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NIOSH



A TECHNICAL REPORT

A GUIDE TO INDUSTRIAL RESPIRATORY PROTECTION

A GUIDE TO INDUSTRIAL RESPIRATORY PROTECTION

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PREFACE

The purpose of this report is to bring together in a single document current technical guidelines for the establishment and implementation of industrial respiratory protection programs. It is written for use primarily by the occupational safety and health professional.

The subject of respiratory protection is very complex, as it is open to much subjective opinion when the needs and wishes of the average worker are considered. Consequently, this Guide represents not only the author's best judgement, but also the technical expertise of many of the most knowledgeable people in the field who were kind enough to review and comment on this material. Without their cooperation, this Guide would have lost a great deal and would have represented only one man's opinion.

Mr. John Pritchard served as Project Director for Los Alamos Scientific Laboratories. Mr. Alan Gudeman was Project Officer for the Control Technology Research Branch, Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health.

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Appreciation is also expressed to Darrel D. Douglas and William H. Revoir who contributed original material for this Guide in areas where they had particular expertise lacked by the author.

Special thanks must be given to the Zia Company, Los Alamos, New Mexico, for their time and assistance in obtaining photographs of various types of respirators being used in typical work situations. The respirator manufacturers were also of great assistance in providing photographs of respirators.

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A GUIDE TO INDUSTRIAL RESPIRATORY PROTECTION

by

John A. Pritchard

ABSTRACT

The Occupational Safety and Health Act of 1970 has increased the emphasis on proper selection and use of respirators in situations where engineering controls are not feasible or are being implemented. Although a great deal of information on respiratory protection has been published, most of it is more technical than necessary for the average user faced with day-to-day problems of respiratory protection in industrial environments.

This Guide is to provide the industrial user a single reference source containing enough information for establishing and maintaining a respirator program that meets the OSHA requirements outlined in 29 CFR Part 1910.134. It includes chapters on respirator selection, use, maintenance, and inspection, a complete description of all types of respirators and their advantages and limitations, and chapters on respirator fitting and wearer training, respiratory physiology, respiratory hazards, and physiological and psychological limitations. Also included are samples of the decision logic used in respirator selection, guidance on setting up an adequate respirator program through formulation of written standard operating procedures, and discussion of the meaning of the "approved" respirator.

CHAPTER ONE

INTRODUCTION

Until the enactment of the Williams and Steiger Occupational Safety and Health Act (OSHA) in 1970, most guidance on respiratory protective device (respirator) use in hazardous environments was advisory rather than mandatory. Now, OSHA Part 1910.134 (presented as Appendix A of this guide) sets forth specific legal requirements for selection, use, and maintenance of respirators, and gives guidelines for establishing a respirator program to meet those requirements. This guide is written to describe methods for meeting the OSHA requirements, especially for those whose knowledge of respirators is limited. It is meant to complement, not replace, other publications such as the American Industrial Hygiene Association and American Conference of Governmental Industrial Hygienists (ACGIH) Respiratory Protective Devices Manual.

BACKGROUND

American National Standard Institute (ANSI) Standard Z88.2-1969, "Practices for Respiratory Protection," is the origin of the first six sections of OSHA Part 1910.134, "Respiratory Protection." The seventh section is a direct, complete inclusion of ANSI Standard K13.1-1969, "Identification of Gas Mask Canisters."

Certain aspects of ANSI Z88.2 deserve comment. Each ANSI standard is the consensus of the Standards Committee that created it. The Z88.2 committee consisted of 30 members and 17 alternates representing government, industry, and respirator manufacturers. The document they produced, a spin-off from the older ANSI Z2.1-1959, "American National Standard Safety Code for Head, Eye, and Respiratory Protection," like all ANSI standards, is to be revised every five years. Presently, Z88.2 can be used to further explain points in the OSHA standards, but it is an advisory document only, not a legal one. However, because insight into the OSHA standards may be gained by reading the corresponding parts of Z88.2, the reader is strongly urged to use a copy as a companion to this guide. It may be obtained from:

American National Standards Institute, Inc.
1430 Broadway
New York, NY 10018.

The OSHA standards state that "approved or accepted respirators shall be used when they are available." That one sentence is the basis for much of this guide. Legally, the Occupational Safety and Health Administration may recognize a respirator evaluated by any competent authority as "approved." However, it has chosen to recognize only those approved by the National Institute for Occupational Safety and Health (NIOSH) and/or the Mine Enforcement and Safety Administration (MESA), the former obtaining its authority from the OSHA provisions and the latter from those of the 1969 Coal Mine Health and Safety Act. The NIOSH and MESA respirator performance requirements are given in Title 30, Code of Federal Regulations, Part 11, commonly known as "Part 11." A copy is presented as Appendix B.

The Bureau of Mines (BOM) began approving self-contained breathing apparatus and gas masks for mine rescue work in 1919 and has added approval schedules for other types of respirators over the years until NIOSH and MESA (which assumed the BOM mine health and safety responsibilities) started the present approval program in 1971. NIOSH performs the respirator approval tests under Part 11, and the results are reviewed by NIOSH and MESA, who grant an approval. The reader should become familiar with Part 11. Understanding of the approval process may provide better understanding of the conditions in which approved devices should, and, more important, should not, be used.

Contributing further to the confusion about respirator standards is the fact that still other Federal Regulations, Military Standards, advisory standards, etc., are made part of the OSHA requirements by reference. Figure 1-1 shows the interrelationship of all these standards.

THE GUIDE

To be effective, a respirator guide must be almost all-encompassing because:

- Respirator users' needs vary greatly. A small manufacturing concern may have to protect only one or two employees from a single hazardous atmosphere, perhaps only infrequently. A large

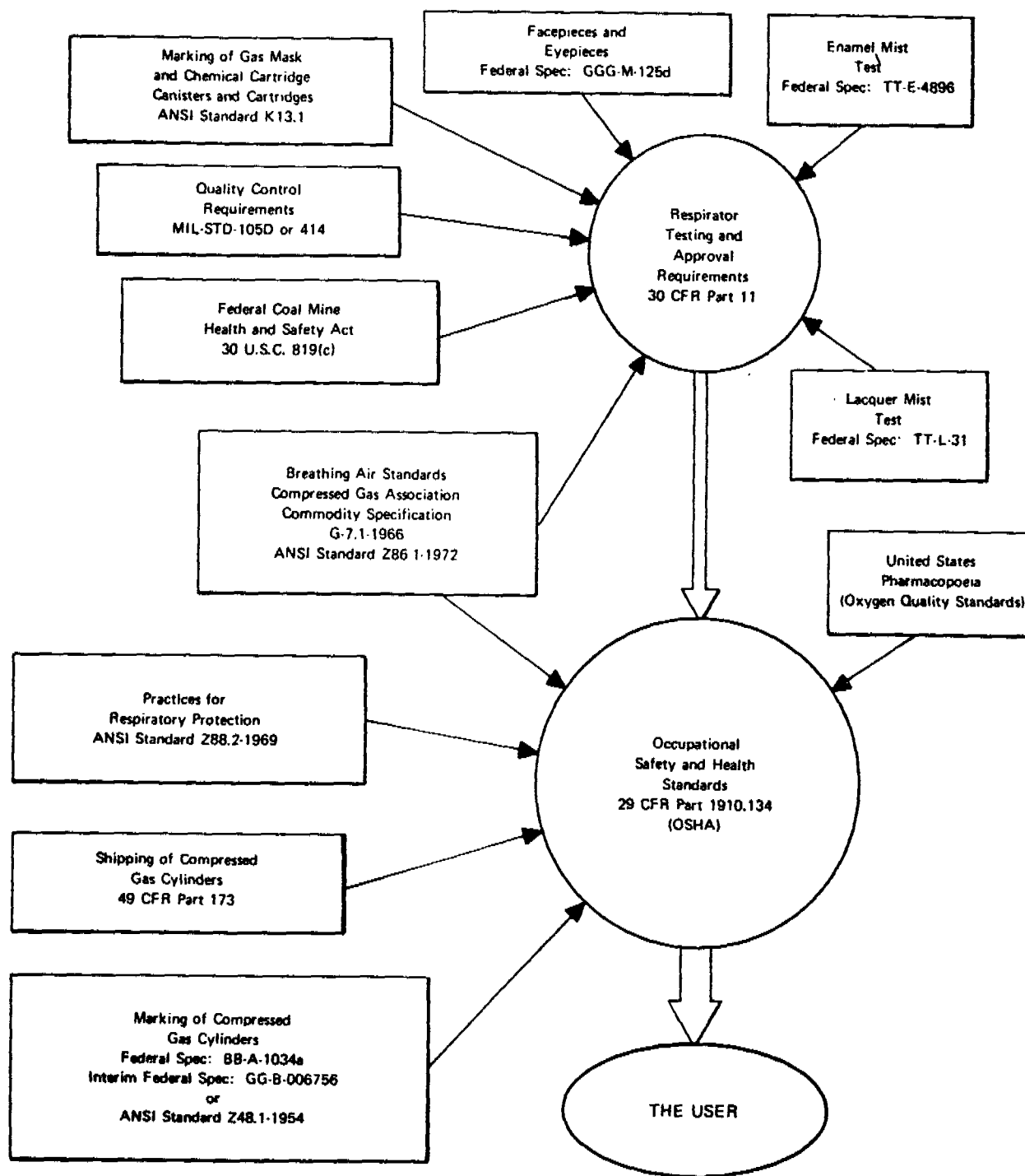


Figure 1-1.
Sources of the OSHA standards.

chemical company may have hundreds of workers who must wear respirators more or less regularly in many different hazardous atmospheres. Unfortunately, the OSHA requirements do not differentiate between such large and small users.

- Users' knowledge of respiratory protection varies. A small firm may have only one, poorly trained, employee. Large concerns with extensive respirator programs to cope with many hazards usually hire industrial hygienists and safety engineers who have detailed knowledge of respiratory protection.

This guide is designed to provide adequately detailed information for the least knowledgeable respirator user. There is a chapter on the basic concepts of the pulmonary system and respiration, one that describes and classifies respiratory hazards, and

one on basic types of approved respirators. These should provide adequate background for a satisfactory respirator program.

Other chapters, useful to both experienced and inexperienced users, discuss detailed methods for providing OSHA's "minimal acceptable respirator program." The program requirements often can be met in more than one way, and an attempt is made to show how both large and small users can do so. Respirator wearers' physiological and psychological limitations are treated separately because of their importance.

To conform to the OSHA usage, "shall" is used here only to indicate an OSHA requirement. "Should" indicates that an action is "strongly advised," but not legally required. "May" indicates that there is a choice of actions.

CHAPTER TWO

HISTORY OF RESPIRATORY PROTECTION

Recognition of the need to protect the respiratory system is very old. Pliny (c. A.D. 23-79) mentioned use of a loose fitting animal bladder in the Roman mines to protect against inhalation of red oxide of lead. The Greek writer Dioscorides (A.D. 50) described the same hazard and other dangers of mining. A century later, Julius Pollox (A.D. 124-192) described a respirator made from an animal bladder with an attached sackcloth filter for protection against the dust in mines. It is interesting that all the surviving early references involve the hazards of mining, an occupation that is still the subject of a significant share of the effort to improve respiratory protection.

Not surprisingly, Leonardo da Vinci (1452-1519) considered the problems of respiratory protection. As usual, he anticipated history by a few centuries in recommending use of a wet cloth as protection against chemical warfare agents. He also devised two types of underwater breathing devices. One used a mysterious substance he called "Alito" which when fastened to the chest with iron rings allowed the wearer to breathe without an outside air source. The other, really quite practical, was a "snorkel," consisting of a breathing tube with an attached float. Later, Bernadino Ramazzin, (1633-1714) wrote a critical review of the inadequate respiratory protection prevalent in his time. He mentioned the hazards faced by such diverse people as arsenic miners; gypsum, lime, and tobacco workers; bakers and millers; sifters and measurers of grain; and stone cutters. Any good work on occupational diseases will show that we now have named diseases incurred in each of these occupations.

In the 1700's appeared the first descriptions of the ancestors of today's atmosphere-supplying devices, such as open and closed-circuit self-contained breathing apparatus and hose masks.

With the coming of the industrial revolution in the early 1800's, respirators rapidly became more sophisticated. One of the greatest advances was realization of the separate natures of particulates and gases or vapors. Until then, the only recognized hazard had been industrial dusts.

John Roberts in 1825 developed a "smoke filter" for firemen, a leather hood and a hose strapped to the leg, the theory being (correctly) that the best air during a fire would be near the floor. At the lower

end of the hose was an inverted funnel containing a coarse woolen cloth to trap particulates and a moist sponge to remove water-soluble gases and vapors. This device is shown in Fig. 2-1.

In 1814 came development of a particulate-removing filter encased in a rigid container, the predecessor of modern filters for air-purifying respirators. In 1823, C. A. Deane developed a "smoke jacket" for firemen which had a breathing hose with a bellows that supplied clean air under pressure. This was the early equivalent of today's hose mask with blower.

Discovery of the phenomenon of Brownian motion by Robert Brown in 1827 explained the zig-zag motion of very small airborne particles caused by their bombardment by rapidly moving gas molecules in the air. This quickly led to improvement in design of



Figure 2-1.
John Roberts "smoke filter," ca 1825.

particulate-removing filters through understanding of the principle involved in filtration. Efficient filters had been produced earlier, but their resistance to breathing was usually intolerably high.

Probably the most significant development during the last century was discovery in 1854 of the properties of activated charcoal in removing organic vapors and gases from air. This discovery was almost immediately put to use in respirators. An example, shown in Figs. 2-2 and 2-3 was a fire-fighting "smoke cap" developed by Sir E. M. Shaw and the famous physicist John Tyndall. Its significant feature was clear recognition of the need to protect against particulates (with dry cotton wool), carbon dioxide gas (with lime), and other gases and vapors (with charcoal).

The most rapid advances in respiratory protection grew out of the use of chemical warfare in World War I. German use of poison gas brought about almost immediate improvement in gas sorbents used in military masks. This was countered by the German attempt to disperse highly toxic particulate matter on the battlefield, which led to development of still more efficient filters. Although crude by today's standards, the WW I military respirators are definitely recognizable as close relatives of devices manufactured now.

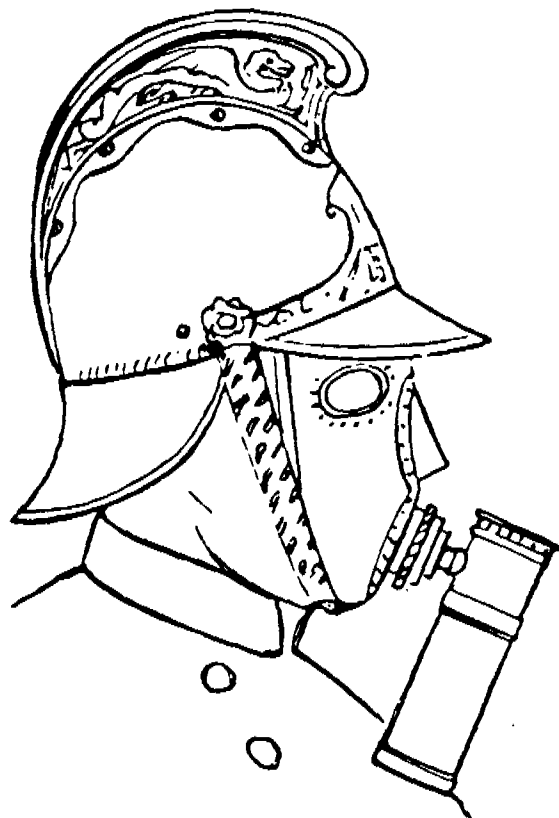


Figure 2-2.
Tyndall and Shaw "smoke cap."

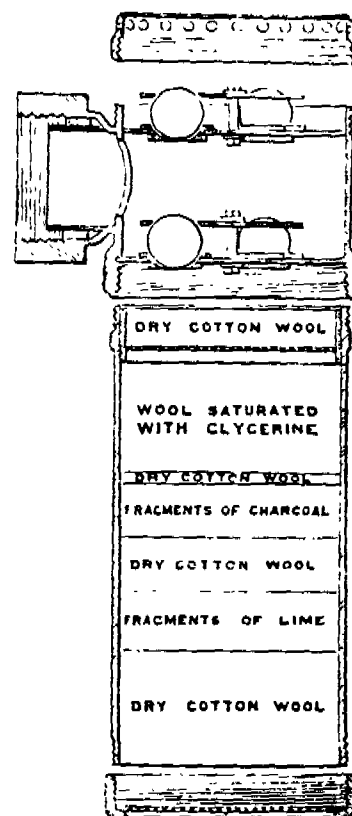


Figure 2-3.
Tyndall and Shaw smoke cap filter.

Since WW I, there have been few major breakthroughs in respirator design, with the possible exception of N. L. Hansen's development of the resin-impregnated dust filter in 1930. This material uses electrostatic force fields to remove dust particles from air. Almost all present respirator use is for protection against moderately toxic dusts, and most dust filters are resin-impregnated. This development has made available efficient, inexpensive filters that have good dust-loading characteristics and low breathing resistance. Another, more recent, development is the ultrahigh-efficiency filter made from paper that contains very fine glass fibers. These extremely efficient filters for very small airborne particles also have low breathing resistance and are commonly used where high dust concentrations are not a problem.

Figures 2-4 through 2-7 show early respirators whose basic designs are still represented in those marketed today.



Figure 2-4.
Magirus, Germany, ca 1840. Early positive
pressure self-contained breathing apparatus.

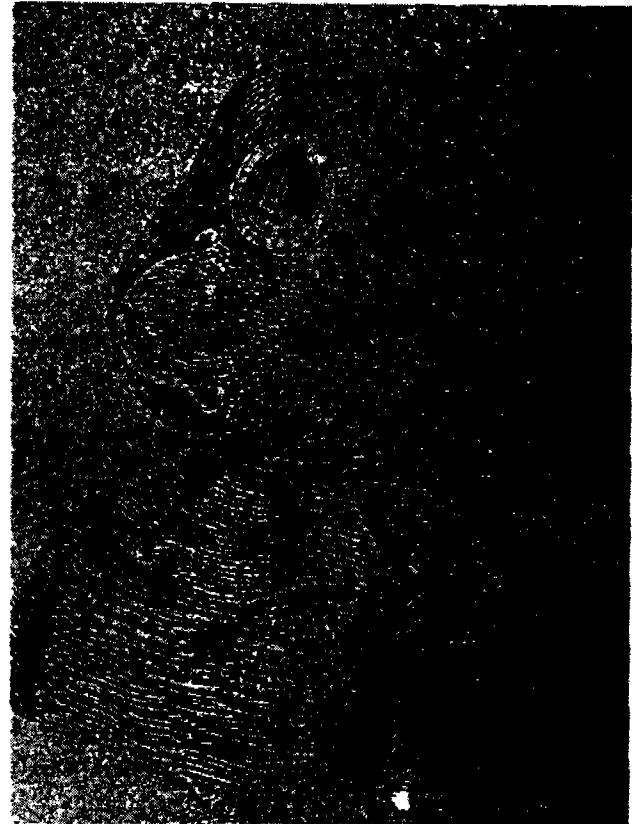


Figure 2-5.
Magirus, Germany, ca 1830. Reusable full face
protection. Sponge placed inside flap over
nose.



Figure 2-6.
Magirus, Germany, ca 1820. Supplied air suit for firemen, similar to today's hose mask or air-line respirator.



Figure 2-7.
Pulmosan dust mask, ca 1920. Very similar to single use dust respirator used today.

CHAPTER THREE

THE RESPIRATORY SYSTEM AND RESPIRATION

METABOLISM

To understand the respiratory system's role, we must consider how the body uses the oxygen that the respiratory system supplies. Figure 3-1 is greatly simplified diagram of this use, called metabolism. At its simplest, the body is a "furnace," or ordered arrangement of countless tiny "furnaces" called cells. As a "furnace," the body takes food into the digestive tract where it is converted into a fuel suitable for use by the individual cells. This fuel, in the form of a sugar—glucose—is transported to the cells by the blood stream. The oxygen needed to burn the fuel originates in the air surrounding the body. The air is drawn into the respiratory system,

and the needed oxygen is transferred to the blood stream, to travel with the glucose fuel to the cells.

In the cells, the glucose and oxygen combine in a combustion process to produce energy. The energy is used in many ways, ranging from muscle action (mechanical) and control of body temperature (thermal) to maintenance of the body systems. The combustion products, as in all such processes, are primarily carbon dioxide and water, which are carried away in the blood stream for elimination from the body.

Because the body contains a lot of water, that produced by metabolism cannot be called a waste product, but it does contain dissolved wastes that

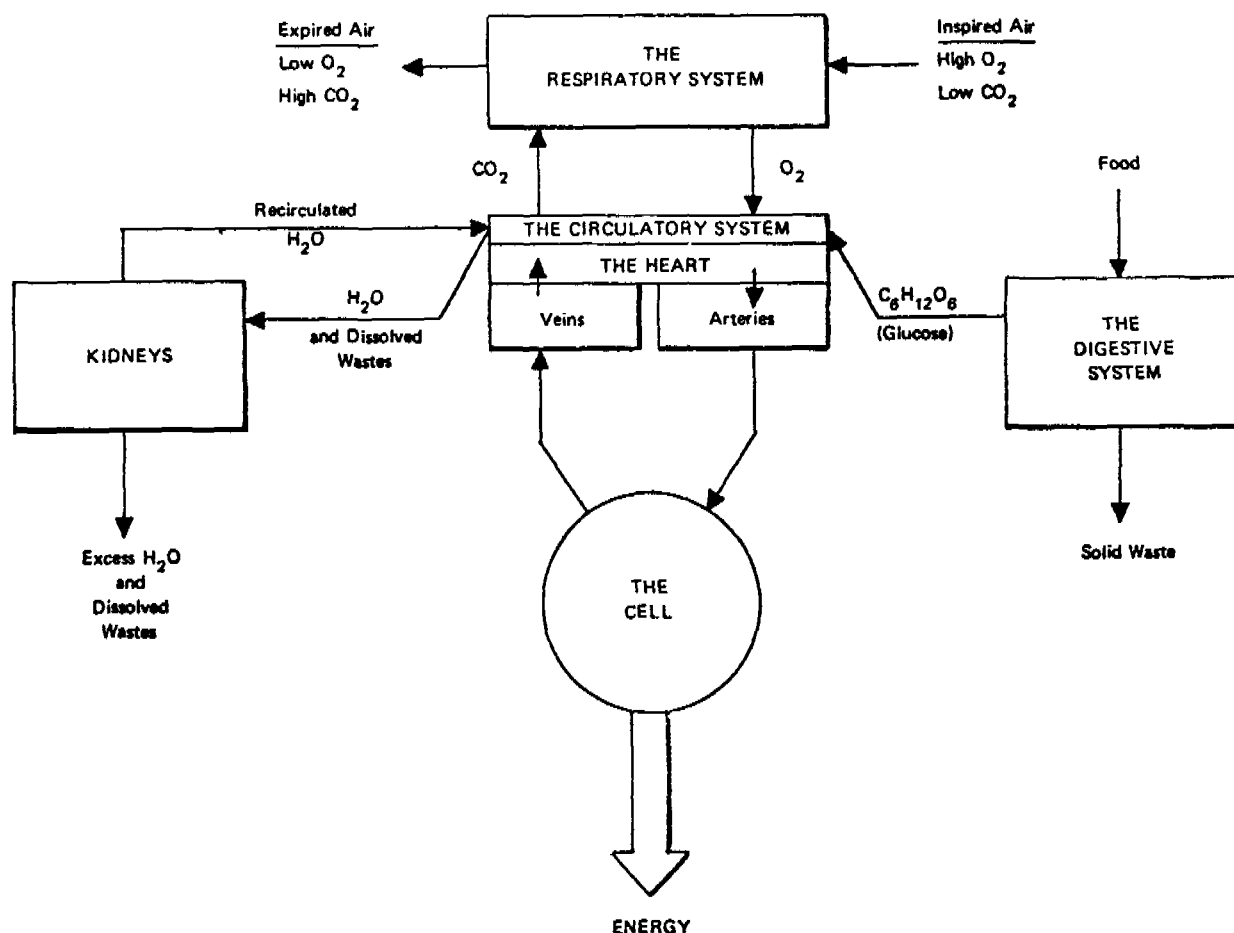


Figure 3-1.
The metabolic process.

must be removed. This is done primarily by the kidneys which remove the dissolved wastes from the blood stream. These wastes are flushed out in the urine along with water that must be replaced through the digestive tract. There is, however, a quantity of water which circulates throughout the system in the blood stream or is contained in the body tissues.

