., 201 North Braddock Ave., Pittsburgh 8, Pa.

Pulmosan Safety Equipment Corp., 644 Pacific St., Brooklyn 17, N.Y.

Ray-O-Vac Co., Willson Products Division, Reading, Pa.

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(2) ________ and McClellan, W. D. 1957. Respiratory protective devices for agricultural pesticides. Phytopathology 47:56-57.

(3) ________ and Smith, F. F. 1958. Respiratory protective devices. Methods for testing them against pesticides. Agr. Chem. 13(8):30-32; 13 (9):22-24.

(4) ________ Smith, F. F., and Gelardo, R. P. 1955. Respiratory protective devices for agricultural use. Jour. Econ. Ent. 48:457-459.

4. No discrimination is intended against any company not mentioned, nor is any guarantee implied for the products of the listed companies.

Table 1.—Respirators and gas-mask canisters that will protect against dusts, mists, and low vapor concentrations of certain pesticides[1]

Pesticides and pesticide mixtures	Respirators with face-mounted cartridges											Supplied-air respirators		Gas-mask canisters						
	A	B	C	D	E	F	G	H	I	J	K	a	b	1	2	3	4	5	6	7
aldrin	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
calcium copper chloride					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
carbophenothion (S-[(p-chlorophenylthio)methyl] O, O-diethyl phosphorodithioate); Trithion.					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ceresan M (N-(ethylmercuri)-p-toluenesulfonanilide)					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
chlordane	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
DD-Mixture (dichloropropane-dichloropropene mixture)					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
DDVP					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Delnav (a mixture of 2, 3-p-dioxanedithiol S, S-bis(O, O-diethyl phosphorodithioate)(70%) and related compounds).					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
demeton					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
diazinon (O, O-diethyl O-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate).					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
dicapthon					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
dieldrin	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
dimethoate					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Di-syston (O, O-diethyl S-[2-(ethylthio)ethyl] phosphorodithioate)					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
endosulfan (6, 7, 8, 9, 10, 10-hexachloro-1, 5, 5a, 6, 9, 9a-hexahydro-6, 9-methano-2, 4, 3-benzodioxathiepin-3-oxide); Thiodan.					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
endrin	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
EPN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
ethion					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
ethylene dibromide					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
ferbam					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
malathion	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
methyl parathion	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Methyl Trithion (O, O-dimethyl S-p-chlorophenylthiomethyl phosphorodithioate).					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
naled (emulsion) (1, 2-dibromo-2, 2-dichloroethyl dimethyl phosphate); Dibrom.					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
naled (xylene solution); Dibrom									+	+	+	+	+	+			+	+	+	+
nicotine	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Panogen (cyano(methylmercuri)guanidine)					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
parathion	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
phorate					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Phosdrin (a mixture of the alpha isomer of 2-carbomethoxy-1-methylvinyl dimethyl phosphate (not less than 60%) and related compounds (not more than 40%).									+	+			+	+			+	+	+	
Phostex (a mixture of bis(dialkyloxyphosphinothioyl) disulfides (alkyl ratio 75% ethyl, 25% isopropyl).					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table 1--Continued

Pesticides and pesticide mixtures	Respirators with face-mounted cartridges											Supplied-air respirators		Gas-mask canisters						
	A	B	C	D	E	F	G	H	I	J	K	a	b	1	2	3	4	5	6	7
ronnel					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
schradan					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Sevin (1-naphthyl N-methylcarbamate)					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Shell SD-3562 (2-dimethylcarbamoyl-1-methylvinyl dimethyl phosphate).					+			+	+	+										
TEPP					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Terrachlor (pentachloronitrobenzene)					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Vapam (sodium N-methyldithiocarbamate)					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
zineb					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Zinophos (O, O-diethyl O-2-pyrazinyl phosphorothioate)						+	+	+	+	+		+	+	+	+	+	+	+	+	+
carbophenothion + methyl parathion + DDT						+				+	+									
DDVP + malathion									+	+				+	+	+	+	+	+	+
DDVP + ronnel									+	+				+	+	+	+	+	+	+
methyl parathion + endrin								+	+	+	+			+			+	+	+	
Methyl Trithion + DDT					+	+	+	+	+	+	+			+	+	+	+	+	+	+
toxaphene, DDT, methyl parathion + ethion					+	+	+	+	+	+	+			+	+	+	+	+	+	+

1/ Letters and numbers refer to those given in the preceding lists. Plus sign (+) indicates acceptability.

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