The system that carries fuel to the cells and removes waste products is unidirectional, as the material enters and leaves the body at separate locations. On the other hand, the system that supplies oxygen and removes carbon dioxide is bidirectional. Although the oxygen gets to the cells through the arteries and carbon dioxide is removed by the veins, transfer to and from the surrounding air takes place at a common location, the lungs. The effect and importance of the lungs' dual role will become apparent when gas transport and exchange are discussed.

THE STRUCTURE OF THE RESPIRATORY SYSTEM

The metabolic aspect of greatest concern here is the structure and workings of the respiratory system, shown much simplified in Fig. 3-2. The respiratory system is a single airway that branches into many smaller passages that end in the lungs. The upper, or conducting, part consists of the nasal passages and

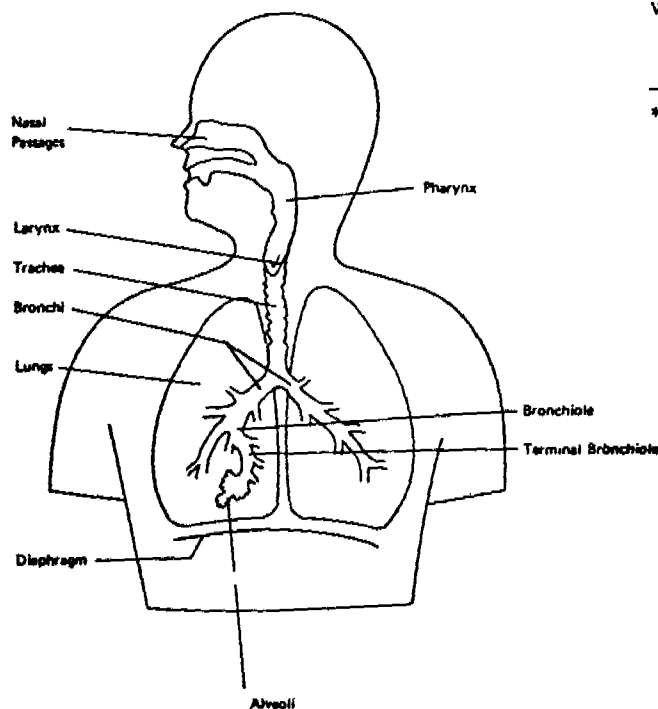


Figure 3-2.
The respiratory system.

pharynx in the head and the larynx and trachea in the neck. Below the trachea, the conducting passages branch into two airways called bronchi that lead into the lobes of the lungs. The bronchi subdivide into smaller and smaller pathways, called bronchioles, ending in very small passages, the terminal bronchioles. No gas transfer takes place in these pathways up to this point.

It is at the respiratory surfaces, shown in Fig. 3-3, that the major function of the lungs takes place. Branching from the terminal bronchioles are the respiratory bronchioles, to each of which are attached three to six clusters of extremely small sacs called alveoli. Each of the approximately 300 million alveoli is separated from the blood stream only by an extremely thin membrane, about 0.2 micrometer (μm) thick.* This membrane, which forms the alveolar wall, is permeable to gas molecules. It is here that most of the oxygen passes into the blood stream and that carbon dioxide is removed.

This barrier is so large that it provides almost instantaneous exchange between the gases in the alveolar spaces and the blood stream on the other side. This membrane is approximately 70-100 square meters in surface area and is two cells thick.

This large lung surface area is necessary because the body cannot store oxygen and, therefore, must be able to absorb a lot of it quickly from the air when necessary. The body has far more storage capacity for water (throughout) and fuel (in the fatty tissues). Man can live for weeks without food and for days without water, but only for minutes without oxygen.

*Human hair is 5-500 μm in diameter.

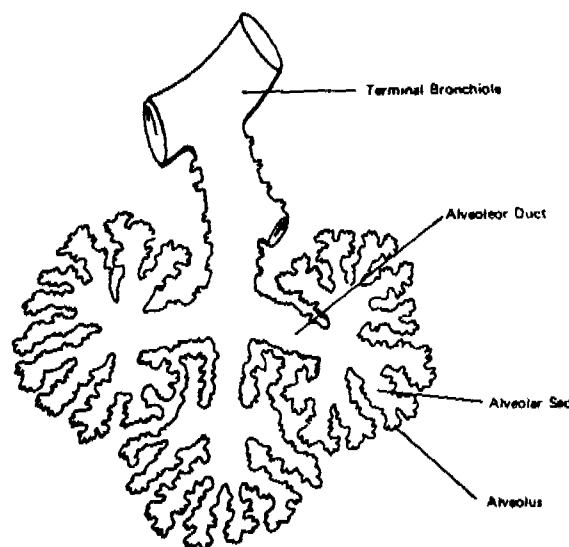


Figure 3-3.
The respiratory surfaces.

The brain is particularly susceptible, as only four minutes without oxygen causes permanent damage, and six to eight minutes kills. Because of its critical relationship to the immediate functioning of the body, the respiratory system demands the utmost protection and care.

THE MECHANICS OF RESPIRATION

Respiration, or breathing, involves inhalation during which fresh air, rich in oxygen and low in carbon dioxide, is drawn into the lungs. This is followed by exhalation in which the air, containing less oxygen and more carbon dioxide owing to gas exchange at the respiratory surfaces, is expelled. One combined inhalation and exhalation is called a breathing cycle. Lung action during a breathing cycle is like the operation of a bellows. The thoracic (chest) cavity, formed by the rib cage around the lungs, expands during inhalation because of contraction of the intercostal muscles attached to the ribs. This contraction enlarges the chest, and the lungs expand to fill the additional space. The chest cavity enlarges further as the diaphragm, a domed muscular partition between it and the abdominal cavity, moves downward.

Expansion of the chest and lungs varies with the body's needs. Under sedentary (inactive) conditions, there is very little expansion because the need for oxygen is slight. Heavy work, however, increases the need for oxygen greatly, causing increased respiration rate and volume. As the chest and lungs expand, a greater surface for transfer of oxygen and carbon dioxide is exposed as the alveoli are ventilated more effectively. The individual alveoli also expand, further increasing the surface area available for gas exchange. This is a mechanism by which the body compensates for its inability to store oxygen; it has a reserve capacity for transferring oxygen by increasing both the size and number of alveoli in use.

During inhalation, the muscles involved are contracted. During exhalation, most of them are relaxed. At the end of inhalation, the intercostal muscles are in a contracted state, and the diaphragm has been pulled down. During exhalation, these muscles and the diaphragm return to their original relaxed state, reducing the volume enclosed by the thoracic cavity (chest) and forcing the air out of the lungs. Almost no physical energy is expended during normal exhalation, analogous to releasing a stretched rubber band.

There are some muscles located in the lower abdomen which can be contracted during forced exhalation, as during heavy work or blowing up a balloon. Because these relatively weak muscles

are not used routinely, most people find their sustained use tiring. This is one reason why exhalation resistance in respirators is kept as low as practicable.

The Concept of Partial Pressures

Air is a mixture of several gases, including nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), and water vapor (H_2O). At sea level, this mixture has a normal atmospheric pressure of 14.7 pounds/square inch (psi), 29.92 inches of mercury (in. Hg), or 760 millimeters of mercury (mm Hg), all equivalent values. Here, pressures are expressed in millimeters of mercury.

The concept of partial pressures is that in any mixture of gases the total gas pressure is the sum of the partial pressures of all the gases. An analogy is a stack of blocks weighing an amount that is the sum of the weights of the individual blocks. Because normal air at sea level contains about 20.9% O_2 at a total pressure of 760 mmHg, the partial pressure of O_2 (PO_2) must be about 159 mm Hg ($760 \text{ mm Hg} \times 20.9\% = 159 \text{ mm Hg}$). Similarly, the partial pressure of CO_2 (PCO_2) makes up about 0.04% of the normal atmosphere, or about 0.3 mm Hg. Nitrogen, although it makes up about 80% of the atmosphere, plays only a minor role in respiration, and then only in special circumstances, such as deep sea diving.

NOTE: It is not the percentage of O_2 in the air, but its partial pressure, which is important. As one ascends, the percentage of O_2 and the other gases stays about the same but the partial pressure of each drops owing to the lower total atmospheric pressure. The importance of this fact will become apparent when we discuss gas exchange in the lungs.

Gas Exchange in the Lungs

During the time the air travels to the alveolar space mixing takes place, reducing the PO_2 to about 110 mm and then increasing the PCO_2 to about 40 mm. At the end of each exhalation, the lungs and upper part of the airway are filled with exhaled air that contains less O_2 and more CO_2 than the atmospheric air, owing to gas transfer. Inhalation draws approximately 500 milliliters (ml) of air into the lungs. However, only about 350 ml of the fresh air reaches the alveoli because the first air that reaches them is the old air left in the upper respiratory tract at the end of the previous exhalation. This 150 ml of air, called the anatomic dead space volume, mixes with the incoming fresh air to give the PO_2 and PCO_2 shown in the alveoli in Fig. 3-4.

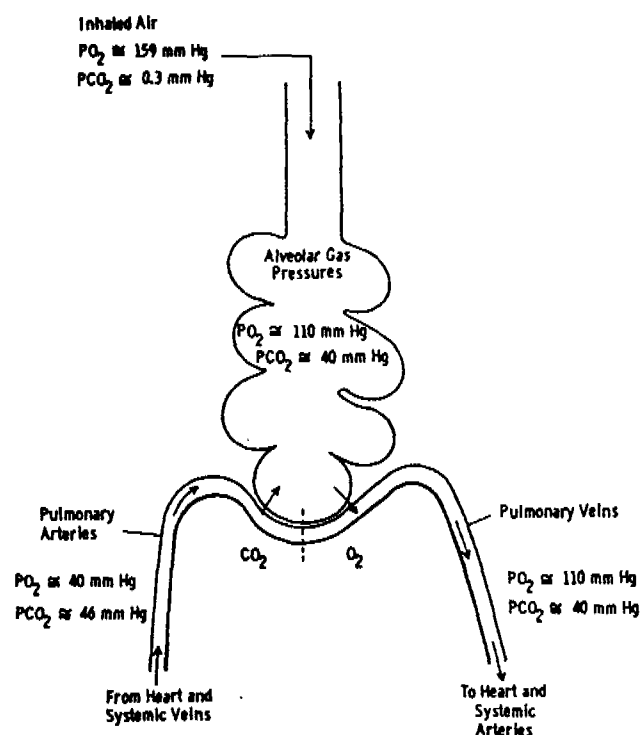


Figure 3-4.
Gas exchange in the lungs.

Increasing the dead space volume, as by wearing a respirator, may have important consequences. For example, consider the following.

- Without a respirator
Dead space = 150 ml,
Volume inhaled per breath = 500 ml,
Breaths per minute = 10.
The volume reaching the alveoli per minute would be $10 \times (500 - 150) = 3500$ ml.
- Wearing a respirator whose volume (dead space) is 100 ml
Dead space = $100 + 150 = 250$ ml,
Volume inhaled per breath = 500 ml,
Breaths per minute = 10,
The volume reaching the alveoli per minute would be $10 \times (500 - 250) = 2500$ ml.

If there is a pressure difference across a permeable membrane like that separating the alveoli from the pulmonary capillaries, gas molecules pass from the high- to the low-pressure region until the pressures are equalized. The 40-mm-Hg PCO_2 in the alveoli (Fig. 3-4) is lower than the 46-mm PCO_2 in the pulmonary arteries carrying the CO_2 -rich blood from the cells, so CO_2 molecules pass from the bloodstream into the alveoli. Conversely, the 110-mm-Hg PO_2 in the alveoli is greater than the 40-mm PO_2 in the pulmonary arteries, so O_2 passes from the alveoli into the bloodstream where the

pulmonary veins, heart, and systemic arteries carry it to the cells to be metabolized. PO_2 and PCO_2 in the pulmonary veins are the same as those in the alveoli because the O_2 and CO_2 pressures are equalized almost instantaneously in a healthy person at rest. However, when one works hard or has impaired breathing, the concentration of oxygen in the blood may be considerably less than that in the alveoli.

Oxygen is carried in the blood physically dissolved in the blood water and chemically combined with the iron atoms in the hemoglobin molecules that are part of the red blood cells. Because O_2 is relatively insoluble in water, 98% of it is carried by the red blood cells. Only about 3 ml of O_2 can be dissolved in 100 ml of blood, but about 197 ml can be carried chemically attached to the hemoglobin molecules in the red blood cells.

Carbon dioxide is carried similar to O_2 , about 8% of it being physically dissolved in the blood plasma and red cells. Sixty seven per cent of it combines with the water in the blood, is converted to carbonic acid (H_2CO_3), and is carried in ionized form ($HCO_3^- + H^+$). (The remaining 25% reacts with the hemoglobin molecules as does O_2 .) Ionized CO_2 is extremely soluble, in contrast to gaseous CO_2 . The concentration of hydrogen ions (H^+) in the blood is crucial in control of respiration, as is discussed in the next section.

Some airborne contaminants hurt the red blood cells' ability to combine chemically with O_2 molecules. For example, carbon monoxide (CO) combines preferentially with the hemoglobin molecules, thereby preventing their combination with O_2 molecules. P-nitroaniline, an organic vapor, changes the chemical state of the iron atoms, abolishing their capacity to combine with O_2 .

Respiration Control

Respiration control is very complex, and can be treated only superficially here. Furthermore, respiration control as a reaction to increased work rate is not fully understood. Briefly, however the major task of the nervous system in regulating respiration rate and depth is to ensure that O_2 is delivered to the cells and CO_2 removed at exactly the rate needed to meet the body's demands (Remember, the body cannot store oxygen.) Intuitively, one could guess that this has something to do with maintaining proper PO_2 and PCO_2 levels in the blood, indeed, this is true. Generally speaking, the PO_2 and PCO_2 balance remains relatively constant, no matter what the level of work. This fact implies that there must be a mechanism that can react quickly to changes in this balance to bring the

PO_2 and PCO_2 back into proper proportion, and this is also true, but not completely understood.

The body is sensitive to changes in both PO_2 and PCO_2 . The PO_2 sensors are located in the carotid artery that supplies blood to the head, near the aorta leading from the heart. These sensors send their signals to the respiratory control center in the lower part of the brain, the medulla. If the PO_2 is reduced by about half, the control center increases lung ventilation. Although this seems an insensitive mechanism, recent studies indicate that the body is much more sensitive to lowered O_2 levels than was thought. What happens is that response to the high PCO_2 is much stronger than response to the lowered PO_2 . Therefore, the PCO_2 response overrides the PO_2 response until the PO_2 becomes very low.

This fact implies that the PCO_2 level influences respiration much more than does the PO_2 level. This is most emphatically true; however, the full answer lies not in the CO_2 molecule itself, but in its ionized form in the blood, HCO_3^- and H^+ . The latest information indicates that the H^+ concentration in the cerebrospinal fluid surrounding the brain and spinal column is the controlling factor. Extremely sensitive sensors detect slight changes in the H^+ concentration and send signals to the respiratory control center, which brings the system back into balance almost immediately by reducing or increasing the breathing rate.

Such roundabout regulation of respiration may seem strange until one remembers that the brain is most easily damaged by lack of oxygen. It makes perfectly good sense that the regulatory mechanism is in the most critical area. In summary, control of respiration is related primarily to the PCO_2 , not the PO_2 , concentration in the blood.

Voluntary and Involuntary Control. The respiratory control system's response to changing gas concentrations in the blood is something over which we have no conscious control; it is an involuntary response. Obviously, we do have a great deal of voluntary control, for we can hold our breath, adjust our breathing rate, and cough almost at will. However, this voluntary control has definite limits. For example, we can hold our breath only so long before the involuntary drive to breathe overrides our intention not to.

Involuntary reactions of other parts of the nervous system sometimes affect the respiration rate. Emotional states, such as fear, joy, or sorrow can change it. Pain increases the respiration rate, and irritation of the respiratory passages causes explosive exhalation, or sneezing.

Effect of Increased Work Rate. As physical activity increases, the respiration rate and volume in-

crease almost immediately as the body compensates for increased metabolic demands through the mechanism just described. Therefore, a greater volume of air per unit of time is taken into and expelled from the lungs. This volumetric flow rate is usually measured as the volume of air inhaled or exhaled per minute, called the minute volume and expressed in liters per minute (lpm). Instantaneous volumetric flow rates at any time during the breathing cycle are measured in the same units.

Air Minute Volume Requirements. The typical worker breathes about 10 cubic meters (m^3) of air in 8 hours. (A cubic meter is approximately a cubic yard.) On a minute volume basis, the flow rates may vary widely with the type of work, as Table 3-1 shows. The minute volumes may range from approximately 9.3 lpm during rest periods to 132 lpm during the heaviest work. An 8-hour work day might involve total inhaled air volumes of 4.5 – 63.4 m^3 . Ten cubic meters in eight hours is about 20.8 lpm, or just slightly above the rate for light work. When one considers the situation if these volumes were laden with harmful respirable particulates or gases and vapors, the need for proper respiratory protection becomes apparent.

Instantaneous Air Flow Rates. With increased physical activity, breathing volume and rate both increase as shown in Fig. 3-5. During rest, breathing is shallow and each cycle takes several seconds. As activity increases, the instantaneous flow rates increase and each cycle becomes shorter as indicated by the curves for moderate and heavy work. The area under both cycles (totaled over 1 min) constitutes the minute volume.

The high instantaneous flow rates required at high work rates become significant when one considers

TABLE 3-1
MINUTE VOLUME AIR FLOW RATES

Activity	Minute Volume (lpm)
Sleep	6.0
Rest	9.3
Light work	19.7
Medium work	29.2
Med heavy work	40
Heavy work	59.5
Maximum work	132.0

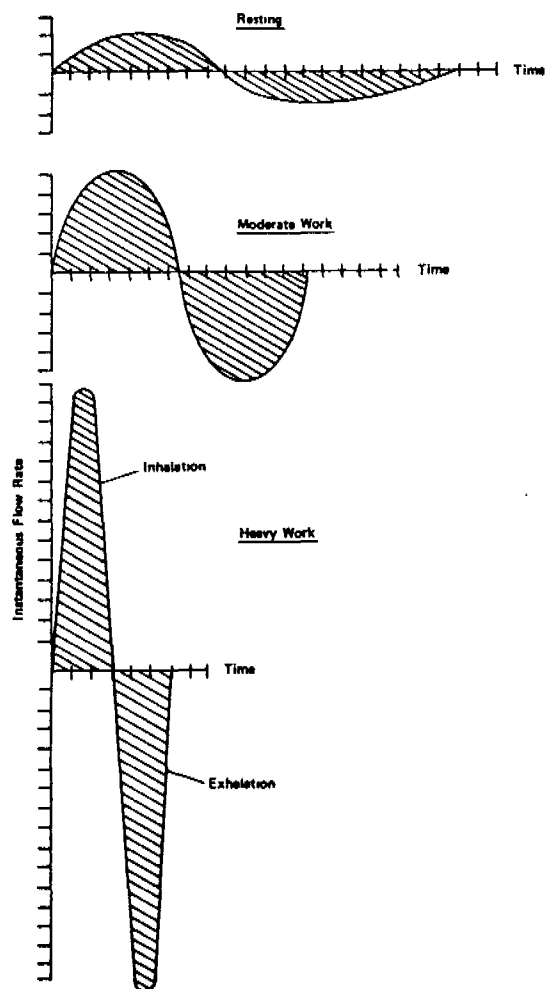


Figure 3-5.
Breathing rate and volume vs activity level.

the resistance to inhalation presented by most air-purifying respirators. As the flow rate through a filter or bed of granular sorbent in a respirator increases, (See Chap. 5) the resistance to air flow also increases. Therefore 30 CFR Part 11 keeps the allowable inhalation resistance offered by respirators at specified flow rates as low as possible. If the resistance is too great, the wearer expends extra energy in over-coming it, and the situation worsens as the work level increases.

CHAPTER FOUR

RESPIRATORY HAZARDS*

RESPIRATORY HAZARDS

In choosing the proper respirator for use against a specific hazard, one obviously must assess the type and extent of the hazard. Here, we will discuss the various classes of respiratory hazards, their effects on the body, and methods for evaluating them.

Respiratory hazards are either:

- Oxygen deficiency or
- Air contamination by
 - Particulates,
 - Vapor and gases, or a
 - Combination of particulates, vapors, and gases.

Respiratory hazards in the work environment must be assessed to determine the effectiveness of engineering and administrative controls and to permit selection of proper respirators.

A hazardous or harmful atmosphere is one that is oxygen deficient or contains a toxic or disease-producing particulate, vapor, or gas in a concentration immediately or ultimately dangerous to life or health.

An atmosphere immediately dangerous to life or health poses an immediate threat to life or health or an immediate threat of exposure that will probably cause delayed harm. Whether there is an immediate threat depends partly on the physical configuration of the workplace. Can the worker, if his respirator fails, escape unharmed? The joint OSHA and NIOSH Standards Completion Program defines an atmosphere immediately dangerous to life and health as one from which a person cannot escape unprotected within a half hour without irreversible health effects or one that has the potential for "obvious severe eye or respiratory irritation which would inhibit escape without injury."

An atmosphere not immediately hazardous to life or health may cause immediate physical discomfort or irritation, produce harm after prolonged exposure, or cause chronic poisoning after repeated short ex-

posures, but it does not cause irreversible damage during a single exposure.

THE NORMAL ATMOSPHERE

Earth's atmosphere has an essentially fixed composition of the following gases in the dry state.

Gas	Vol%	Partial Pressure (mm Hg at sea level)
Nitrogen	78.09	594
Oxygen	20.95	159
Argon	0.93	7
Carbon dioxide	0.04	0.03

Normal air always contains small amounts of other gases such as neon, helium, and krypton. Water vapor, an important constituent of the normal atmosphere, may be up to 5% of the total volume. Note that the per cent by volume of these gases does not vary with altitude, but that the partial pressures decrease with increasing altitude because the total pressure decreases.

OXYGEN DEFICIENCY

An atmosphere that does not contain enough oxygen to support metabolism for an unlimited period is called "oxygen deficient." The precise description of an oxygen deficient atmosphere is important for strictly physiological reasons and also for proper respirator selection. If an atmosphere is oxygen deficient, only atmosphere-supplying, not air-purifying respirators may be used (see Chap. Five). Making this distinction would seem a simple matter of applying the description of an oxygen deficient atmosphere. Unfortunately, no one definition (value) is universally accepted. The range of definitions listed in government regulations and other documents can leave the respirator user in a quandary. Table 4-1 is a partial listing of definitions, based primarily on the volume per cent (vol%) of oxygen in the atmosphere at sea level. With a range of 16.0-19.5 vol% to choose from, the respirator user's only

*With the kind permission of the American Optical Corporation, Southbridge, MA, this chapter is adapted in part from a "Refresher Course in Respiratory Protection," presented by W. H. Revoir at the 1974 Conference of the American Industrial Hygiene Association in Miami Beach, FL.

TABLE 4-1

DEFINITIONS OF OXYGEN DEFICIENT ATMOSPHERE

Source	Oxygen Content (vol%)	Conditions for Determination	Sea Level PO (mm Hg)
ACGIH Threshold Limit Values for 1973	18.0	"...under normal atmosphere-pressure..."	135
Federal Regulations			
29 CFR Part 1915.81 (Maritime Standards)	16.5	(not specified)	125.4
29 CFR Part 1910.94 (Ventilation Standards)	19.5	(not specified)	148
29 CFR Part 1910.134 (Respirator Standards)	16.0	(not specified)	122
30 CFR Part 11 (Respirator Approval Tests)	19.5	"...by volume at sea level..."	148
ANSI Standards			
Z88.2-1969 (Respirator Practices)	16.0	"...normal air..."	122
Z88.5-1973 (Firefighting)	19.5	"...where oxygen partial pressure is less than 148 mm Hg at sea level..."	148
K13.1-1973 (Marketing of air-purifying canisters and cartridges)	19.5	"...at sea level..."	148

NOTE: ANSI Standard Z86.1-1972, "Commodity Specification for Air," as revised in October 1974, specified 19.5-23.5 vol% O₂ for all grades of breathing air.

practical course is to use the definition listed in the regulation by which his work is governed.

It is instructive to consider oxygen deficiency (or, in medical terminology, anoxia and asphyxia) from a strictly physiological standpoint. *Anoxia* is defined as diminished availability of oxygen to the cells of the body, and *asphyxia* is the condition of the body due to anoxia. (If the reader has not yet read Chap. Three, he should do so.) Table 4-2 lists the outward indications of oxygen deficiency, or asphyxia, and shows that in atmospheres containing less than 19 vol% oxygen some adverse physiological effects occur but they are unnoticeable. In atmospheres containing less than 16 vol% oxygen, some impairment may be noticed. In those containing less than 6 vol% oxygen, death occurs quickly.

Obviously, there are various opinions as to what constitutes an oxygen deficient atmosphere. Although we cannot change the legal definitions, we can place them in a physiological context. As described in Chap. Three, normal ambient air at sea level contains about 20.9 vol% oxygen, or 160-mm-Hg PO₂, which is reduced to 110-mm PO₂ in the alveolar space. As Fig. 4-1 shows, the hemoglobin is about 95% saturated with oxygen at this PO₂ level. As the oxygen content in the ambient air and, consequently, the alveolar PO₂, are reduced, the saturation of the hemoglobin drops, but at an alveolar PO₂ of 60-mm, the hemoglobin is still 90% saturated. It is at this point that most physiologists agree that oxygen deficiency symptoms become evident. In the following discussion, 60-mm Hg alveolar PO₂ is taken to be the physiological limit that establishes an oxygen deficient atmosphere.

TABLE 4-2
EFFECTS OF OXYGEN DEFICIENCY

O ₂ Vol % At Sea Level	Physiological Effect
16-12	Increased breathing volume, Accelerated heartbeat, Impaired attention and thinking, Impaired coordination.
14-10	Very faulty judgment, Very poor muscular coordination Muscular exertion causes rapid fatigue that may cause permanent heart damage, Intermittent respiration.
10-6	Nausea, Vomiting, Inability to perform vigorous movement, or loss of all movement, Unconsciousness, followed by death.
Less than 6	Spasmodic breathing, Convulsive movements, Death in minutes.

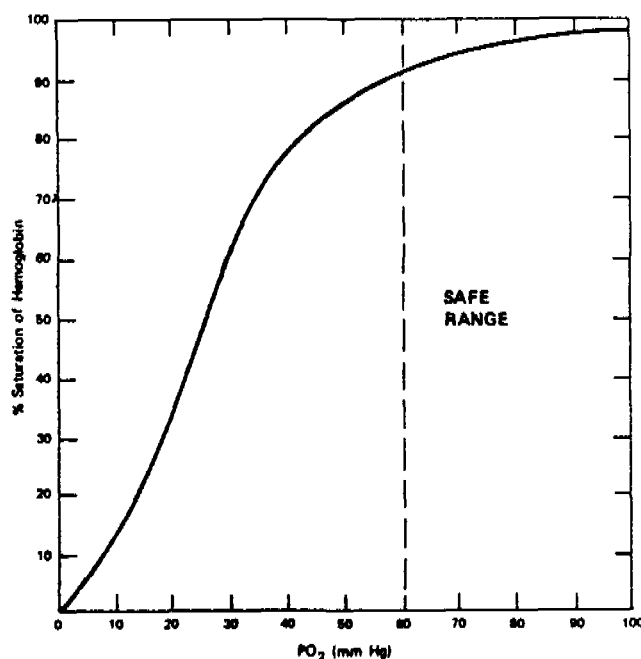


Figure 4-1.
Hemoglobin saturation curve.

PO₂ is taken to be the physiological limit that establishes an oxygen deficient atmosphere.

This 60-mm-Hg PO₂ limit can be approached in two ways. The first is through reduction of the O₂ content of the ambient air at a given altitude. At sea level, this means that the O₂ content could drop to about 14.5 vol% before the PO₂ in the alveolar space dropped to 60 mm Hg. The lowest defined value, 16%, in Table 4-1 therefore provides a margin of safety.

The second way to approach a PO₂ of 60-mm Hg is through increasing altitude. Because the total atmospheric pressure decreases with altitude, the PO₂ also decreases, until at about 10 000 ft the PO₂ in the aveolar space is about 60-mm Hg. (Remember that even at this high altitude the air still contains 20.9% oxygen, but it is 20.9% of a much lower total pressure.) The physiological significance is that altitudes over 10 000 ft are normally oxygen deficient and workers theoretically should be prohibited from wearing air-purifying respirators. There are isolated locations, primarily in Colorado, where air-purifying respirators are being used at about 10 000 ft, apparently without difficulty, so even this statement cannot be taken as absolute.

As the altitude increases, the PO₂ in the aveolar space comes closer to the 60-mm-Hg level. Therefore, a higher minimum volume per cent of O₂ must be maintained to keep the alveolar PO₂ from dropping below 60. Figure 4-2 shows the *minimum* volume per cent of O₂ in the air which must be

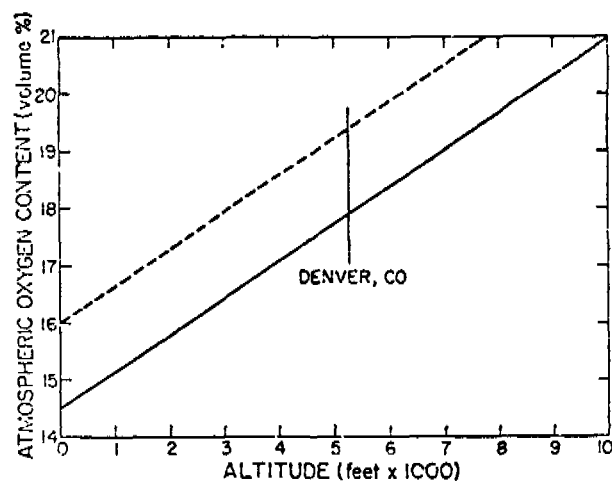


Figure 4-2.
The effect of altitude on the definition of oxygen deficient atmospheres.

maintained. Note that this does not provide any safety factor, as do the listed sea level definitions of oxygen deficiency.

To understand Fig. 4-2, let us consider Denver, Colorado, at an elevation of 5280 ft. The solid line indicates that an atmosphere in Denver must contain approximately 17.9 vol% oxygen to avoid being oxygen deficient, assuming no safety factor. To calculate the same safety factor as the lowest sea level definition of oxygen deficiency—16 vol%—provides, we can draw a line parallel to the solid line, starting at 16% at sea level. This dashed line indicates that we would need about 19.4 vol% O_2 in Denver to provide the same margin of safety that 16% provides at sea level.

What should the respirator user do with information that seems to disagree with the legal requirements? The important thing is the respirator wearer's safety. If the legal definition of O_2 deficiency is above the O_2 level you can consider safe for humans, you are justified in following the legal definition. If the O_2 deficiency level as legally defined is less than the O_2 concentration you believe safe for human exposure, you must consider raising your minimum O_2 level above the legal limit. Although not infallible, the PO_2 limit of 60 mm Hg in the alveolar space should be the absolute minimum to which the O_2 level should be allowed to drop. This means that the PO_2 in the ambient air should not drop below about 120 mm Hg. This problem is under study, and eventually "oxygen deficient atmosphere" will be redefined to eliminate the present discrepancies and account for the effect of altitude.

ENTRY OF TOXIC MATERIALS INTO THE BODY

Toxic materials can enter the body through the skin, the digestive tract, or the respiratory tract.

Through the Skin

When a toxic substance touches the skin, four things can happen.

- The skin may act as a barrier that the substance cannot enter or penetrate.
- The substance may injure the skin surface.
- The substance may penetrate the skin surface and injure the skin tissues.
- The substance may penetrate the skin, enter the blood stream, and be disseminated throughout the body to injure various parts of it.

Generally the skin is an effective barrier, and few substances enter the body through it. However, serious injury and even death may result from short

exposures of skin to high concentrations of certain very toxic substances, pesticides for example. Lacerations and open wounds obviously increase the possibility of their entering the body.

By the Digestive System

The body may absorb toxic substances through the digestive system. A harmful amount of toxic material can be swallowed accidentally, but ingestion of toxic substances is uncommon in industry. Particles in inspired air which are insoluble in the mucous of the respiratory tract may be carried to the mouth where they are either spit out or swallowed so that they enter the digestive system.

The fact that a substance has been swallowed does not necessarily mean that it will be absorbed, as a certain selectivity in absorption through the walls of the digestive tract tends to prevent absorption of unnatural substances or to limit the amount absorbed. Materials not absorbed are eliminated in the feces. Food and liquid in the digestive tract dilute the toxic substance and may react with it to produce a harmless or insoluble substance. Also, the toxic substance, if absorbed by the blood stream, will pass to the liver which may alter and detoxify it, but possibly be damaged in the process.

By the Respiratory Tract

The respiratory tract is the most important route by which toxic substances enter the body. (Most industrial poisonings result from inhalation of toxic substances.) One reason why the respiratory tract is the most important route of entry is that it has a much larger surface area than the skin or digestive tract. The surface area of the adult respiratory tract, about 70 – 100 m^2 during inhalation, is large compared to the total skin area, which is not over 2 m^2 , or the total surface area of the digestive tract, which is not more than 10 m^2 . The huge quantity of air inhaled, the continuous flow of blood through the pulmonary capillaries surrounding the alveoli (see Chap. Three), and the fact that the air in the alveoli and the blood in the pulmonary capillaries are separated by membranes whose total thickness is only two cells also help make the respiratory tract the most important route.

PARTICULATE CONTAMINANTS (AEROSOLS)

Particles of solid or liquid matter suspended in air may be classified according to their physical state

and properties or according to their effects on the body. The term aerosol is often applied to particles in air. An aerosol is a system in which air is the continuous phase or dispersing medium and the particles are the dispersed phase or dispersoid.

Physical Classification

Mechanical Dispersoid. A mechanical dispersoid consists of particles of solid or liquid matter, formed and dispersed into air by mechanical means such as grinding, crushing, drilling, blasting, and spraying.

Condensation Dispersoid. A condensation dispersoid consists of particles of solid or liquid matter formed and dispersed into air by reactions such as combustion.

Dust. A dust's dispersed phase is a solid mechanical dispersoid. Dust particles range from sub-microscopic to visible.

Spray. A spray's dispersed phase is a liquid mechanical dispersoid. The particles are generally visible.

Fume. A fume's dispersed phase is a solid condensation dispersoid. The particles are extremely small, generally less than 1 μm in diameter.

Mist. A mist's dispersed phase is a liquid condensation dispersoid. The particles vary from sub-microscopic to visible.

Fog. A fog is a mist dense enough to obscure vision.

Smoke. Smoke generally is defined as the products of incomplete combustion of organic substances in the form of solid and liquid particles suspended in air and gaseous products mixed with air. It is usually visible or obscures vision.

Smog. Smog may consist of any combination of dispersoids, solid and/or liquid, suspended in air and gas or vapor contaminants dispersed in air. Smog sometimes is referred to as a mixture of fog and smoke. It is generally visible or obscures vision.

Physiological Classification

Nuisance and/or Inert. These aerosols produce no known injuries when inhaled but may cause discomfort and minor irritation. However, large quantities of nuisance and/or inert particulate may overwhelm the lungs' capacity to dispose of them and large deposits in the lungs may, in the long run, produce injury. Examples of nuisance and/or inert aerosols are dusts containing particulate clay, limestone, gypsum, or aluminum oxide.

Inert Pulmonary Reaction Producing. These aerosols produce nonspecific reactions in the lungs. Examples are dusts containing particulate silicates or aluminum.

Minimal Pulmonary Fibrosis Producing. These aerosols produce nodulation (discrete deposits of particulate) and a slight diffuse fibrosis (growth of scattered non-elastic tissue) in the lungs. Examples are dusts containing particulate barium sulfate, iron, or iron oxide, and fumes containing particles of iron oxide or tin oxide.

Extensive Pulmonary Fibrosis Producing. These aerosols produce extensive nodulation and fibrosis in the lungs. Examples are dust containing particulate silica and asbestos. Silicosis and asbestosis are the occupational diseases that result from breathing air containing these contaminants.

Chemical Irritant. These aerosols irritate, inflame, and ulcerate the respiratory tract. Examples are dusts, sprays, fumes, and mists containing particulate acids, alkalies, peroxides, or chromates.

Systemic Poison. These aerosols when inhaled and absorbed produce toxic pathological reactions, including cancer in various body systems. Examples are dusts, sprays, fumes, and mists containing particulate lead, manganese, cadmium, pesticides, or radioactive materials.

Allergy-Producing. These aerosols produce allergic, hypersensitivity reactions such as itching, swollen membranes, and increased liquid secretion in the nose; sneezing; labored breathing; and reduced ventilating capacity of the lungs. Examples are dusts containing particulate pollen, plastic resins, gums, spices, fur fibers, tobacco, or vegetable fibers such as cotton, jute, and soft hemp.

Febrile-Reaction Producing. These aerosols produce chills followed by intense fever. Examples are dusts containing particulate bagasse (sugar cane residue) and fumes containing particulate metals such as zinc and copper.

GASEOUS CONTAMINANTS

Vapors, or gases mixed with air also may be classified according to their chemical properties and composition or their physiological effects.

Chemical Classification

Gaseous air contaminants cannot be classified perfectly according to chemical composition and properties, because there are a multitude of chemical compositions and the chemical properties within each can vary widely. The following is a meaningful classification system for air contaminants. Some of the classes depend on chemical composition only; others involve chemical properties

only. Some contaminants could belong to more than one chemical class.

Acidic. Gaseous air contaminants that are acids or react with water to become acid are called acid vapors and gases. Acids contain hydrogen and produce positively charged hydrogen ions when dissolved in water. Acids taste sour, are corrosive, react with metals to produce hydrogen gas and salts, and react with alkaline substances to produce salts. Acids that readily release hydrogen ions in water solution and react rapidly with other substances are called strong; those that do not are called weak. Strong acid gaseous contaminants include hydrogen chloride, sulfur dioxide, chlorine, and fluorine; weak ones are carbon dioxide, hydrogen sulfide, and hydrogen cyanide. The toxicity does not depend upon the strength; some of the most toxic gaseous air contaminants are weak acids.

Alkaline. Gaseous air contaminants that are alkalies or react with water to become alkaline are called alkaline (or basic) vapors and gases. Alkalies (or bases) produce negatively charged hydroxyl ions when dissolved in water. (A hydroxyl ion consists of an oxygen and a hydrogen atom, but acts like a single entity. It always has a negative charge.) Alkalies taste bitter, may be corrosive, cause organic materials to disintegrate, and react with acids to produce salts. Alkalies that readily produce hydroxyl ions in water solution and react readily with other substances are called strong; those that do not are called weak. No really strong alkaline substances exist in the gaseous state. The toxicity does not depend upon the strength; some of the most toxic gaseous air contaminants are very weak alkalies. Examples of gaseous air contaminants that can be considered moderate to weak alkalies are ammonia and amines; very weak ones include phosphine, arsine, and stibine.

Organic. Gaseous air contaminants that are organic compounds are classified as organic vapors and gases. Organic compounds are compounds of carbon, which can form many compounds because its atoms can share electrons with many other kinds of atoms and with many other carbon atoms. There are thousands of known organic compounds and more are discovered or synthesized constantly.

Organic compounds are classified by molecular structure. Some of the more common and important organic gaseous air contaminants are vapors and gases of saturated hydrocarbons such as methane, ethane, and propane; unsaturated hydrocarbons such as ethylene and acetylene; methyl and ethyl alcohol; methyl and ethyl ether; formaldehyde and acetaldehyde; dimethyl and methyl-ether ketone; formic and acetic acid; halides such as chloroform, carbon tetrachloride, and trichlorethylene; formamide and acetamide; toluene diisocyanate;

methylamine and ethylamine; epoxies such as epoxvethane, epichlorohydrin, and propylene oxide; and aromatics such as benzene, toluene, and xylene.

Organometallic. Organometallic compounds are those in which metals are chemically bonded to organic groups. Some are volatile and can become gaseous air contaminants. One example is tetraethyl lead.

Hydride. Hydrides are compounds in which hydrogen is chemically bonded to metals and metalloids (elements intermediate between metals and nonmetals). Examples of gaseous hydride air contaminants are diborane, pentaborane, and decaborane.

Inert. Substances that seldom react chemically with other substances are called inert. Inert gases include helium, neon, argon, krypton, and xenon.

Physiological Classification

Gaseous air contaminants can be classified by their effect on the body. Such classification is imperfect because the effects of many vapors and gases depend on their concentrations and some have more than one effect.

Irritant. Gaseous irritants are corrosive. They injure the respiratory tract by producing painful inflammation and increased mucus secretion. Severe inflammation and a large accumulation of mucus may close the respiratory tract and cause suffocation. Inflammation of the lungs' terminal air sacs, the alveoli, may cause pulmonary edema, increased secretion of fluids into the alveoli and the spaces between them. This edema may interfere severely with gas exchange between the air in the alveoli and the blood in the pulmonary capillaries and obstruct blood flow through the pulmonary capillaries, thus straining the heart. Pulmonary edema can kill by suffocation or heart failure. Gaseous irritants that affect the upper respiratory tract include ammonia, hydrogen chloride, hydrogen fluoride, sulfur trioxide, formaldehyde, acetaldehyde, and vinegar. Those that affect both the upper and lower respiratory tract include sulfur dioxide, iodine, bromine, chlorine, fluorine, ozone, phosphorous trichloride, and phosphorus pentachloride. Those that affect chiefly the lower and terminal parts are nitrogen dioxide, phosgene, and arsenic trichloride.

Asphyxiant. Gaseous asphyxiants interfere with the supply or use of oxygen in the body. They act without directly interfering with breathing. They may be subdivided into two groups, simple and chemical. Simple asphyxiants are inert gases that dilute the oxygen in the air below the concentration required for body function. They must be present in quantity to have appreciable effect. Chemical

asphyxiants, even in very low concentrations, by diluting the ambient atmosphere, interfere with the supply of oxygen or its use in the body. They prevent the blood from transporting oxygen from the lungs to the body tissue cells or prevent the tissue cells from using oxygen to release the energy needed for life. Asphyxiation may kill or it may injure various organs, particularly the nervous system. Simple asphyxiants include nitrogen, hydrogen, helium, methane, and ethane. Chemical asphyxiants include carbon monoxide which combines with hemoglobin, thus interfering with the blood's oxygen-carrying capacity, and hydrogen cyanide which inhibits utilization of oxygen in tissue cells by interfering with the catalytic action of enzymes that regulate the reactions of oxygen with substances in the cells.

Anesthetic. Anesthesia is partial or complete loss of sensation. Local anesthesia is loss of sensation in a particular area, whereas general anesthesia is total loss of sensation and unconsciousness. Gas or vapor anesthetics depress the central nervous system. The initial effect is mild intoxication with dizziness and loss of coordination. Continued exposure causes unconsciousness, and severe or long exposure may cause respiratory paralysis and death. All organic vapors and gases are anesthetics. Some are also systemic poisons, as mentioned below. Anesthetics are sometimes called narcotics. Anesthetics that generally have no serious effects are nitrous oxide, hydrocarbons (such as propane, butane, ethylene, and acetylene), and ethyl and isopropyl ether.

Systemic Poison. Gaseous systemic poisons injure specific organs and body systems. They include mercury, a protoplasmic poison (a substance that destroys the vitality of any living matter it contacts) that damages mainly the nervous system, the kidneys, and various glands and undermines the general health; phosphorus that makes bones fragile; hydrogen sulfide that paralyzes the respiratory control center and stops breathing; hydrogen selenide that severely injures the liver and spleen; and arsine that destroys red blood cells; and severely injures the liver.

Carbon tetrachloride injures the liver and kidneys; methyl chloride severely injures the kidneys, heart, and nervous system; ethylene dichloride severely injures the liver and kidneys; benzene damages bone marrow where the red blood cells are formed and thus interferes with production of red blood cells; and methyl alcohol seriously damages the nervous system, especially the optic nerve.

EXPRESSING AIR CONTAMINANT CONCENTRATIONS

The concentration of particles suspended in air may be expressed as the number of particles or as the mass of particles in a given volume of air. When concentration is expressed as the number of particles, it generally is given in terms of millions of particles in one cubic foot (abbreviated mppcf) or as the number of particles in one cubic centimeter (ppcc). When concentration is expressed as the mass of particles, it usually is given in terms of milligrams of particulate in one cubic meter (mg/m^3), milligrams in one liter (mg/l), or micrograms in one liter ($\mu\text{g}/\text{l}$).

The concentration of vapor or gas in air may be expressed as the per cent by volume or as the number of volumes per million volumes of air (ppm). Sometimes, extremely small quantities are given as the number of volumes per billion volumes of air (ppb). When the concentration is expressed as the mass of vapor or gas in a given volume of air, it generally is given as the number of milligrams per cubic meter (mg/m^3) or per liter (mg/l).

HAZARD EVALUATION

Normally, respiratory hazards are evaluated by a safety engineer who understands the concepts of industrial hygiene. The industrial hygienist or safety engineer often calls upon other specialists such as the industrial physician, toxicologist, and chemist. The evaluator must have the cooperation of others in obtaining information on the industrial process, the work area, and work activities and materials.

Small firms that do not have their own industrial hygienist or safety engineer may have respiratory hazards assessed by qualified personnel from outside. Casualty insurance companies employ industrial hygienists to make occupational health surveys of insured firms. There are also many private industrial hygiene consultants and consulting firms. Most states have an industrial hygiene division in their department of labor or health which will make studies without charge. The OSHA requires the U.S. Department of Health, Education, and Welfare (HEW) to evaluate hazards on written request by any employer or group of employees. Such

evaluations are free. (If HEW finds a violation of OSHA standards, there will not automatically be an OSHA inspection.) The NIOSH Health Hazard Evaluation Program is given in the code of Federal Regulations (42 CFR 85, Federal Register, Nov. 7, 1972).

Procedure

Proper assessment of industrial respiratory hazards involves a systematic procedure such as:

- Learning about the industrial process, including
 - Construction of equipment,
 - Operation of equipment,
 - Physical conditions during equipment operation.

- Learning about the work area, including
 - Size,
 - Equipment layout,
 - Ventilation,
 - Temperature and humidity.

- Learning about personnel activity in the work area, including
 - Job routines,
 - Work locations,
 - Time spent in work area, both continuously and intermittently,
 - Work rates.

- Learning about the materials involved in the process, including
 - Raw materials,
 - End-products,
 - Actual and potential by-products.

- Listing known and potential respiratory hazards, including their
 - Chemical composition,
 - Type (oxygen deficiency or air contamination)
 - Acute and chronic toxicity at various concentrations.

- Established concentration limits for breathing.

- Using the above information to select the proper instrument(s) and procedure(s) for determining the degree of workers' exposure to respiratory hazards.

- Using the instruments to measure

- Time-weighted average exposure concentrations,

- Peak exposure concentrations

- If possible, having a biochemist test body tissues and wastes to determine worker exposure to respiratory hazards.

- Having a physician determine how the hazards affect exposed workers.

- Studying and evaluating the measured time-weighted average and peak exposure levels. Comparing them with the biochemical and

physiological test results and with established concentration limits for breathing, to determine whether and how to improve engineering and administrative controls to eliminate or reduce the hazards and to determine what types of respirators, if any, are needed in the meantime.

The above procedure is only one of many approaches, and some parts may not be applicable in a given situation, whereas other conditions may require additional considerations. Industrial hygiene experience and professional judgment should play an important part in any hazard evaluation procedure.

Identification of Potential Hazards

Detailed information about the physical and chemical characteristics of raw materials, end-products, and by-products of the industrial process should be available from the manufacturing or engineering departments. If they provide insufficient information, it may be necessary to consult the purchasing department or the material suppliers. If data on end-products are inadequate, it may be necessary to consult a chemist or engineer. Determination of what by-products are produced may require considering all possible chemical reactions that could occur. Consultation with a chemist or engineer who will consider the raw materials and the conditions under which they are processed may be helpful.

Identifying potential respiratory hazards in an industrial work area requires thorough knowledge of the raw materials, end-products, and by-products, the industrial process, the means by which substances could escape from the processing equipment into the work area, and chemical reactions that could take place between escaped substances and the atmosphere in the work area or other materials present there. Many relatively inert, nontoxic materials, when machined, heated, dissolved in liquids, or placed in contact with other materials, decompose or react to form highly toxic substances.

The type and form of a hazard are determined by the materials and conditions. Dust may be generated by crushing, grinding, abrading, or polishing solids. Spray particles may be produced by atomizing a liquid. Heating and vaporizing a solid may form a solid fume particulate when the vapor condenses. Liquid mist particles can be produced when a vapor condenses. Often, fume and mist particles are formed through oxidation of finely divided condensation particles by the oxygen in the air. Two gases may react chemically to produce solid fume or liquid mist particles, and the hazard then may consist of both particulate and gas. Heating some solids and liquids decomposes them and releases gas.

Some vapors and gases react with water vapor in the air to generate new vapors, gases, or liquid particles. Certain gases have a great affinity for water, and their molecules act as nuclei for condensation of water vapor that will cause development of a liquid mist particulate.

Certain solid particles also act as nuclei for water vapor condensation to form liquid mist particles. High temperatures like those in welding and cutting flames cause nitrogen and oxygen in the air to form toxic gaseous nitrogen oxides. Radiant energy from sources such as gas-shielded welding arcs may decompose chlorinated hydrocarbon vapors to produce new substances including highly toxic phosgene gas.

In an enclosed space, some substances slowly combine with the oxygen in the air to produce an oxygen-deficient atmosphere. Release of a large quantity of gas, although it is inert or nontoxic, can dilute the oxygen in a work space and cause oxygen deficiency.

Toxicity

Toxicity and hazard are not the same. Toxicity is a material's ability to hurt the body. A hazard is toxic material in a condition in which it can cause bodily harm. Almost any substance can be toxic if enough of it is absorbed. Toxicity depends on the *quantity* of material absorbed and the *rate, method,* and *site* of absorption. In assessing respirator hazards, toxicities should be considered.

Information on toxicity is given in industrial hygiene and occupational medicine journals and books, product bulletins, and product labels. It also can be obtained from Industrial Safety Data Sheets, published by the National Safety Council (NSC); Hygiene Guides, published by the American Industrial Hygiene Association; and Chemical Safety Data Sheets, published by the Manufacturing Chemists Association. Toxicity information also is available from casualty insurance firms, the industrial hygiene division of state labor or medical departments, and the manufacturers of chemical products. Also, consulting toxicologists are available for a fee. Any regional NIOSH or HEW office will provide free toxicity data. These offices have access to NIOSH computerized technical information.

The OSHA requires HEW to publish, at least annually, a list of all known toxic substances and the concentrations at which they become toxic. The act also requires HEW to determine, upon written request by an employer or authorized employee representative, whether any substance in the work area atmosphere is potentially toxic in the concentrations used or found.

Concentration Limits

Recently enacted federal occupational safety and health laws require that workers be provided a safe, healthful work environment. They specify atmospheric quality standards for work areas and list time-weighted average concentrations and, in some cases, ceiling concentrations for air contaminants. These laws and standards necessitate use of engineering and administrative controls to reduce respiratory hazards in work areas to levels that will not cause bodily harm, and if these controls are inadequate or not feasible, workers must wear suitable respirators.

Determining Degree of Exposure

The degree of exposure to respiratory hazards is determined by measuring the concentration of airborne contaminant in the worker's breathing zone. This testing must be adequate to define the time-weighted average concentration and the peak concentration. The volume of air sampled must contain enough of the substance for accurate analysis. The volume to be sampled, or the duration of sampling, depends on:

- Estimated concentration of the substance,
- Sensitivity of instrument and test procedures.
- Established concentration limit for the substance.

Concentrations of a substance in the worker's breathing zone should be measured during the time he spends in the work area to define the time-weighted average concentration and peak concentration accurately. The concentrations are affected by changes in process operation, changes in rate and direction of air movement and temperature, changes from day to night operations, and seasonal changes.

Instruments and Procedures

There are many instruments and procedures for measuring concentrations of airborne substances. There is no single, universal instrument for all such measurements, and there probably never will be. In fact, the trend is toward development of a greater number of specialized instruments.

Instruments and procedures may be classified as follows:

- Those that give a direct reading,
- Those that remove the substance from a measured volume of air for later analysis,
- Those that collect and retain a measured volume of air for later analysis. Choice of instrument and procedure depends on many factors, including:

Portability of instrument and ease of operation,
Sensitivity and accuracy of instrument or
procedure,
Reliability of instrument,
Availability of instrument,
Type of information desired,
Personal experience.

Grab, or instantaneous direct reading, tests require only a few seconds to a few minutes. They indicate fluctuations in concentration of airborne substances and are useful in determining maximum and minimum concentrations. Many grab tests or

samples are needed to determine a time-weighted average concentration.

A continuous test or collected sample requires from several minutes to an entire work shift. Such tests give information on the average concentration of the airborne substance. There is a definite need for both grab and continuous methods, as both give useful information. Instruments and procedures for measuring air contaminant concentrations are specified in some federal standards. Both NIOSH and OSHA have published such lists.

CHAPTER FIVE

RESPIRATORS

Several hundred different respirators have been approved under various BOM schedules and 30 CFR Part 11. To select the correct respirator for protection against a particular hazard as the OSHA requires, one must have a thorough knowledge of those available. Choosing among the hundreds of devices as individual items would be a formidable task.

Unfortunately, there has been a tendency to think of respirators as individual items rather than as part of a system. The 30 CFR Part 11 approval tests, as well as the old BOM tests, cultivated this attitude by approving respirators for protection against specific hazards or groups of hazards, for example, only dust, fumes, and mists, or a specific gas or vapor.

Here, we take a different approach and present respirators by classes. There are two major classes each of which has many subclasses of the basic respirator modified for particular purposes. Study of this chapter, especially Figs. 5-1 and 5-2, will make selection and use of the proper device easier.

GENERAL RESPIRATOR CLASSIFICATIONS

The basic purpose of any respirator is, very simply, to protect the respiratory system from harmful airborne physical or chemical agents. It provides this protection by removing the contaminant from the air before it is inhaled or by supplying an independent source of respirable air.

Basically, a respirator is an enclosure (in 30 CFR 11 terms, a respiratory inlet covering) that covers the nose and mouth or the entire face or head. They are of two general types, tight fitting and loose fitting. Tight-fitting ones are generally a molded, impervious rubber or plastic facepiece that covers the nose and mouth or the entire face. In the latter case, the facepiece has a lens or eyepieces. Sometimes these coverings are called "masks" or, more technically, "oronasal masks." A mouthpiece, held in the wearer's mouth and a clamp that closes his nostrils sometimes make up the respirator.

Loose-fitting respirators include hoods, helmets, blouses, or full suits, all of which cover the head completely. Their configuration varies widely depending on the use for which they are designed.

Attached to the coverings are the elements for removing contaminants from the air (in tight-fitting facepieces only), or hoses to supply respirable air (in both tight- and loose-fitting coverings). It is these accessories that divide respirators into two major classes. If the device removes contaminants, it is an *air-purifying respirator* (see Fig. 5-1). *These devices do not supply oxygen, so they cannot be used in oxygen-deficient atmospheres. This point must never be forgotten.* A wide variety of air-purifying elements are available to tailor respirators for protection against specific contaminants. These also fall into two subclasses; particulate-removing elements that intercept particles before they enter the facepiece, and vapor- and gas-removing elements that entrap gas and vapor molecules. Here we call particulate-removing elements "filters" and vapor- and gas-removing elements either "chemical cartridges" or "canisters." Combination elements for protection against both particulates and vapors and gases are also available.

If, instead of cleaning the air, the accessory attached to the respirator provides respirable air from a source other than the surrounding atmosphere, the respirator is called *atmosphere-supplying* (see Fig. 5-2). These respirators are generally complex and come in many configurations. Because they supply breathable air, they may be used in oxygen-deficient atmospheres (subject to some limitations) as well as against particulates, vapors, and gases.

Air-Purifying and Atmosphere-Supplying Respirators

Here, we will discuss air-purifying respirators by the types available for use against specific hazards. Atmosphere-supplying devices are more nearly of a single type, so they are subclassified by mode of operation.

Classification of air-purifying respirators is dictated primarily by the NIOSH approval tests in 30 CFR Part 11 (see App. B). This approval is reflected in Figs. 5-1 and 5-2 where the pertinent Part 11 paragraphs are indicated below each type of device. To fully understand this relationship, one might use Figs. 5-1 and 5-2 and the appropriate paragraphs in Part 11 together.

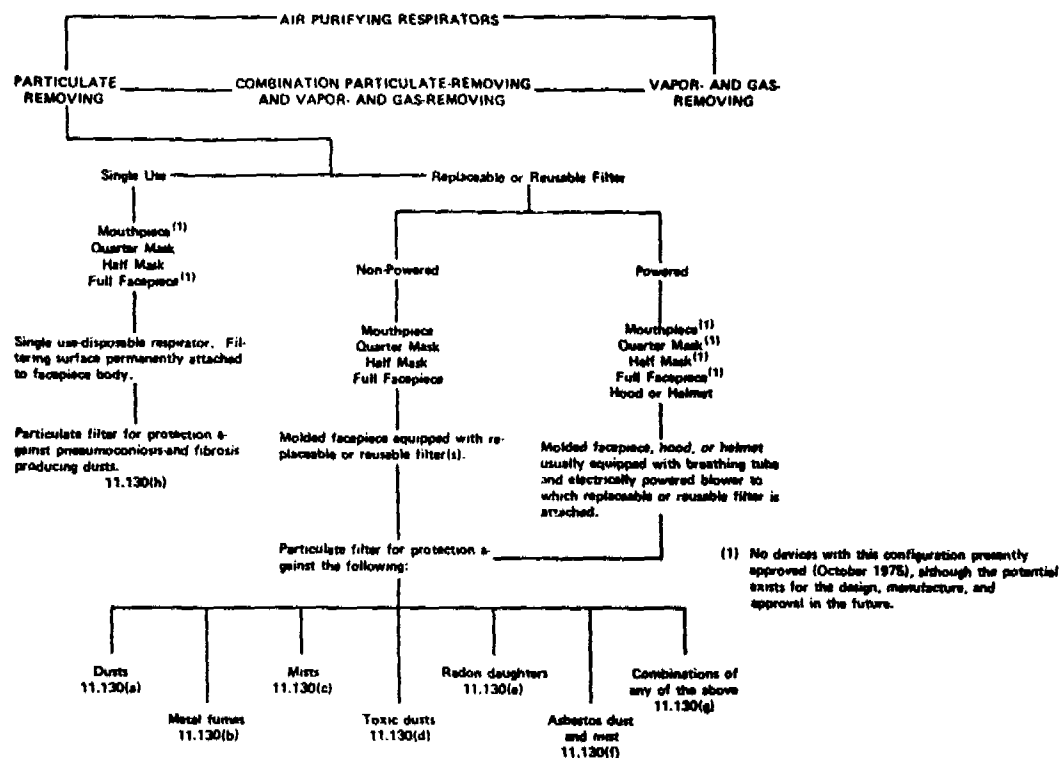


Figure 5-1(a).
Particulate removing respirators.

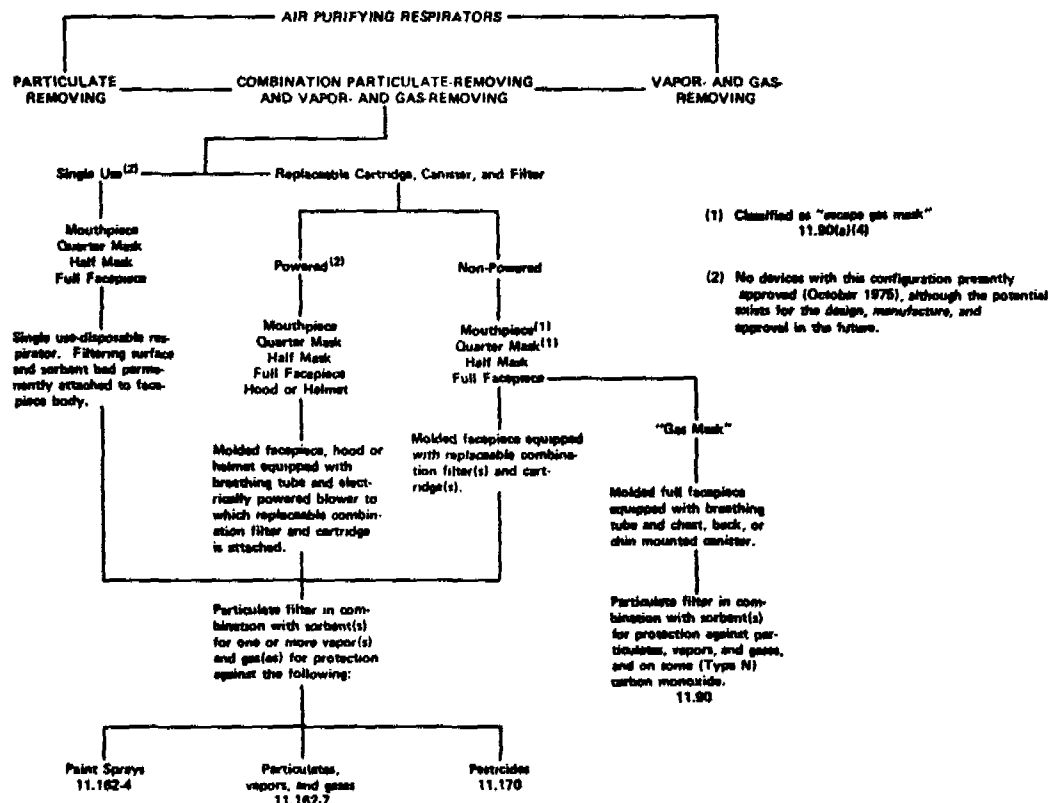


Figure 5-1(b).
Combination particulate- and vapor- and gas-removing respirators.

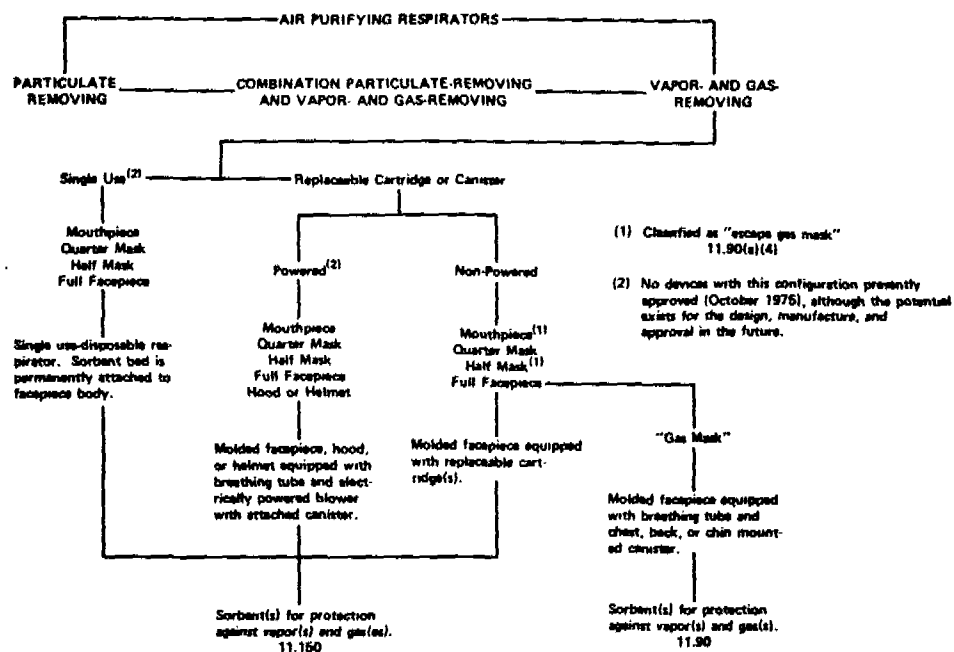


Figure 5-1(c).
Vapor- and gas-removing respirators.

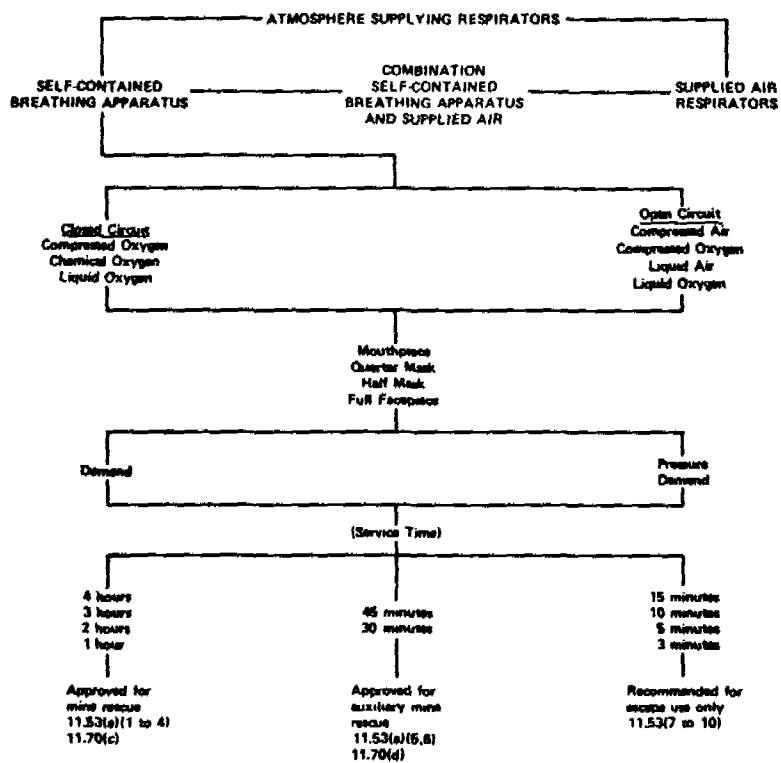


Figure 5-2(a).
Self-contained breathing apparatus.

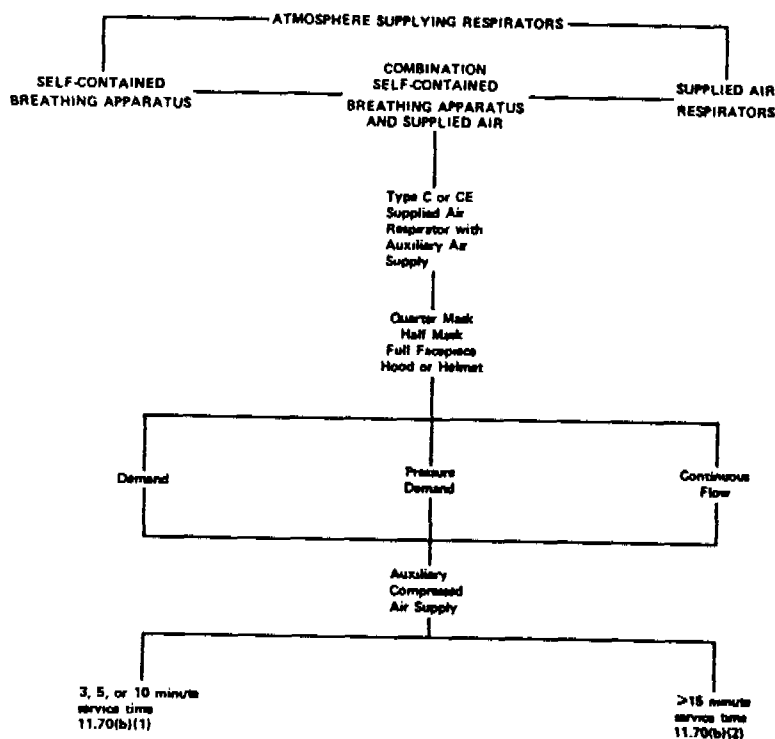
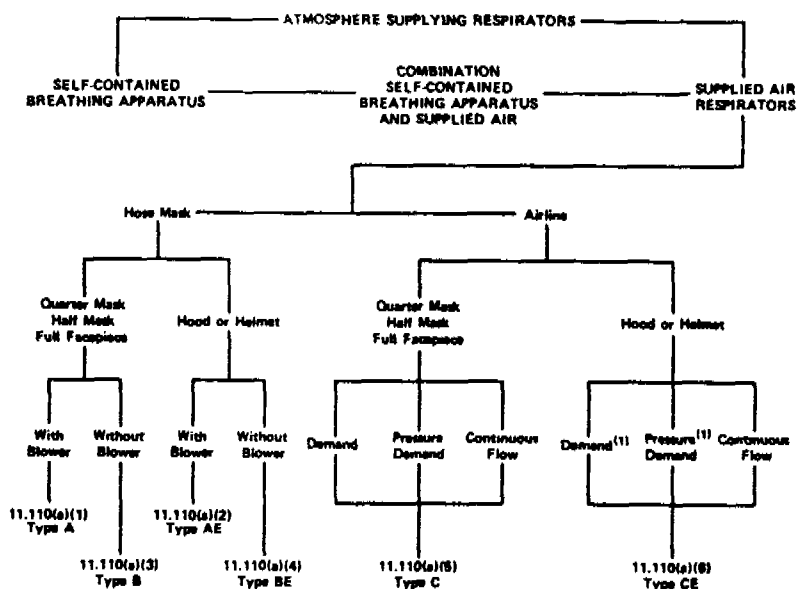


Figure 5-2(b).
Combination SCBA and supplied air respirators.



(1) No devices with this configuration presently approved (October 1975), although the potential exists for the design, manufacture, and approval in the future.

Figure 5-2(c).
Supplied air respirators.

Particulate-removing respirators are generally called "dust," "fume," or "mist" respirators, or combinations thereof. Although the implication is that there are specialized respirators for specialized functions, *all dust, fume, and mist respirators protect in exactly the same way, by removing and retaining the particulate before it can be inhaled.* The types of particulate-removing respirators that may be approved are listed in 30 CFR Part 11 K, "Dust, Fume, and Mist Respirators."

Vapor- and gas-removing respirators for protection against specific hazards are available. Chemical cartridges and canisters are approved under Part 11 for protection against acid gases, such as sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), alkaline gases, such as ammonia (NH_3), and organic vapors such as carbon tetrachloride or carbon monoxide (CO). The approvals may be for a single vapor or gas or a combination of several. Further descriptions are given in Part 11, Subparts I, L, and M, "Gas Masks," "Chemical Cartridge Respirators," and "Pesticide Respirators," respectively. These Subparts also describe the combination particulate and gas- and vapor-removing respirators such as paint spray respirators and those for protection against pesticides.

Atmosphere-supplying respirators (Fig. 5-2) are divided into self-contained and supplied-air types. When wearing self-contained apparatus, the user carries a supply of respirable air or oxygen and can move around as he pleases. Supplied-air respirators depend on air supplied through a hose. They use compressed air, never compressed oxygen. See Part 11 H, "Self-Contained Breathing Apparatus," and J, "Supplied-Air Respirators." The pertinent paragraphs are indicated under each device in Fig. 5-2.

Combination self-contained and supplied-air respirators are covered by Part 11 H. These are generally supplied-air respirators to which a small auxiliary compressed air supply is attached for emergency escape use.

Respiratory Inlet Coverings

The respiratory inlet covering serves as an impervious barrier against the contaminated atmosphere and as a framework to which air-purifying or atmosphere-supplying elements may be attached.

Tight-Fitting Coverings. Tight-fitting coverings are usually called "facepieces" and made of flexible molded rubber or plastic. Rubber or woven elastic headstraps are attached at two to six points. They buckle together at the back of the head, or sometimes are a continuous loop of material.

Facepieces are available in three basic configurations. The first, called a "quarter-mask," covers the mouth and nose, and the lower sealing surface rests between chin and mouth (Fig. 5-3). Good protection may be obtained with a quarter-mask, but it is more easily dislodged than other types. Some "dust" respirators have quarter-masks.

A second type, the "half-mask," fits over the nose and under the chin (Fig. 5-4). Half-masks generally seal more reliably than quarter-masks, so they are preferred for use against more toxic materials.

A third type (Fig. 5-5) is the "full facepiece," which covers from roughly the hairline to below the chin. They provide the greatest protection and usually seal most reliably. Also, the lenses or eyepieces must meet the impact and penetration requirements of Federal Specification GGG-M-125d, October 11, 1965, and thereby provide eye protection as well. Full-facepiece respirators, both air-purifying

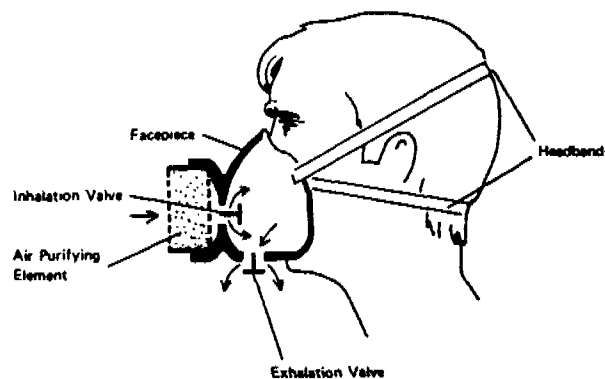


Figure 5-3.
Typical quarter-mask respirator.

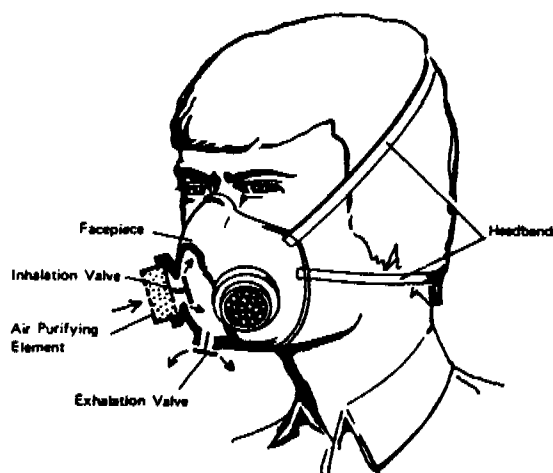


Figure 5-4.
Typical half-mask respirator.

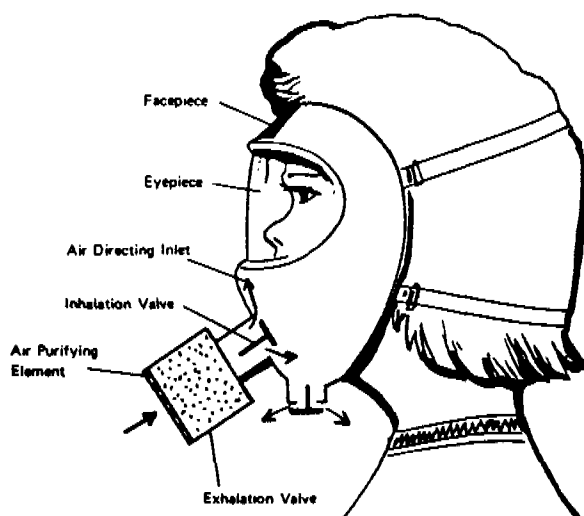


Figure 5-5.
Typical full-facepiece respirator.

and atmosphere-supplying, are designed for use in higher concentrations of toxic materials than are quarter- or half-mask respirators. They may be used in less toxic atmospheres, but, as they are expensive and difficult to maintain, little is gained by so using them.

A special tight-fitting respirator that is coming into increasingly extensive use is the "single-use" disposable type. It is shaped much like the half- or quarter-mask, but the air purifier is permanently attached to the facepiece, or the entire facepiece is made of filter material. At present, these respirators are approved only for pneumoconiosis- and fibrosis-producing dusts.

Another special type of respirator is the "mouthpiece and nose clamp," shown in Fig. 5-6. It consists of a mouthpiece held in the teeth (the lips seal around it) and a clamp that closes the nostrils. The air-purifying elements are either permanent or replaceable. These small devices are easily carried in a pocket and are designed primarily for emergency escape or intermittent use. They do not provide eye protection.

Loose-Fitting Coverings. Loose-fitting respirators include hoods, helmets, suits, and blouses. The wide variety of designs precludes any simple description, but Fig. 5-7 shows a blouse that illustrates the principles of construction and operation of all such devices.

Generally, loose-fitting respirators enclose at least the head, neck, and shoulders. This enclosure usually contains perforated rigid or flexible tubing through which clean compressed air is distributed

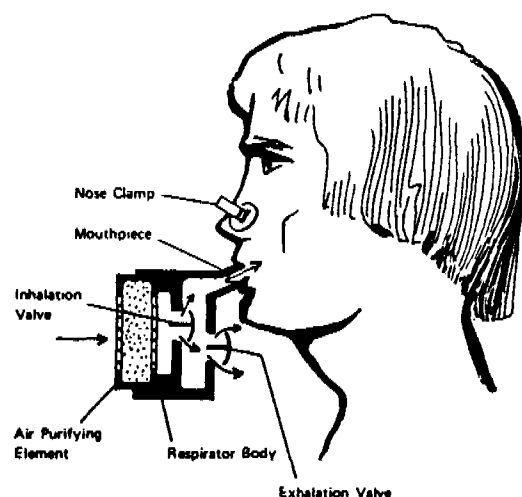


Figure 5-6.
Typical "mouthpiece" respirator.

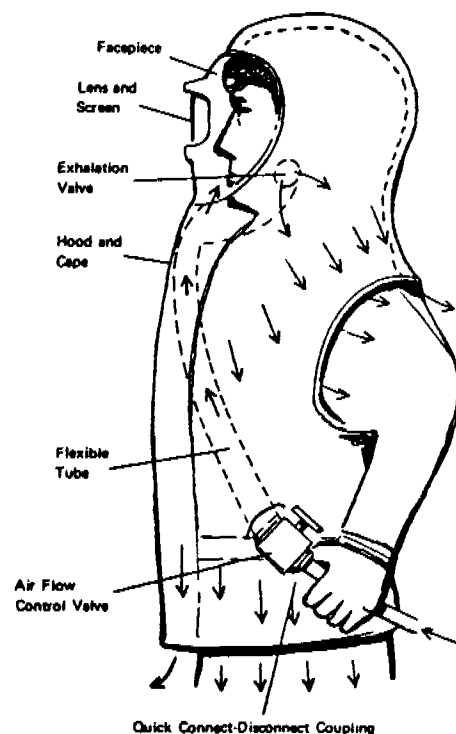


Figure 5-7.
Typical supplied-air blouse.

around the breathing zone. A light flexible device covering only the head, neck, and shoulders is called a hood. If rigid protective headgear is incorporated into the design, it is called a helmet. Blouses extend down to the waist, and some have wrist-length sleeves. Full suits, as the name implies, enclose the whole body, and, in them, additional air is supplied

to the extremities for cooling. Generally, full suits are used where skin protection as well as respiratory protection is required.

The permeability of the respirator material by toxic gases and vapors must be considered. Tritium, a radioactive gas, is a good example. The 14 OSHA carcinogen standards specify use of full suits in certain conditions, so permeability by these substances must be considered. At present, there is no NIOSH approval test for supplied-air suits, so no approved suits are available.

A special type of loose-fitting covering in common use is the abrasive-blasting hood (Fig. 5-8). The hood material is designed to withstand rebounding particles of abrasive sand, steel shot, etc. Also, there is usually an impact-resistant glass or plastic viewing lens with plastic, glass, or woven wire shielding that deflects the rebounding particles.

AIR-PURIFYING RESPIRATORS

Particulate-Removing.

All particulate-removing respirators use fibrous material (a filter) to remove the contaminant. As a particle is drawn into the filter, it is trapped by the fibers. The probability that a single particle will be trapped depends on such factors as its size relative to the fiber size, its velocity, and, to some extent, the

composition and shape of both particle and fiber. Here it is enough to say that the particles are retained on the filter fibers.

No filter is 100% efficient in removing particles. An essentially 100% efficient filter could be made, but it would be unacceptably hard to breathe through. Therefore, manufacturers try to produce the most efficient filter with the lowest breathing resistance. Generally, the higher the efficiency, the greater the breathing resistance.

Another consideration is particle loading. As more and more particulate material collects on the fibers, the openings between them become smaller, so the breathing resistance increases. The filter also becomes more efficient. Filters in general, and dust filters in particular, are designed to remove as much material as possible without excessive breathing resistance.

For the 30 CFR Part 11 approval tests, particulate filters are classified as designed for protection against dust, fumes, mists, and any combination thereof. High-efficiency filters are also dust, fume, and mist filters, but they are designed to protect against particulate contaminants with a threshold limit value (TLV)* less than 0.05 mg/m^3 . These filters are at least 99.97% efficient against $0.3\text{-}\mu\text{m}$ particles.

Figure 5-9 shows a typical high-efficiency dust, fume, and mist filter. The filter is a flat sheet of material that is pleated and placed in the filter "can." The pleating provides a large filtering area to improve the particle-loading capacity and lower the breathing resistance. When viewed from the top, this type of filter shows a series of concentric rings. This

*Threshold limit values are time-weighted concentrations of airborne substances to which nearly all workers may be continuously exposed (during 8-hour workdays and 40-hour workweeks) without adverse effects.

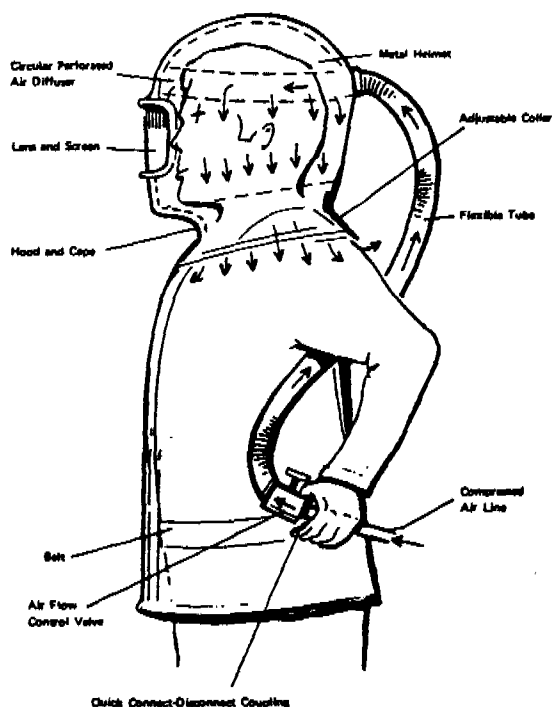


Figure 5-8.
Typical abrasive blasting hood.

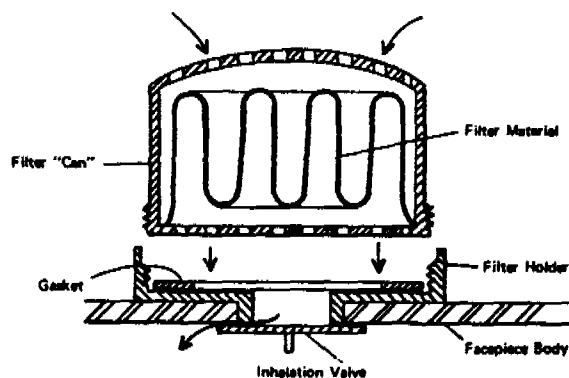


Figure 5-9.
Typical high-efficiency dust, fume, and mist filter.

configuration is common, but other methods of construction also are used.

High-efficiency filters generally have poorer particle-loading characteristics than those designed for protection against the less toxic dusts. Some filters for protection against fumes of various metals, used on the so-called "fume" respirators, look similar. The basic difference is that the fume filter is less efficient (90-99% against 0.6- μ m particles) and is approved only for contaminants whose TLV is 0.05 mg/m³ or more.

Less efficient are the so-called "dust" filters used on respirators designed for protection against "pneumoconiosis- and fibrosis-producing dusts" whose TLV is 0.05 mg/m³ or more. Some of these respirators are also approved for mists whose TLV is 0.05 mg/m³ or more, as well as for dusts. This class of respirator accounts for as much as 90% of total sales. Their lower efficiency (80-90% against 0.6- μ m particles) results from being designed to withstand heavy dust loadings without unacceptably increasing breathing resistance.

Two types of dust filter predominate. The first and probably most common (Fig. 5-10) is a flat disk of compressed natural wool or synthetic fiber felt, or a blend, to which an electrostatic charge is imparted during manufacture by impregnating the material with a resin and mechanically beating or "needling" it. This charge increases the filter efficiency by electrostatically attracting the particles to the fibers. These filters are less expensive than the pleated type and protect adequately against most industrial dusts, but one precaution must be observed in their use. Certain agents such as oil mists, extremely small solid particles, and storage in very humid air remove the electrostatic charge. Therefore this type of filter should be used as soon as possible after purchase and should be kept out of oil mists, such as occur around lathes, and high (>80%) humidity.

The resin-impregnated felt filter is readily identified by rubbing it between the fingers and then

rubbing the fingers together. They will feel slightly sticky.

Another type of dust filter is shown in Fig. 5-11. The filtering medium is only loosely packed in the filter "can," so it is much thicker than the compressed type. Such filters are generally made of fiberglass, although nonfelted resin-impregnated natural wool fibers have been used. They are not so common as the felted type. A typical dust respirator is shown in Fig. 5-12.

A major variant is the single-use, or disposable dust respirator shown in typical use in Fig. 5-13. In these devices, the filter is either an integral part of the facepiece, or it may be the entire facepiece itself. When the filtering surface is permanently attached to the facepiece, the material often is resin-impregnated natural wool fiber or synthetic fiber felt. In some currently approved devices, the entire facepiece is a fabric filtering medium. At present single-use disposable respirators are approved only for pneumoconiosis- and fibrosis-producing dusts although they could also be approved for such mists.

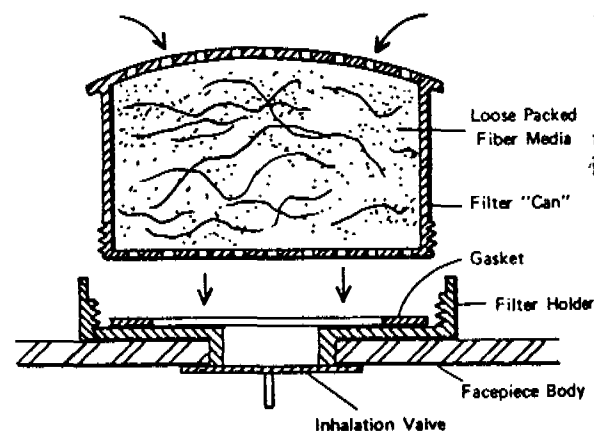


Figure 5-11.

Typical dust filter with loose-packed medium.

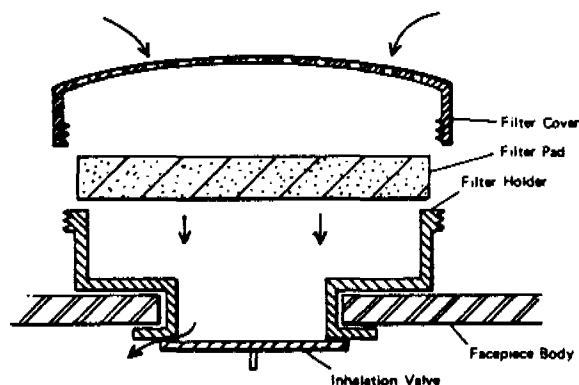


Figure 5-10.

Typical resin-impregnated felt dust filter.



Figure 5-12.

Typical dust respirator with replaceable filters.



Figure 5-13.
Typical single use dust respirators.

This does not mean that it is impossible or impractical to make more efficient single-use respirators for protection against more toxic dusts and mists and even fumes. It means only that they cannot be approved as Part 11 is now written. Significant advances probably will be made in single-use respirators, and the user should watch for developments.

Some particulate filters may vary from the designs described. The important thing to recognize is the type of medium rather than the shape.

Vapor- and Gas-Removing

The other major class of airborne contaminants consists of gases and vapors. Air-purifying respirators are available for protection against both specific gases and vapors, such as ammonia, and classes, such as organic vapors or acid gases. In contrast to filters, which are effective to some degree no matter what the particulate, the cartridges and canisters used for vapor and gas removal are designed more for protection against specific contaminants.

Vapor- and gas-removing respirators all remove the contaminant by interaction of its molecules with a granular, porous material, commonly called the sorbent. The general method by which the molecules are removed is called sorption.

Adsorption, Absorption, Chemisorption, and Catalysis. Three sorptive mechanisms are used in vapor- and gas-removing respirators. The first, adsorption, retains the contaminant molecule on the exposed surface of the sorbent granule by physical or chemical attraction whose intensity varies with the type of sorbent and contaminant.

In physical attraction, the adsorbed molecules are held more or less weakly. These bonds may be broken by heating the sorbent so that the gas and vapor molecules are released into their original state. If chemical forces are involved, the adsorption process is called chemisorption. Then the bonds holding the molecules to the sorbent granules are much stronger and can be broken only with great difficulty.

A characteristic common to all adsorbents is a large specific surface area, up to $1500 \text{ m}^2/\text{g}$ of sorbent. Activated charcoal is probably the most common adsorbent. It is used primarily to remove organic vapors, although it does have some capacity for adsorbing acid gases. Activated charcoal also can be impregnated with other substances to make it more selective against specific gases and vapors. Examples are activated charcoal impregnated with iodine to remove mercury vapor, with metallic oxides to remove acid gases, and with salts of metals to remove ammonia gas. Other adsorbents used in vapor- and gas-removing respirators include molecular sieves, activated alumina, and silica gel.

Absorbents differ from adsorbents in that, although they are porous, they do not have as large a specific surface area. Absorption is also different because the gas or vapor molecules penetrate deeply into the molecular spaces throughout the sorbent and are held there chemically. Probably, absorption cannot occur without prior adsorption on the surface of the particles. Furthermore, adsorption occurs instantaneously, whereas absorption is slower. Most absorbents are used for protection against acid gases. They include mixtures of sodium or potassium hydroxide with lime and/or caustic silicates.

A catalyst is a substance that influences the rate of chemical reaction between other substances. A catalyst used in respirator cartridges and canisters is hopcalite, a mixture of porous granules of manganese and copper oxides, which speeds the reaction between toxic carbon monoxide and oxygen to form relatively nontoxic carbon dioxide.

As applied to respirators, the foregoing processes are essentially 100% efficient until the sorbent's capacity to adsorb gas and vapor or catalyze their reaction is exhausted. Then the contaminant will pass completely through the sorbent material and into the facepiece. This is in contrast to particulate-removing filters which become more efficient as matter collects on them and plugs the spaces

between the fibers. This difference is important to remember. Water vapor reduces the effectiveness of some sorbents and increases that of others. Vapor- and gas-removing cartridges must generally be protected from the atmosphere while in storage.

Cartridges and Canisters. The basic difference between cartridges and canisters is the volume of sorbent contained, not its function. Cartridges are vapor- and gas-removing elements that may be used singly or in pairs on quarter- and half-masks and occasionally on full facepieces. The sorbent volume of a cartridge is small, about 50-200 cm³, so the useful lifetime is usually short, particularly in high gas or vapor concentrations. Therefore, use of respirators with cartridges generally is restricted to low concentrations of vapors and gases.

Canisters have a larger sorbent volume and may be chin-, front-, or back-mounted. Respirators with canisters can be used in higher vapor and gas concentrations than those with cartridges. Chin-style canisters have a volume of about 250-500 cm³ and are used on full-facepiece respirators. Front or back-mounted canisters are held in place by a harness and connected to the facepiece by a corrugated, flexible breathing tube. They have a sorbent volume of 1000-2000 cm³ and are designed for use in higher concentrations or for prolonged use in lower concentrations of gases and vapors. Front- or back-mounted canisters are used with full facepieces as part of "gas masks." The "gas masks" is not a special, exotic type of respirator. It differs from the chemical cartridge respirator only in its larger sorbent volume and the higher concentrations of vapors and gases against which it provides protection.

Labeling. As vapor- and gas-removing cartridges and canisters are designed for protection against specific contaminants, or classes thereof, how does the user know he is selecting the proper device? An American National Standard, ANSI K.13.1, established a color code for the various types of sorbent cartridges and canisters which identifies the contaminants they are designed to protect against. The printed approval label also clearly lists these contaminants. Whether the user memorizes the color code or not, he should always **READ THE LABEL!** This is the only foolproof way of ensuring use of the correct cartridge or canister. ANSI K.13.1 has been included verbatim in the OSHA regulations, 29 CFR 1910.134(g).

Construction. Construction of vapor- and gas removing cartridges and canisters varies little from manufacturer to manufacturer. The type of sorbent for a particular substance may differ with manufacturer, but the basic construction problems are about the same, to provide enough sorbent bed depth and

volume to ensure that the contaminant is totally removed in the test times specified in the 30 CF Part 11 bench tests, and that the sorbent remain mechanically stable in the container.

Figure 5-14 shows a typical chemical cartridge approved for use with a half- or quarter-mask. The bed of sorbent granules is retained in the cylindrical "can" by a screen and coarse filter pad at the top and by a coarse particulate filter pad and a screen at the bottom. The pads only keep the fines in the sorbent from escaping from the cartridge; they are not designed for protection against particulate contaminants. Various precautions for use of these cartridges are discussed in Chap. Seven, Respirator Use.

One problem in design and manufacture of sorbent canisters is to prevent passage of large quantities of air through small areas of the bed of packed sorbent granules. Such air channeling through the canister reduces its useful service life. Selection of the proper sorbent granule size and careful packing in the canister minimize air channeling. There is also a tendency toward channeling where the irregular sorbent granules touch the smooth canister wall. Sometimes this is prevented by forming ridges in the canister shell like those in Fig. 5-15. The retaining screens and pads hold the granular sorbent bed in place. The spring ensures that the sorbent remains tightly packed.

Even with these precautions, sorbent canisters may be damaged by dropping. This can crush the granules, disturb the retaining screens or pads, or create channels between the sorbent granules and the canister wall. Cartridges and canisters should also be stored upright. In short, treat sorbent canisters very carefully.

Chemical Cartridge Respirators. Figure 5-16 shows a typical chemical cartridge air-purifying respirator. In 30 CFR Part 11.150 is a listing of the vapors and gases and maximum concentrations for which chemical cartridge respirators are approved. Note the accompanying restrictions on use and

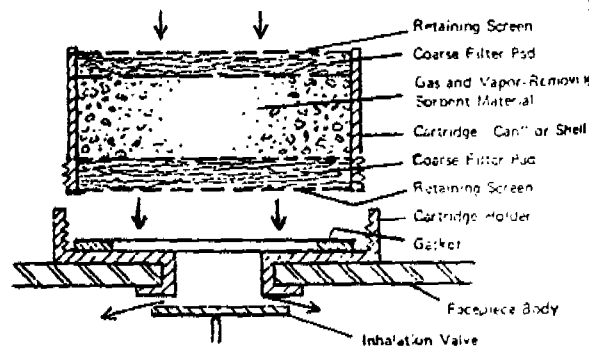


Figure 5-14.
Typical chemical cartridge.

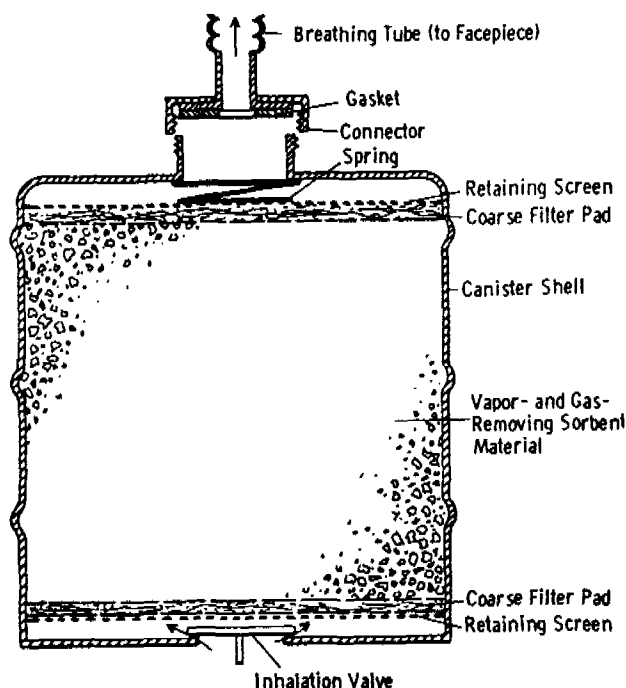


Figure 5-15.

Typical front- or back-mounted canister.



Figure 5-16.

Typical chemical cartridge respirator being used during weed spraying.

remember that these concentrations pertain to the cartridge only, not to facepiece fit.

Gas Masks. According to Subpart I of Part 11, the following gas masks may be approved.

Front- or back-mounted

Type N, front- or back-mounted, combination gas, vapor, and particulate

Chin-style Escape

Front- or Back-Mounted. Front- or back-mounted gas masks are usually approved for use with a full facepiece. A "super size" or "industrial" size canister is fastened to the user's body, and a breathing tube connects the canister to the facepiece inlet. A typical front- or back-mounted canister is shown in Fig. 5-15. Note that the construction does not differ markedly from that of the chemical cartridge shown in Fig. 5-14. Other than the volume of sorbent contained ($1000-2000\text{ cm}^3$), the greatest difference is that the canister, rather than the facepiece, usually contains the inhalation valve. Figure 5-17 shows typical front- (back)-mounted canister gas masks.

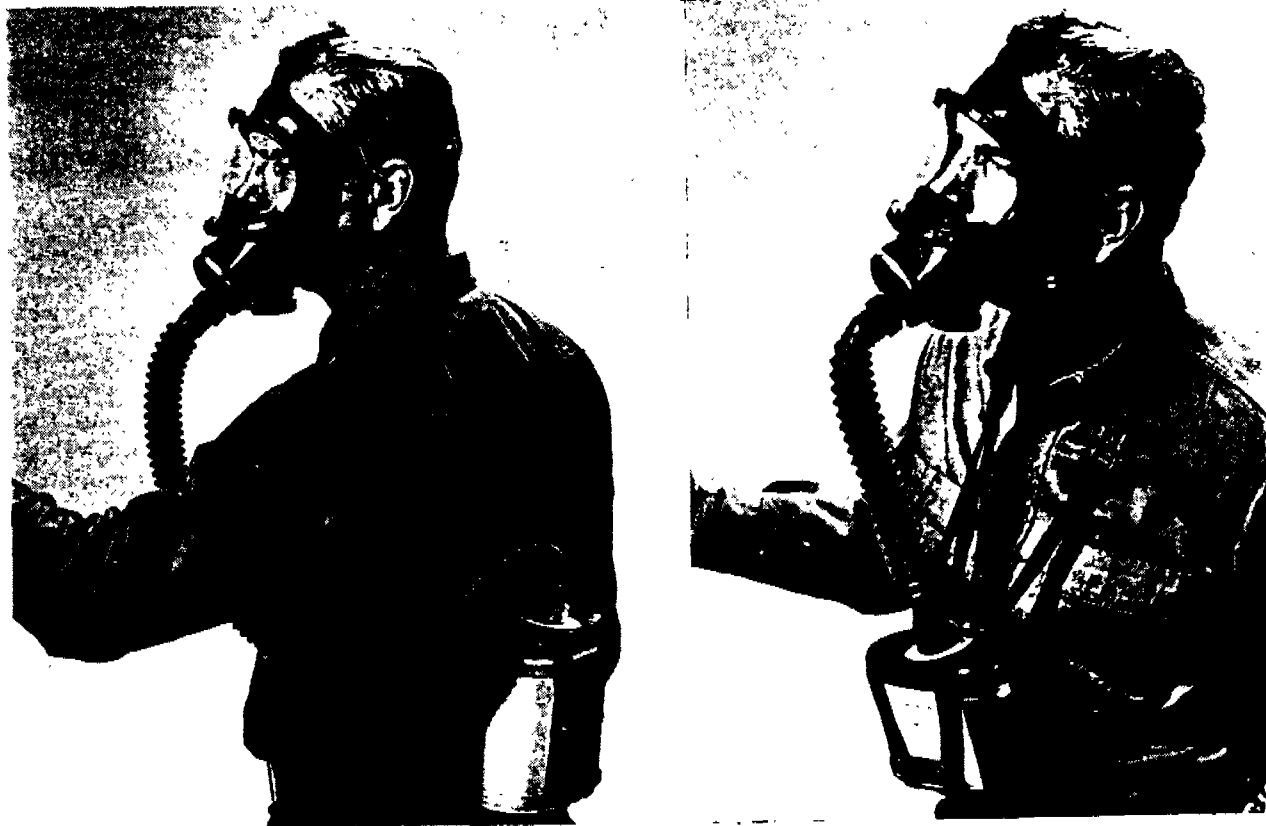
Type N. Type N, front- or back-mounted, combination gas, vapor, and particulate gas masks are approved under Subpart I of Part 11 for protection against acid gases, ammonia, carbon monoxide, organic vapors, and particulates. However, we discuss these devices because the Type N canister contains a high-efficiency particulate filter as well as various sorbents, so it should be classified as part of a combination particulate- and vapor- and gas-removing respirator.

Chin-Style. Chin-style gas masks typically have a medium-sized ($250-500\text{-cm}^3$) canister (Fig. 5-18), rigidly attached to a full facepiece. The useful lifetime is less than that of a front- or back-mounted canister owing to the smaller sorbent volume, but greater than that of chemical cartridges. Figure 5-19 shows a typical chin-style gas mask.

Other types of canisters are designed for protection against more than one vapor or gas. In them, the sorbents are either arranged in layers or intermixed. Figure 5-20 shows these two arrangements as either might appear in a chin-style canister. In certain instances, one type of construction has an advantage over the other, but mostly it is a matter of manufacturing convenience, with sorbent layering being most common.

Maximum use concentrations established in 30 CFR Part 11 for all types of gas masks, are being withdrawn (1975). NIOSH is advising the user to contact the NIOSH Testing and Certification Laboratory, Morgantown, West Virginia or the Mine Enforcement Safety Administration, Pittsburgh, Pennsylvania for guidance in use of gas masks in high contaminant concentrations.

Escape Masks. Gas masks for use during escape from (not reentry into) atmospheres immediately hazardous to life and health are approved under Subpart I, 30 CFR Part 11. They can be approved



Courtesy Mine Safety Appliances Co.

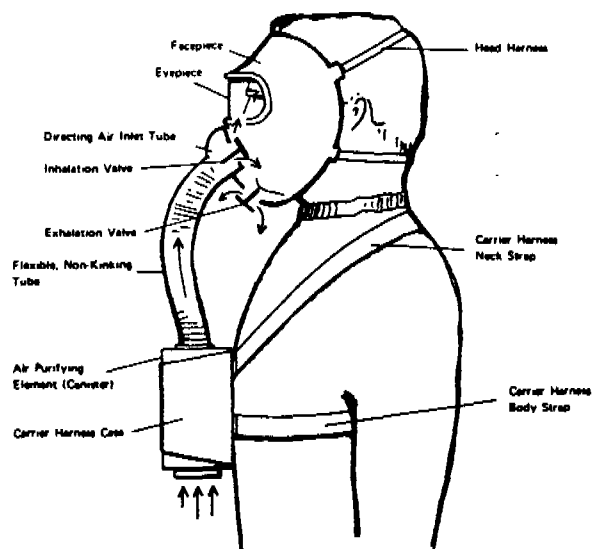


*Figure 5-17.
Typical front- or back-mounted canister gas masks*

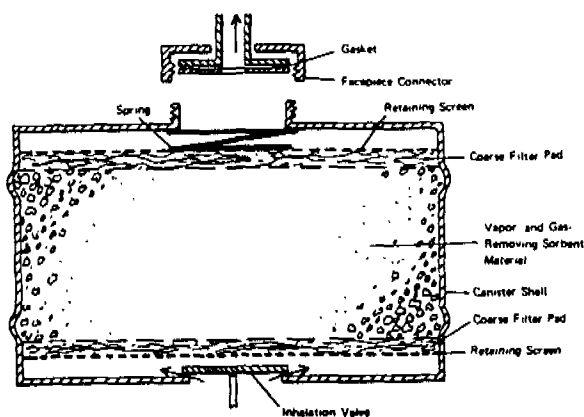


Figure 5-18.
Typical chin-mounted canister.



Figure 5-19.
Typical chin style gas mask in use in a chemical plant.

only if they have a half-mask facepiece or a mouthpiece. Where eye irritation is a consideration, a full-facepiece gas mask is preferable.

Particulate-, Vapor-, and Gas-Removing

Cartridges and canisters are available to protect against both particulates and vapors and gases.

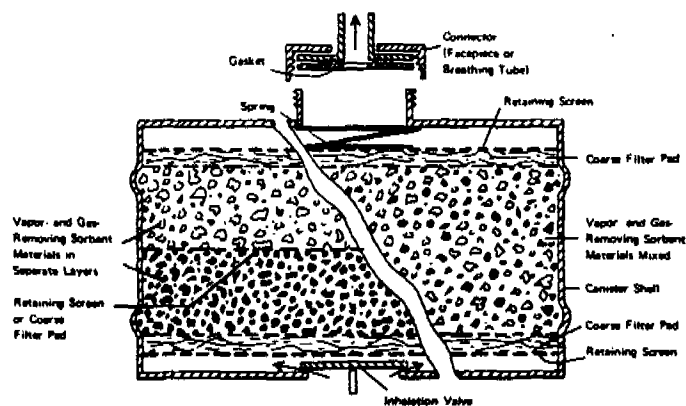


Figure 5-20.
Methods of packing more than one sorbent.

These devices look much like the sorbent cartridge or sorbent canister alone. Figure 5-21 shows the two methods of attaching a particulate filter to a typical cartridge used with half- or quarter-masks. In A, the particulate filter is inside the cartridge "can," in B it is outside the can and held in place by a snap-on cover. Other variations may be found, but the principle is the same. Pesticide and paint spray respirators use combination respirator cartridges, although paint spray respirators are approved under Subpart L of 30 CFR 11 (Chemical Cartridge Respirators), and pesticide respirators under Subpart M. A typical combination particulate- and vapor- and gas removing respirator is shown in Fig. 5-22, being used in paint spraying.

High-efficiency particulate filters are included on some types of combination canisters like the chin-mounted canister shown in Fig. 5-23.

A very specialized type of combination particulate- and vapor- and gas-removing canister is the so-called "Type N," or "Universal" canister, Fig. 5-24. It looks much like a front- or back-mounted canister, being about the same size and held on the body in the same way. Internally, however, there is a great deal of difference. The distinguishing feature is that it contains several different sorbents for various vapors and gases; a catalyst, hopcalite, to convert carbon monoxide to carbon dioxide; and fibrous filters for particulates.

The multiple protection the Type N canister provides has led to unfortunate, sometimes tragic, misuse. Usually the user assumed that he could get the same useful service life from a Type N canister as from an industrial canister of about the same size. Obviously, this is not so, for as Fig. 5-24 shows, sorbents for several different vapor and gas contaminants, two layers of drying agent to protect the catalyst from water vapor, and fibrous particulate

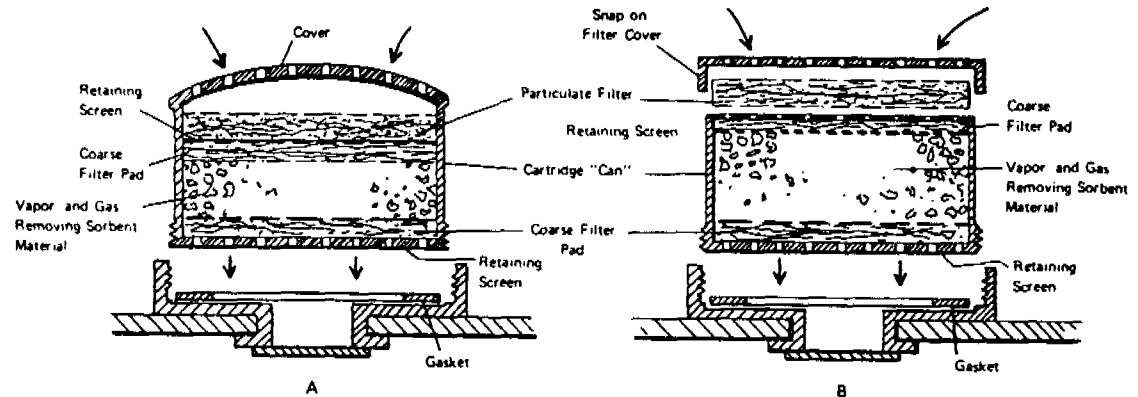


Figure 5-21.
Typical combination particulate- and vapor- and gas-removing cartridges.



Figure 5-22.
Typical combination particulate- and gas- and vapor-removing cartridge respirator being used in paint spraying.

filters are packed into the equivalent space. Therefore, the sorptive capacity of any single layer of sorbent in the Type N canister must be less than that of the large sorbent bed in the industrial size canister for use against a single contaminant. Consequently, the useful service life of the Type N canister is short.

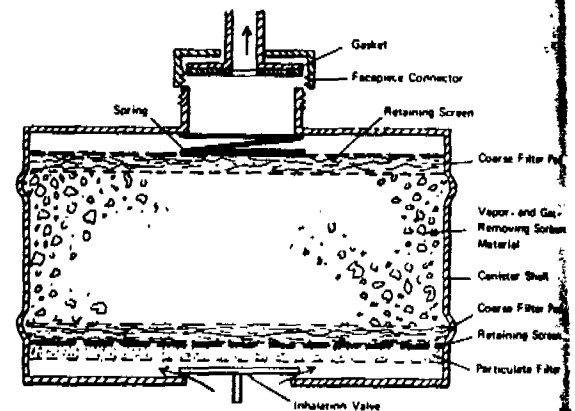


Figure 5-23.
Typical chin-mounted combination particulate-removing and gas- and vapor-removing canister.

All Type N canisters have an indicator, usually behind a small window, that supposedly shows when the canister is exhausted. Actually, it indicates the condition of the drying agent upstream of the catalyst. The CO sorbent, hopcalite, is rendered useless by moisture, and this indicator tells only the condition of this critical layer, not that of the actual gas, ammonia gas, or organic vapor sorbent. Therefore, it cannot be used as an indication of the overall canister condition.

Because of the difficulties in use of Type N canisters, they are being withdrawn from the market. These canisters were originally designed for emergency use, a purpose being met increasingly by atmosphere-supplying devices. However, even with its drawbacks, the Type N canister is useful if the user is well aware of its limitations. Figure 5-22 shows a typical Type N canister attached to a full facemask.

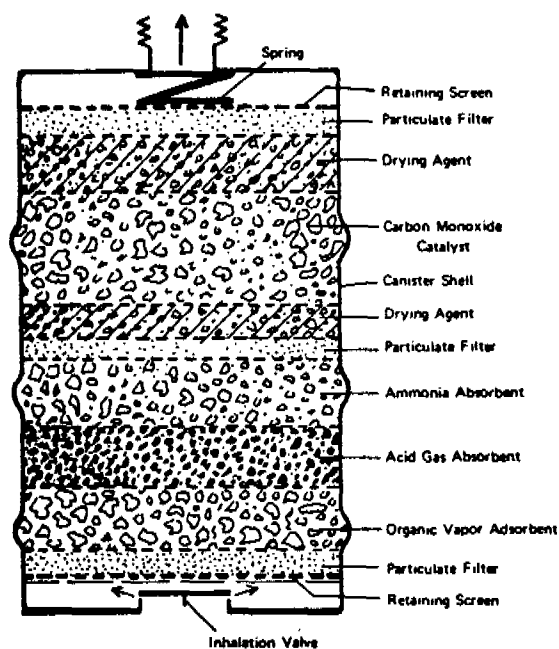


Figure 5-24.
Typical Type N canister.

Powered Air-Purifying Respirators

The powered air-purifying respirator uses a blower to pass contaminated air through an element that removes the contaminants and to supply the purified air to a respiratory-inlet covering. The purifying element may be a filter to remove particulates, a cartridge to remove vapors and gases, or a combination filter and cartridge. The covering may be a facepiece, helmet, or hood. These respirators are approved under 30 CFR, Part 11, Subparts K, L, and M.

One type of powered air-purifying respirator consists of an air-purifying element attached to the housing of a small battery-powered blower that is connected by flexible tubing to the respiratory inlet covering. The wearer carries this entire assembly. Another type consists of an air-purifying element attached to a stationary blower, powered by a battery or externally supplied electricity and connected by a long flexible tube to the respiratory inlet covering. The respirator approval document requires that the blower deliver at least 4 cfm of air to a tight-fitting facepiece and at least 6 cfm to a loose-fitting helmet or hood. A battery-powered air-purifying respirator should supply air for at least 4 hours without recharging of the battery.

The great advantage of the powered air-purifying respirator is that it usually supplies air at positive



Figure 5-25.
Typical Type N canister attached to a full facepiece. (Courtesy Mine Safety Appliances Co.)

pressure so that any leakage is outward from the facepiece. Thus, even if the fit is poor, contaminated air cannot enter. The type and degree of protection depend on the air-purifying element whose protection level and useful service time depend, in turn, on its material, size, and shape and on the nature and concentration of the contaminant.

Also affecting the degree of protection is the wearer's work rate. At high work rates, it is possible, through rapid breathing to create a negative pressure in the facepiece, thereby potentially increasing facepiece leakage. Furthermore, because there is a constant air flow through the air-purifying element, instead of flow only during inhalation, the useful lifetimes of sorbent canisters and cartridges attached to the blower assemblies are much shorter than when the same elements are attached to the common air purifying respirator.

Advantages and Limitations of Air-Purifying Respirators

It is important that the user be thoroughly familiar with the following information. Many instances of misuse arise because the user is unaware of the performance limits of a particular device.

Advantages. Air-purifying devices are small, relatively inexpensive, and easily maintained. They restrict the wearer's movement least. Many combinations of facepieces, mouthpieces, filters, cartridges, and canisters allow the user to match the device to the particular situation.

Disadvantages.

General. Air-purifying respirators cannot be used in atmospheres immediately hazardous to life and health or when the contaminant has poor warning properties, except for escape.

Quarter-Mask, Half-Mask, and Mouthpiece Respirators. Maximum use concentrations may be restricted because of unreliable sealing. These respirators do not protect the eyes or skin. Further restrictions should be placed on their use owing to small sorbent or filter capacity.

Full Facepiece Respirators. Eye protection is provided, but use may be restricted by limited sorbent capacity. They are more expensive than other facepieces.

ATMOSPHERE-SUPPLYING RESPIRATORS

The class of respirators which provide air from a source independent of the surrounding atmosphere instead of purifying the atmosphere is shown in Fig. 5-2. The basic types of atmosphere-supplying respirators vary less than the air-purifying types, but there is greater variation among devices designed for a given purpose. It may be difficult to recognize a particular type of device by appearance alone. The different types may be recognized in two ways, by the method by which air is supplied and the way in which the air supply is regulated.

Self-Contained Breathing Apparatus

The distinguishing feature of all types of self-contained breathing apparatus (SCBA) is that the wearer need not be connected to a stationary air source, such as a compressor. Instead, enough air or oxygen for up to 4 hours, depending on the design, is carried on the person. As Fig. 5-2 shows, SCBAs are classified as "closed-circuit" or "open-circuit."

Closed-Circuit. Another name for closed-circuit SCBAs is "rebreathing" device, indicative of the mode of operation. The air is rebreathed after the exhaled carbon dioxide has been removed and the oxygen content restored by a compressed or liquid oxygen source or an oxygen-generating solid. Descriptions and approval tests for the closed-circuit apparatus are given in Subpart H of 30 CFR Part 11.

These devices are designed primarily for 1- to 4-hour use in oxygen-deficient atmospheres such as might be encountered during mine rescues. They have been used thus since the early 1900's when the Gibbs and McCaa devices were developed. The designs have not changed much since then, a significant commentary on their acceptance and good performance. *NOTE: 30 CFR Part 11 approves for mine rescue only devices that give 1 hour or more performance. Devices that give 30-min or longer performance may be approved for auxiliary mine rescue service.*

Closed-circuit devices are not a cure-all; there are design features that restrict their use. Because negative pressure is created in the facepiece during inhalation, there is increased leakage potential. Therefore, the devices should be used in atmospheres immediately hazardous to life and health only when their long-term use capability is necessary, as in mine rescue. They should not be used in preference to pressure demand SCBAs for short times in immediately hazardous atmospheres. For use in oxygen-deficient atmospheres over a long period, these devices are ideal. For 1/2 hour or less, in highly toxic atmospheres immediately hazardous to life, a positive pressure open-circuit SCBA is recommended.

Two basic types of closed-circuit SCBA are available, distinguished by whether they use a tank of compressed oxygen or a solid oxygen-generating substance. Figure 5-26 shows a typical closed-circuit SCBA with a small cylinder of compressed oxygen. Available from several manufacturers, these devices are all based on the old McCaa device. Breathable air is supplied from an inflatable bag. The exhaled air passes through a granular solid adsorbent that removes the carbon dioxide, thereby reducing the flow back into the breathing bag. The bag collapses so that a pressure plate bears against the admission valve which opens and admits more pure oxygen that reinflates the bag. Thus, the consumed oxygen is made up. The advantage of the rebreathing process is that only the oxygen supply need be carried, as all the other air constituents except the waste carbon dioxide are recirculated. The advantage of this type of device is its long-term (1- to 4-hour) protection. However, it is bulky and does not provide the ultimate in protection because negative pressure is created in the facepiece during inhalation. Figure 5-27 shows a closed-circuit SCBA in use.

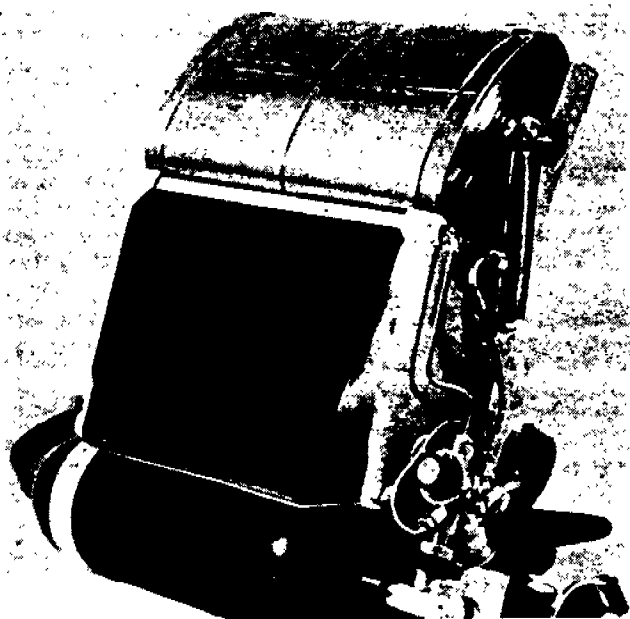
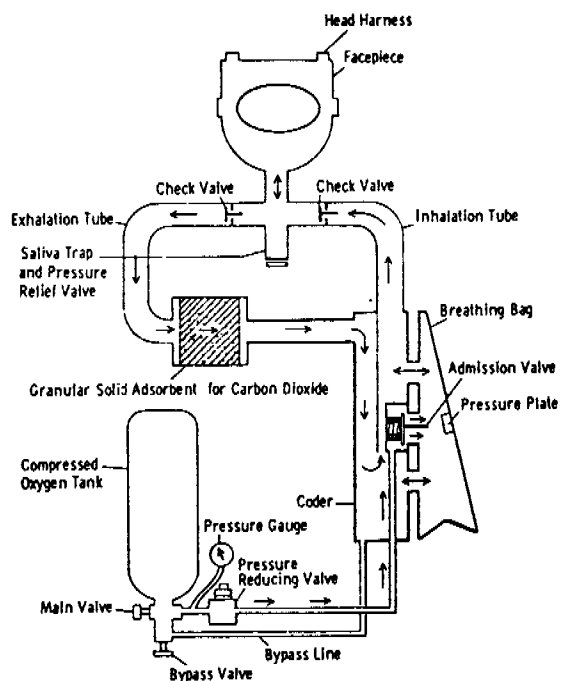


Figure 5-26.
Closed-circuit SCBA.

The second type of closed-circuit SCBA (Fig. 5-28) uses an oxygen-generating solid, usually potassium superoxide (KO_2). The H_2O and CO_2 in the exhaled breath react with the KO_2 to release O_2 .

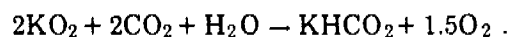
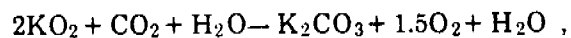


Figure 5-27.
Typical oxygen-supplying closed circuit SCBA
as used for mine rescue.

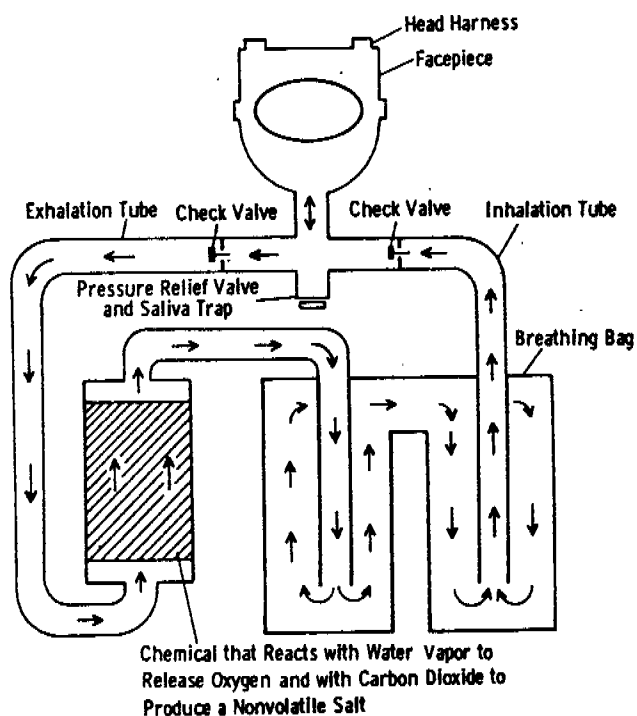


Figure 5-28.
Oxygen-generating closed circuit SCBA.

As the O_2 is released when the wearer's exhaled breath reaches the canister, there is a short time lag after the canister is initiated before O_2 flow begins. This has been overcome in some devices by providing a "quick start" feature, a canister section filled with mixed sodium chlorate and iron. Oxygen flow is started by striking the device, somewhat like lighting a match. This provides enough oxygen until the potassium superoxide in the canister begins to function.

Oxygen is continually released into the breathing bag(s) which acts as a reservoir to accommodate breathing fluctuations. A pressure relief valve and saliva trap release the excess pressure created by nitrogen buildup in the facepiece.

This closed-circuit apparatus is lighter, simpler, and cheaper than the tank type. However, it is useful for only about 1 hour and, once initiated, cannot be turned off. The precautions mentioned for the type containing a cylinder of compressed oxygen apply. Figure 5-29 shows a typical oxygen-generating closed-circuit SCBA being worn.



Figure 5-29.
Typical oxygen-generating closed circuit
SCBA. (Courtesy Mine Safety Appliances Co.)

Open-Circuit. An open-circuit SCBA exhausts the exhaled air to the atmosphere instead of recirculating it. 30 CFR Part 11 does not specify what breathing gas may be approved for these devices, but it is almost always compressed air. Compressed oxygen could be used in a device designed for compressed air, but it must not be, because minute amounts of oil or other foreign matter in the device components can cause an explosion. In fact, 30 CFR Part 11 prohibits approval of any device designed to permit interchangeable use of oxygen and air. **IN GENERAL, OXYGEN SHALL NEVER BE USED IN A DEVICE UNLESS IT IS SPECIFICALLY DESIGNED FOR THAT PURPOSE.** Figure 5-30 shows a typical open-circuit SCBA. A tank of high-pressure (~2000-psi) compressed air, carried on the back, supplies air to a two-stage regulator that reduces the pressure for delivery to the facepiece. This regulator also serves as a flow regulator by passing air to the facepiece only on demand. A flexible corrugated hose connects the regulator to the respiratory-inlet covering, usually a full facepiece.

Because it has to provide the total breathing requirements, not just the oxygen requirements as in the closed-circuit SCBA, the service life of the open-circuit SCBA is usually shorter. Most open-circuit devices have a service life of 30 min. NIOSH approves units with less than 1-hour, but not less than 30-min, service time, for auxiliary mine rescue. Therefore open-circuit devices are very seldom used for this purpose, but they are widely used in fire fighting and industrial emergencies. They are less

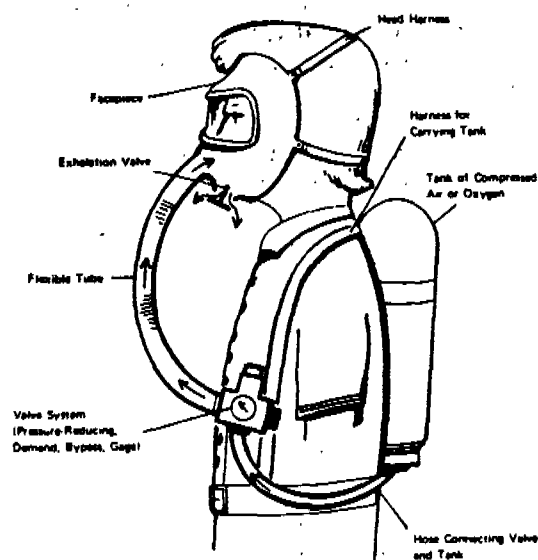


Figure 5-30.
Open-circuit SCBA.

expensive than the closed-circuit SCBAs. SCBAs with less than 30-min service time are approved but only for escape use in combination with a supplied-air airline respirator.

Two types of open-circuit SCBA are available, "demand" or "pressure-demand." The difference is very important and best explained by describing the operation of a typical open-circuit SCBA regulator, shown in Fig. 5-31. This is a "demand"-type regulator. Air at approximately 2000 psi is supplied to the regulator through the main valve. A bypass valve passes air to the facepiece in case of regulator failure. Downstream from the main valve, a two-stage regulator reduces the pressure to approximately 50-100 psi at the admission valve, which is actuated by movement of a diaphragm and its associated levers. The admission valve stays closed as long as positive pressure in the facepiece (during exhalation) presses the diaphragm away from the valve assembly. Inhalation creates negative pressure in the facepiece, and the diaphragm contracts, opening the admission valve and allowing air into the facepiece. In other words, air flows into the facepiece only on "demand" by the wearer, hence the name.

A pressure-demand regulator is very similar except that there is usually a spring between the diaphragm and the outside case of the regulator. This spring tends to hold the admission valve slightly open, theoretically allowing continual air flow into the facepiece. This would be true except that all pressure-demand devices have a special exhalation valve that maintains about 1.5-3 in. H₂O positive back pressure in the facepiece, and opens only when the pressure exceeds that value. This combination of modified regulator and special exhalation valve maintains positive pressure in the facepiece at all times, and the regulator still supplies additional air on "demand." Because of the positive pressure, any leakage is outward so a pressure-demand SCBA

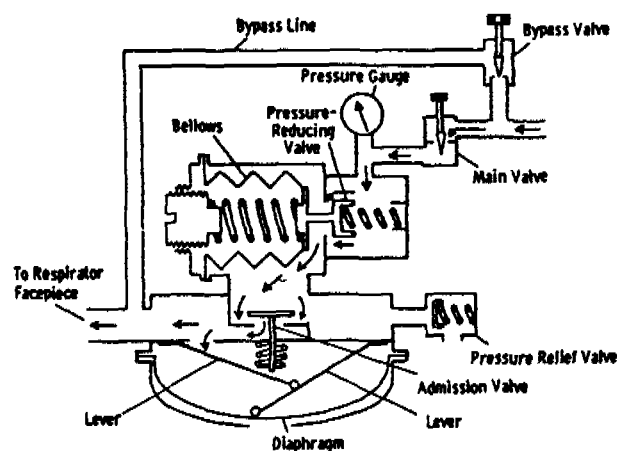


Figure 31.
Open-circuit SCBA regulator.

provides very good protection. Contrary to common belief, the pressure-demand SCBA has the same service time as a demand version of the same device, if it seals well on the wearer's face. Any leakage increases air consumption and decreases service time. **A FACEPIECE WHOSE EXHALATION VALVE IS DESIGNED FOR DEMAND OPERATION CANNOT BE USED WITH A PRESSURE-DEMAND REGULATOR AS AIR WILL FLOW CONTINUALLY AND QUICKLY EXHAUST THE AIR SUPPLY.**

In a demand-type SCBA, negative pressure in the facepiece during inhalation opens the demand valve. This negative pressure is approximately the same as that created in an air-purifying respirator. Therefore, leakage is inward and of the same magnitude as that in an air-purifying respirator. Recent studies showed that a demand-type SCBA is no more efficient than an air-purifying respirator with the same facepiece. Therefore, *a demand type open-circuit SCBA should not be used in atmospheres immediately hazardous to life or health.* Like closed-circuit SCBAs, they are, however, adequate against oxygen-deficient atmospheres.

Some open-circuit SCBAs can be switched from demand to pressure-demand operation; others are available only in one configuration or the other. There is certainly an advantage in being able to change from demand to pressure-demand at will, but there is also a good argument against it. Because these devices are primarily for emergency use, the user should not have the choice, as a demand device is no more efficient than an air-purifying respirator with the same facepiece. In short, if the ultimate in protection is required for emergency use, a pressure-demand SCBA should be purchased.

Because of the high instantaneous flow rates that may be required during inhalation (see Chap. Three), both demand and pressure-demand regulators can deliver flows of 350-400 lpm. This ensures that the wearer will obtain adequate air and generally not be able to "overbreathe" a device. Overbreathing creates extreme negative pressure in the facepiece of a demand SCBA, potentially increasing facepiece leakage. This also can happen in a pressure-demand SCBA, but is less likely because the wearer must overcome the 1.5- to 3-in. H₂O positive pressure.

Several required safety features on all approved closed- and open-circuit, SCBAs provide additional protection. Among these are:

- Pressure gauges or liquid level gauges visible to the wearer which indicate the quantity of gas or liquid (air or oxygen) remaining in the cylinder.
- Remaining service-life indicators or warning devices that show when only 20-25% remains.



Figure 5-32.
Typical open-circuit SCBAs.

- Fittings on devices that use compressed or liquid oxygen which are incompatible with compressed or liquid air fittings.

The choice of demand or pressure-demand device is best left to the user, and should be based on thorough evaluation of the respiratory hazards. If there is any potential atmosphere immediately hazardous to life, a pressure-demand SCBA should most certainly be used. Typical demand or pressure-demand SCBAs are shown in Fig. 5-32.

Supplied-Air Respirators

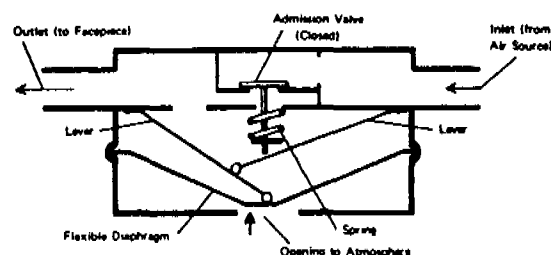
Airline respirators are categorized in 30 CFR Part 11 J as one of the types of supplied-air respirators, along with hose masks which will be described later. The distinction of airline devices is that they all use a stationary source of compressed air delivered through a high-pressure hose. 30 CFR Part 11 specifies that the pressure shall not exceed 125 psi at the point where the hose attaches to the air supply. When the manufacturer submits an airline respirator for approval, he must specify the operating pressure and the hose length, from 25 to 300 ft. At the lowest pressure and greatest hose length, the device must deliver at least 6 cfm to a helmet or hood. The flow rate must not exceed 15 cfm.

Airline respirators are available in demand, pressure-demand, and continuous flow con-

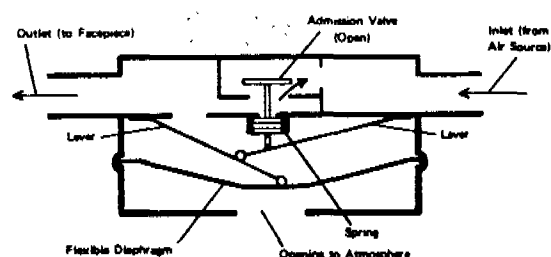
figurations (see Fig. 5-2). They are called Type "C" supplied-air respirators. The respiratory-inlet covering may be a facepiece, helmet, hood, or complete suit, although there are presently no approval tests for suits. When a full facepiece, helmet, or hood provides special protection against impact and abrasion from rebounding abrasive material, it is called a Type "CE" supplied-air respirator.

A demand or pressure-demand airline respirator is very similar to a demand or pressure-demand open-circuit SCBA, except that the air is supplied through a small-diameter hose from a stationary source of compressed air rather than from a portable high-pressure air source. Because the air pressure is limited to 125 psi, regulators for airline respirators have only single-stage reduction. Figure 5-33 shows a typical demand-type regulator. Its operation is self-explanatory and identical to that of a demand-type open-circuit SCBA regulator. Like the pressure-demand open circuit SCBA regulator, the pressure-demand airline regulator has a spring between the diaphragm and the outer case. In combination with a special exhalation valve on the facepiece, it provides positive pressure in the facepiece at all times. Fig. 5-34 shows typical demand or pressure-demand airline respirators with tight fitting facepieces. Note that the regulator sometimes is mounted on the facepiece.

Continuous-flow airline respirators maintain air flow at all times, rather than only on demand. In place of a demand or pressure-demand regulator, an



Exhalation. High pressure of exhaled air stretches diaphragm. Resulting lever movement and spring action close admission valve, and air flow ceases.



Inhalation. Low pressure created by inhalation pulls diaphragm inward. Resulting lever movement compresses spring and opens admission valve. Air flows through valve.

Figure 5-33.
Typical demand-type air flow regulator.

air flow control valve or orifice partially controls the air flow. According to 30 CFR Part 11, a flow of at least 4 cfm to a tight-fitting respiratory-inlet covering and 6 cfm to a loose-fitting one must be maintained at lowest air pressure and longest hose length specified. This means that by design, the control valve cannot be closed completely, or a continually open bypass is provided to allow air to flow around the valve and maintain the required minimum rates.

Never replace an air flow control valve with another type of valve, even one from another manufacturer's airline respirator. Besides possibly creating a hazard owing to improper air flow rates, substitution of another component negates NIOSH and MESA approval of the device. Furthermore, only the air supply hose furnished by the respirator manufacturer may be used with a supplied-air respirator. Substitution of another type of hose, even though equivalent, negates approval of the device.

Figure 5-35 depicts a typical continuous flow airline respirator with a tight fitting facepiece. Notice

the air-purifying element on the air supply line. Figure 5-36 shows typical such devices, which also may be obtained with half-masks.

Although addition of an air-purifying element in the supply line just upstream of the air supply hose attachment is a good idea, other precautions also must be taken to ensure breathing air quality. The air supply to airline respirators is required to meet the requirements for Type I gaseous air (Grade D or higher quality) set forth by the Compressed Gas Association Commodity Specification for Air, G-7.1. Furthermore, OSHA requires that a breathing air compressor have certain safety devices to protect the air quality (see Chap. Six).

Airline respirators with special items to protect the wearer's head and neck from rebounding abrasive material may have facepieces, helmets, or hoods. Plastic, glass, and metal wire screen are used to protect the lenses of facepieces and the windows of helmets and hoods against the rebounding material. These respirators are known as abrasive-blasting airline respirators or Type "CE" supplied-air respirators.

Figures 5-7 and 5-8 showed two types of continuous flow airline abrasive blasting hoods, although it might be preferable to call them "blouses" as they extend to the waist. The figures indicate the design variations within the Type "CE" device category. Figure 5-37 shows a typical abrasive blasting hood, and Fig. 5-38 shows a variation designed specifically for lead grinding. Note the protective screen over the lens and the heavy apron on the abrasive blasting hood.

Full-suit airline respirators are available. They provide purified air not only for breathing but also to isolate the whole body from the surrounding atmosphere. They are used against substances that irritate or corrode the skin or which may penetrate the skin and enter the blood stream to produce toxic effects. Presently, 30 CFR Part 11 does not provide for approval of airline suits. Typical full suits are shown in Figs. 5-39 and 5-40.

Airline respirators provide a high degree of protection, but their use is limited to atmospheres not immediately hazardous to life. The reasoning is that the wearer is totally dependent upon the integrity of the air supply hose. Therefore, he must be able to escape from the contaminated area without endangering his life.

Combination SCBA and Supplied Air Respirators

To be usable in an atmosphere immediately hazardous to life, an airline respirator must have an auxiliary air supply to protect against potential



Figure 5-34.
Typical demand or pressure demand airline
respirators

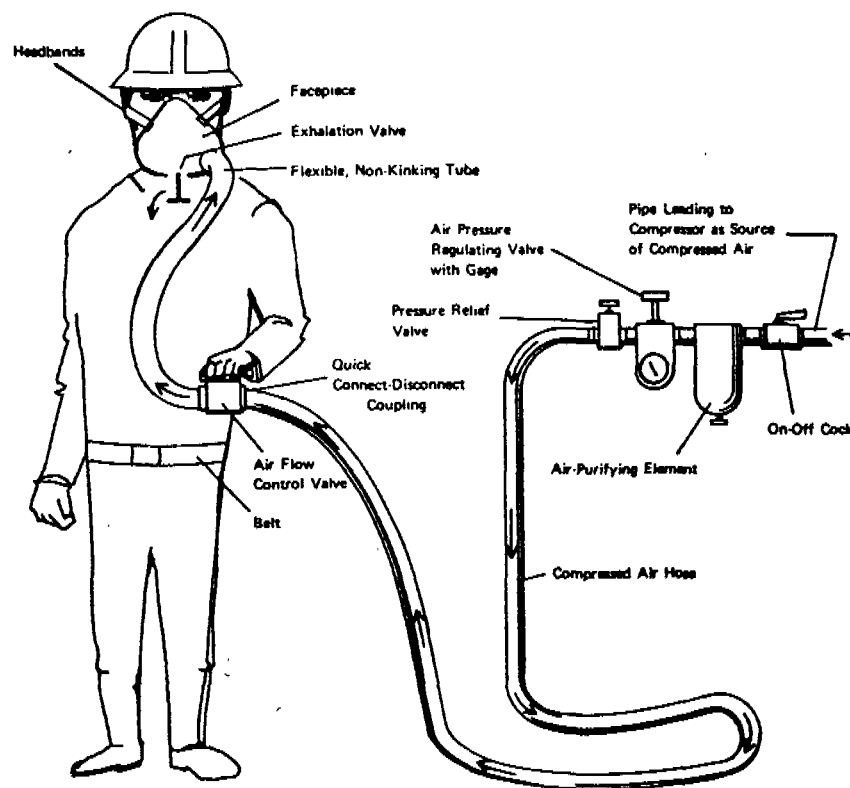


Figure 5-35.
Continuous flow airline respirator.

failure of the primary supply. This is provided by adding a self-contained tank of high-pressure compressed air to a Type "C" or "CE" airline respirator. The auxiliary air supply may be approved for 3-, 5-, or 10-min service time, or for 15 min or longer (see Fig. 5-2). The approval tests for these combination devices are found in 30 CFR Part 11, Subpart H, "Self-Contained Breathing Apparatus."

The combination airline and SCBA respirator is essentially the same as the airline respirator itself, with an added small compressed air cylinder that may be carried on one's back or at one's side in a sling. The device shown in Fig. 5-41 is only representative of this general class; designs vary widely.

Because of the short service time of the self-contained breathing air supply, combination units generally are used for *emergency* entry into and escape from atmospheres immediately hazardous to life. The self-contained part of the device is used only when the airline part fails and the wearer must escape, or when it may be necessary to disconnect the air line temporarily while changing locations. A combination airline and SCBA may be used for *emergency* entry into a hazardous atmosphere (to connect the airline), if the SCBA part is classified for 15-min or longer service and not more than 20% of

the air supply's rated capacity is used during entry. It is seldom used as a routine means of protection, as the open-circuit SCBA might be.

Hose Masks

Hose masks supply air from an uncontaminated source through a strong, large-diameter hose to a respiratory-inlet covering. Two types are available. One has a hand- or motor-operated air blower that pushes low-pressure air through the hose to the respiratory-inlet covering. The blower is designed so that air flows freely through it when it is not in operation. Therefore, if the blower fails, the wearer can still inhale respirable air by normal breathing. The other type of hose mask has no blower and requires the wearer to inhale through the hose.

The hose mask with a blower is categorized by 30 CFR Part 11 Subpart J, as a Type "A" supplied-air respirator and is approved for use in atmospheres immediately dangerous to life or health. The hose mask without a blower is categorized as Type "B" and is approved for use only in atmospheres not immediately hazardous to life or health. The hose mask with a blower may have a facepiece, helmet, or hood,



Fig. 5-36.

Typical air line continuous flow respirators with full facepieces. (Courtesy Mine Safety Appliances Co.)

but the one without a blower must have a tight-fitting facepiece. Hose masks may have special equipment to protect the wearer's head and neck from rebounding material during abrasive blasting. Such a hose mask with a blower is classified as a Type "AE" supplied-air respirator, and the one without a blower is classified as Type "BE."

An approved hose mask with a blower may have up to 300 ft of air supply hose in multiples of 25 ft, but one without a blower may have only up to 75 ft in multiples of 25 ft. The hand- or motor-operated blower must deliver air through the maximum length of hose at not less than 50 lpm. The motor-operated blower of a device with 50 ft of hose must deliver no more than 145 lpm. However, no maximum air flow rate is specified for the hand-operated blower. Figure 5-42 shows a typical hose mask with a hand-operated blower. Notice that a harness and attached lifeline are necessary for use in atmospheres immediately dangerous to life or health.

The wearer's mobility and area of movement are restricted by the large hose that requires him to leave a contaminated area by the way he entered. He must be careful not to damage the hose and to prevent it from becoming caught on objects.

NOTE: Although the hose mask with blower is presently approved for use in atmospheres immediately dangerous to life or health, it is not permitted for such use in the standards that NIOSH is developing for OSHA.

A hose mask with blower should not be used in an atmosphere immediately hazardous to life or health because air flow as low as 50 lpm will result in negative air pressure during inhalation, permitting contaminated air to leak into the covering. Also, if the air supply hose is cut or flattened, the wearer will be unprotected. Figure 5-43 shows a typical hose mask with hand operated blower in use in a tank reentry operation.



Figure 5-37.
Typical abrasive blasting hood. (Courtesy
Mine Safety Appliances Co.)



Figure 5-38.
Supplied air hood for lead grinding. (Courtesy
Mine Safety Appliances Co.)



Figure 5-39.
Simple flexible plastic full suit.



Figure 5-40.
Complex full suit for protection in demanding
conditions.



Figure 5-41
Typical combination air line and SCBA respirator. (Courtesy Mine Safety Appliances Co.)



Figure 5-43.
Typical hose mask with hand-operated blower being used for tank entry. (Courtesy Mine Enforcement Safety Administration.)

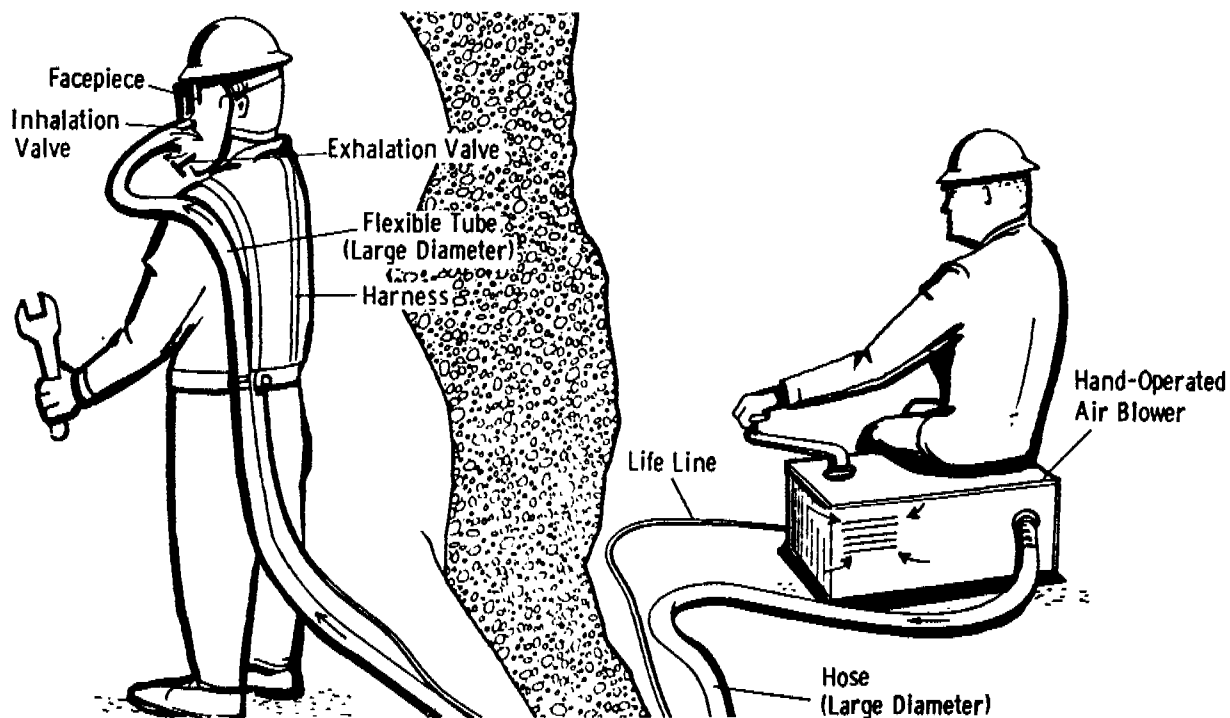


Figure 5-42.
Hose mask respirator with hand-operated blower.

CHAPTER SIX

RESPIRATOR SELECTION

OSHA STANDARDS

OSHA 1910.134 states that respirators shall be selected on the basis of the hazards to which workers are exposed and that ANSI Z88.2-1969 shall be used for guidance in their selection. OSHA also requires that approved or accepted respirators be used when available. For certain respiratory hazards, specific instructions about respirator use are given in other OSHA regulations. The trend seems to be toward regulations that specify the conditions of respirator use for each task. OSHA 1910.134 is then consulted for general instructions. Regardless of the regulations, respirators must be selected with the environment in which they will be used in mind. To do so requires certain basic information, so one should always ask the following questions before selecting a respirator.

1. What is the estimated contaminant concentration where the respirator will be used?
2. What is the permissible exposure limit to the contaminant?
3. Is the contaminant a gas, vapor, mist, dust, or fume?
4. Could the contaminant concentration be termed immediately hazardous to life or health?
5. If the contaminant is flammable, does the estimated concentration approach the lower explosive limit?
6. Does the contaminant have adequate warning properties?
7. Will the contaminant irritate the eyes at the estimated concentration?
8. If the contaminant is a gas or vapor, is there an available sorbent that traps it efficiently?
9. Can the contaminant be absorbed through the skin as a vapor or liquid? If so, will it cause serious injury?

The answers to these questions can provide enough information for choosing a respirator for routine use. There is nothing strange or unique about these questions. They represent the factors that a good industrial hygiene program would incorporate for respirator selection or any other type of control and form the basis for the Respirator Decision Logic (incorporated verbatim as Appendix F)

used in the Joint NIOSH and OSHA Standards Completion Program.

You should review the Decision Logic when considering respirator selection because it incorporates the above questions in an orderly sequence. By following this logic, you will be able to choose a respirator that is satisfactory for the situation at hand and be assured that you have not overlooked any important factor.

The Decision Logic is being used (in 1975) in development of detailed work practices for the material listed in 29CFR Part 1910.1000, Tables Z-1, 2, and 3. It will be useful to you in developing your own respirator program until standards are listed for the particular materials in which you are interested. Before proceeding to examples of how to use the Decision Logic, we would like to point out four criteria of particular interest.

- When respirators are used for protection against gases and vapor, it is commonly recommended that cartridges be changed when the wearer smells the vapor. This indicates that there must be some smell or irritation to alert the wearer. Section IV B of the Decision Logic states that a substance should be considered to have warning properties if the odor or irritation threshold is not more than three times the exposure limit, and there is no ceiling limit. Consideration is given to whether undetected exposure in this concentration range could cause serious or irreversible health effects. If not, the substance is considered to have adequate warning properties.
- Section IV C states that where there is supporting evidence of vapor breakthrough in less than three minutes at concentrations immediately dangerous to life or health or below, a cartridge or canister sorbent air purifying device should not be allowed for any use. The principal sources of information on sorbent efficiencies are Lawrence Livermore Laboratory and 30 CFR-11 on certain specific materials on which cartridge tests are run. Users should be alert to any future information on sorbent efficiency, as it will definitely affect choice of air purifying respirators.

- Section IV D states that for routine operations any perceptible eye irritation is considered unacceptable. No definition of perceptible eye irritation is given.
- Section IV E concerns atmospheres immediately dangerous to life or health, (IDLH). Opinions on the correct definition of IDLH differ, but this section gives several guidelines to assist you in defining it. Although not everyone will agree with all the conservative guidelines given, this is the best information available for assessing IDLH problems.

ANSI Z88.2-1969 STANDARDS

Before development of the NIOSH and OSHA Decision Logic, the ANSI 288.2-1969 Standards were the main source of information on respirator selection. Section 3.5.2, Requirements for a Minimal Acceptable Respirator Program, states that respirators shall be selected on the basis of the hazards to which workers are exposed. Section 3.8 states that approved or accepted respirators shall be used when available. Section 6 is devoted exclusively to respirator selection; however, new technology has made much of that information obsolete. The Standard is being revised, and when it is reissued it should contain useful details on respirator selection.

SELECTION

OSHA 1910.134 requires that approved or accepted respirators be used when available. What does "available" mean? If at least one brand of approved or accepted respirator suitable for the specific application exists, it is available. Therefore, those who must provide respirators to workers must select and use approved or accepted respirators.

An approved respirator is one that has been tested, found to meet established performance criteria, and listed as approved by an authority such as the Mining Enforcement and Safety Administration (MESA) of the U.S. Department of the Interior, or the National Institute for Occupational Health, (NIOSH) of the U.S. Department of Health, Education, and Welfare.

The Bureau of Mines (BOM) no longer tests and approves respirators; however, BOM-approved respirators now in the possession of industrial firms who must provide them to workers will be recognized as approved for various periods depending upon their type. Approval will continue until March 31, 1976, for particulate-filter and chemical cartridge respirators, until March 31, 1979, for self-contained

breathing apparatus, and until March 31, 1980, for supplied-air respirators. An expiration date for gas masks had not been established at the time of printing. MESA and NIOSH now test and approve respirators jointly under the provisions of a respirator test and approval document, 30 CFR Part 11.

There are some respirators, full suits, for example, for which there are no approval criteria. Such a special respirator is said to be "accepted" if it has been tested and found satisfactory for its specific application by some recognized organization.

SELECTION OF RESPIRATORS FOR ROUTINE USE

Routine use of a respirator is daily or frequent use on a regular basis. For such use, a respirator of low initial cost, simple maintenance to keep operating costs down, minimal wearing discomfort, low resistance to breathing, light weight, and compact construction should be considered. Nonpowered air-purifying respirators and airline and hose mask supplied-air respirators are suitable.

SELECTION OF RESPIRATORS FOR NONROUTINE AND EMERGENCY USE

A respirator used nonroutinely is used for hazardous situations that occur only occasionally. For such applications, initial costs and maintenance costs are less important than for routine applications. The degree of protection and the useful service time provided are important.

Any respirator that protects adequately against a hazardous atmosphere that occurs suddenly may be used for escape purposes. If the hazardous atmosphere causes eye irritation, the respirator should have a full facepiece. Compact air-purifying respirators with mouthpieces and nose clamps have been used successfully for escape from some hazardous atmospheres.

If an area containing an unknown air contaminant concentration must be entered, a pressure demand SCBA or a combination SCBA and airline supplied-air respirator, either of which is specifically designed to maintain positive air pressure inside the facepiece, should be used.

A pressure demand SCBA should be used in fire fighting. All the questions that should be answered in selecting respirators for routine use should also be answered in selecting respirators for emergency use.

In the NIOSH Decision Logic, emergency use is mentioned under respirator protection factors.

RESPIRATOR PROTECTION FACTORS

Definition

The respirator protection factor indicates how much protection a respirator provides. It is the ratio of the contaminant concentrations outside and inside the respirator. Determination of the protection factor requires quantitative performance tests of the respirator worn in a test atmosphere during exercise simulating motions made by workers, or worn by workers carrying out tasks in contaminated work areas (see Chapter 8).

Assignment

Much research has been done recently on assigning protection factors to various types of respirators. Table 6-1, reproduced verbatim from the LASL protection factor document, lists assigned respirator protection factors resulting from this research. When using Table 6-1, pay strict attention to its footnotes as they are essential in interpreting the table and assist in application of protection factors. The protection factors listed in the Decision Logic are taken from Table 6-1.

Application

To apply an assigned protection factor for a particular type of respirator, one must know both the actual contaminant concentration in the work area and the established time-weighted average concentration. Multiplying the time-weighted average concentration by the respirator protection factor gives the maximum concentration of the contaminant against which the particular type of respirator may be used. If the actual concentration is less than the calculated maximum use concentration, the respirator may be used.

In describing use of protection factors in respirator selection, it is assumed that a complete respirator program is in force. A protection factor is not applicable if the wearer cannot satisfactorily seal the respirator to his face or head. Anything such as facial hair or spectacles that prevents satisfactory sealing of a respirator nullifies application of a respirator protection factor. A protection factor can be used only if the respirator is in good operating condition,

so the respirator must be properly maintained. Other limitations of various types of respirators discussed in Chapter Eight must also be considered in applying protection factors.

EXAMPLES OF RESPIRATOR SELECTION

The following are hypothetical but typical examples of the respirator selection process. They should not be used as cookbook models, but as guides to the rationale for selecting particular respirators, and, equally important, to the industrial hygiene aspects of the hazards. In these examples, we assume that regular use of respirators is permissible.

1. A miller operator in a foundry complains of dust in the air, and the superintendent supplies him a single-use, disposable respirator. The steward tells the superintendent that this is a violation of the OSHA Regulations as the particular respirator does not have NIOSH and MESA approval. Who is right, and what should be done?

Answer: Nothing bans the sale or use of unapproved devices in areas where respirators are not required. Before deciding about use of this respirator, we need information about the dust concentration in the air. Samples were taken in the miller's breathing zone, and the dust concentration was found to be 5 mg/m^3 . The amount of crystalline silica (quartz) in the dust was 48%. The permissible quartz dust exposure limit in such conditions is 1.5 mg/m^3 .

Now refer to Section II of the Respirator Decision Logic, Appendix F. Because the material is a particulate, statements 2, 4, and 6 are not pertinent. As to the other statements: 3) Silica is not known to be an eye irritant, 5) the IDLH concentration is far above the 5-mg/m^3 dust level found in this case, and 7) to date, there is no evidence of injury from silica through skin absorption. As the material is a particulate, we can proceed to Section III B, the specific decision logic chart for respiratory protection against particulates. The restrictions under Routine Use do not apply, so we can proceed to Appendix 1, Section A, "Protection Factors for Particulate Filter Respirators." As the dust concentration is less than five times the permissible limit, we can choose any respirator from this list. A single-use respirator with a protection factor of 5 or a half-mask respirator with a protection factor of 10 probably would be chosen.

2. A woman doing silk screening without any local exhaust ventilation complained of headaches and nausea from the vapors and fumes. She was given a dust respirator customarily used by a sandblaster's helper. (Obviously a dust respirator for use against

TABLE 6-1
RESPIRATOR PROTECTION FACTORS¹

Type Respirator	Facepiece ² Pressure	Protection Factor
I. Air-Purifying		
A. Particulate ³ removing		
Single-use, ⁴ dust ⁵	—	5
Quarter-mask, dust ⁶	—	5
Half-mask, dust ⁶	—	10
Half- or Quarter-mask, fume ⁷	—	10
Half- or Quarter-mask, High-Efficiency ⁸	—	10
Full Facepiece, High-Efficiency	—	50
Powered, High-Efficiency, all enclosures	+	1000
Powered, dust or fume, all enclosures	+	X ⁹
B. Gas and Vapor-Removing ¹⁰		
Half-Mask	—	10
Full Facepiece	—	50
II. Atmosphere-Supplying		
A. Supplied-Air		
Demand, Half-mask	—	10
Demand, Full Facepiece	—	50
Hose Mask Without Blower, Full Facepiece	—	50
Pressure-Demand, Half-Mask ¹¹	+	1000
Pressure-Demand, Full Facepiece ¹²	+	2000
Hose Mask With Blower, Full Facepiece	—	50
Continuous Flow, Half-Mask ¹¹	+	1000
Continuous Flow, Full Facepiece ¹²	+	2000
Continuous Flow, Hood, Helmet, or Suit ¹³	+	2000
B. Self-Contained Breathing Apparatus (SCBA)		
Open-Circuit, Demand, Full Facepiece	—	50
Open-Circuit, Pressure-demand Full Facepiece	+	10,000 ¹⁴
Closed-Circuit, Oxygen Tank-type, Full Facepiece	—	50
III. Combination Respirator		
A. Any combination of air-purifying and atmosphere-supplying respirator.		Use minimum protection factor listed above for type of mode of operation.
B. Any combination of supplied-air respirator and an SCBA		

Exception: Combination supplied-air respirators, in pressure-demand or other positive pressure mode, with an auxiliary self-contained air supply, and a full facepiece, should use the PF for pressure-demand SCBA.

NOTE: Table is not to be reproduced without the accompanying footnotes.

¹ The overall protection afforded by a given respirator design (and mode of operation) may be defined in terms of its protection factor (PF). The PF is a measure of the degree of protection afforded by a respirator, defined as the ratio of the concentration of contaminant in the ambient atmosphere to that inside the enclosure (usually inside the facepiece) under conditions of use. Respirators should be selected so that the concentration inhaled by the wearer will not exceed the appropriate limit. The recommended respirator PF's are selection and use guides, and should only be used when the employer has established a minimal acceptable respirator program as defined in Section 3 of the ANSI Z88.2-1969 Standard.

² In addition to facepieces, this includes any type of enclosure or covering of the wearer's breathing zone, such as supplied-air hoods, helmets, or suits.

³ Includes dusts, mists, and fumes only. Does not apply when gases or vapors are absorbed on particulates and may be volatilized or for particulates volatile at room temperature. Example: Coke oven emissions.

⁴ Any single-use dust respirator (with or without valve) not specifically tested against a specified contaminant.

⁵ Single-use dust respirators have been tested against asbestos and cotton dust and could be assigned a PF of 10 for these particulates.

⁶ Dust filter refers to a dust respirator approved by the silica dust test, and includes all types of media, that is, both nondegradable mechanical type media and degradable resin-impregnated wool felt or combination wool-synthetic felt media.

⁷ Fume filter refers to a fume respirator approved by the lead fume test. All types of media are included.

⁸ High-efficiency filter refers to a high-efficiency particulate respirator. The filter must be at least 99.97% efficient against 0.3 μm DOP to be approved.

⁹ To be assigned, based on dust or fume filter efficiency for specific contaminant.

¹⁰ For gases and vapors, a PF should only be assigned when published test data indicate the cartridge or canister has adequate sorbent efficiency and service life for a specific gas or vapor. In addition, the PF should not be applied in gas or vapor concentrations that are: 1) immediately dangerous to life, 2) above the lower explosive limit, and 3) cause eye irritation when using a half-mask.

¹¹ A positive pressure supplied-air respirator equipped with a half-mask facepiece may not be as stable on the face as a full facepiece. Therefore, the PF recommended is half that for a similar device equipped with a full facepiece.

¹² A positive pressure supplied-air respirator equipped with a full facepiece provides eye protection but is not approved for use in atmospheres immediately dangerous to life. It is recognized that the facepiece leakage, when a positive pressure is maintained, should be the same as an SCBA operated in the positive pressure mode. However, to emphasize that it basically is not for emergency use, the PF is limited to 2,000.

¹³The design of the supplied-air hood, suit, or helmet (with a minimum of 6 cfm of air) may determine its overall efficiency and protection. For example, when working with the arms over the head, some hoods draw the contaminant into the hood breathing zone. This may be overcome by wearing a short hood under a coat or overalls. Other limitations specified by the approval agency must be considered before using in certain types of atmospheres.

¹⁴The SCBA operated in the positive pressure mode has been tested on a selected 31-man panel and the facepiece leakage recorded as less than 0.01% penetration. Therefore, a PF of 10,000+ is recommended. At this time, the lower limit of detection 0.01% does not warrant listing a higher number. A positive pressure SCBA for an unknown concentration is recommended. This is consistent with the 10,000+ that is listed. It is essential to have an emergency device for use in unknown concentrations. A combination supplied-air respirator in pressure-demand or other positive pressure mode, with auxiliary self-contained air supply is also recommended for use in unknown concentrations of contaminants immediately dangerous to life. Other limitations, such as skin absorption of HCN or tritium, must be considered.

an organic vapor is a completely wrong choice.) The woman's continued complaints of headaches and nausea lead to an OSHA inspection. Air sampling revealed 40 ppm of isophorone in her breathing zone. It was pointed out that this was above the permissible 25-ppm limit for isophorone. A local exhaust system was suggested. Management agreed, and while the local exhaust system was being installed supplied the employee with what type of respirator if any?

Answer: The measured 40-ppm concentration is 1.6 times the 25-ppm permissible limit. In the Decision Logic, Section II, note that questions 2-6 and 7 are unanswered. A review of the literature on isophorone will show that it can be detected well below the 25-ppm level and that 40 ppm presents a definite sensation to the eyes. This, using the Decision Logic interpretation, would be interpreted as eye irritation. The lower explosive limit and the concentration immediately hazardous to life are well above 40 ppm. Finally, there is no evidence of poor sorbent efficiencies or problems of skin absorption with this material.

Proceed to Section III A, the Chart for Respiratory Protection Against Gases or Vapors. Item C, Eye Irritation, eliminates use of half-mask respirators. Protection factors for chemical cartridges and gas masks are listed in Appendix I B. Although the protection factor necessary is only 3, chemical cartridge half-mask respirators with protection factors of 10 are eliminated because of the eye irritation problem. A minimum of a chemical cartridge respirator with a full facepiece must be provided.

3. A sandblaster and his helper are working outdoors on a 50-foot scaffold. Are respirators necessary? If so, what type of respirators?

Answer: To fully answer these questions, we must ask what abrasive is being used and what surface is being treated. Let's assume that the abrasive is silica sand and the surface is granite. These create a silica dust problem, and the OSHA ventilation standards 1910.94 require that the employer furnish respiratory protection whenever silica sand is used as an abrasive. Furthermore, even if a different abrasive were used, silica dust would be produced from the granite. Therefore the operator must be furnished an approved abrasive blasting respirator, a Type AE, BE, or CE device.

Another aspect of this problem which must be considered closely is the workplace geometry. The sandblaster and his helper are working on the scaffold. We have specified protection for the sandblaster, but how about his helper? He is in the immediate vicinity of the blasting, so he should have the same degree of protection. However, he will probably have to leave the scaffold occasionally to perform some task. Then, having to remove the abrasive blasting hood will be a nuisance, and trying to climb down from the scaffold while wearing it will be dangerous.

There are several solutions to this problem. The best would be to arrange that the helper stay on the ground, ascending to the scaffold only when absolutely necessary. Then, a half-mask dust respirator would be adequate. If the helper must be on the scaffold with the sandblaster most of the time, work practices should specify that he must stay as far away from the sandblaster as the scaffolding allows. If this is done in conjunction with periodic air sampling to ensure that the airborne silica concentrations do not exceed the OSHA limit by more than 10 times, a half-mask dust respirator

can be used. If this is impossible, the only recourse is provide the helper the same protection as the sandblaster. Remember, the air supply system must meet the requirements for Grade D or better compressed air.

The point illustrated in this example is that it is not enough to abide only by the requirements of 29 CFR Part 1910.134 which is concerned with general use of respirators. There are other requirements within the OSHA regulations which may also affect respirator selection and use.

Use of the Decision Logic was not mentioned in this example. The regulations requiring use of a supplied air hood were made before assembly of the Decision Logic. You will note that the Decision Logic Protection Factor Table lists a PF of 2000 for the supplied air hood. Considering the unknown concentration of silica dust to which the sandblaster can be exposed, the protection required is consistent with the Decision Logic.

4. A man assigned to clean a large degreaser must occasionally go into the degreaser pit. He complains that the odor of trichloroethylene (trichlor) is so strong that it comes through his respirator cartridges after only a short time. Should he be assigned another type of respirator?

Answer: The fact that the worker complains about the short lifetime of the sorbent cartridges warns that the trichlor concentrations may be high. This brings up the dual hazards of toxicity and oxygen deficiency. Degreaser pits are places where vapors may collect and, unless ventilated, actually reduce the oxygen below safe levels. Unless the pit is ventilated to prevent oxygen depletion, a positive pressure SCBA must be used. If the pit is ventilated, it will not be necessary to wear a respirator if tests show that the trichlor concentration is below the exposure limit and that the oxygen has not been depleted.

Again, the Decision Logic Section III A shows that for entry and escape from unknown concentrations the only type of device that can be used is positive pressure self-contained breathing apparatus.

5. A flagman for an aerial crop duster using Phosdrin dust is supplied a single-use disposable dust respirator. Is this adequate?

Answer: Several points listed in the Decision Logic flow chart are pertinent here. Pesticides such as Phosdrin are noted for their ability to kill by absorption through the skin. The single-use respirator certainly does not provide complete skin protection. In such cases, protective clothing is as important as a proper respirator.

The pesticide is mixed with the dust; however, some of it may vaporize from dust. This is one reason

why the only respirators approved for pesticide use have organic charcoal in back of the dust filter.

The Phosdrin concentration to which the flagman is exposed is not stated. Before a respirator can be assigned, we must know the approximate concentration expected. If the concentration cannot be estimated, the flagman will have to be provided with a self-contained breathing apparatus.

6. Hydrocyanic acid is used in a fumigation chamber. By state regulation, a full-face respirator or gas mask with a hydrocyanic acid canister is required. Is such protection satisfactory?

Answer: To decide whether the respirator is adequate, one must have some knowledge of the toxicity and potential concentration of the hydrocyanic acid. The TLV for hydrocyanic acid is listed as 10 ppm, with a warning that skin absorption is a problem. Regardless of the respiratory protection provided, there must be some protection for the skin in such an atmosphere.

A review of the toxicity of hydrocyanic acid will show that a concentration of 270 ppm is immediately fatal and concentrations of 110 ppm are fatal within half an hour. Concentrations of hydrocyanic acid in fumigation chambers usually exceed 1% (10,000 ppm). The full-face gas mask is accorded a protection factor of only 50 in Table 6-1. Therefore, it would not be useful in concentrations above 500 ppm. Such a mask would not be satisfactory in this case. The Decision Logic offers a quicker solution. Section III A notes that when the contaminant concentration exceeds that immediately dangerous to life or health, only positive pressure self-contained breathing apparatus is acceptable respiratory protection.

7. A salvage company is to demolish a large open-framework steel structure built in 1910 in a southern city. The job will require extensive use of cutting torches. Will respirators be required, and if so, of what type?

Answer: Respirators definitely must be used. As the structure was built in 1910, it undoubtedly has many coats of lead-base paint, which when heated by the cutting torches will create a severe airborne lead problem. Therefore a respirator approved for protection against metal fumes can be used. Whether this will be a quarter- or half-mask or full-facepiece respirator can be determined only after air samples are taken in the wearers' breathing zones. Because this is an outdoor operation, the concentrations will vary widely. However, similar operations have shown that concentrations of 2 mg/m³ are not unusual. Considering the low protection factors for air-purifying respirators, the high temperatures in this climate, and the added heat

loss from the cutting torches, a continuous flow air line respirator should be considered. The trailing air hoses should not present much of a problem, as the workers will already be encumbered with the gas supply lines to the cutting torches. When equipped with a half-mask facepiece to allow wearing of the necessary goggles, the air line respirator will provide a more than adequate protection factor of 2000.

Providing this protection involves the expense and maintenance of the air supply system, plus the cost of the expensive air line respirator itself. However, in this example, these complications seem more than justified.

9. A large packing firm in Washington state stores apples in warehouses containing a nitrogen atmosphere with less than 3% oxygen. Inspectors must enter the storage areas periodically to examine the apples. What type of protection do they need?

Answer: Obviously with only 3% oxygen, the atmosphere inside the warehouse must be considered immediately hazardous to life. This fact seems to dictate use of a positive pressure supplied air device. This is not entirely true, as we are dealing only with reduced oxygen content of the air, not toxic materials in it. As discussed in Chapters Three and Four, the sea level oxygen content can be reduced, on a physiological basis—not a legal one, to about 14.5% without significant physiological effects. This amounts to reducing the partial pressure of oxygen in the air from a normal 160 mm Hg to about 110 mm. This 50-mm reduction is about 30% of the total normal oxygen ($50/160 \times 100 = 31\%$). Translated into respirator leakage, this means that the wearer could tolerate about 30% leakage of air containing no oxygen into the facepiece. On the basis of facepiece leakage alone, a half-mask with a protection factor of 10 would allow up to 10% leakage, and a full facepiece would allow up to 2% leakage with a protection factor of 50. Atmosphere-supplying

devices with either of these facepieces would provide adequate protection and a reasonable margin of safety. Many choices could be made. If the inspectors must remain inside for more than 30 minutes, an air line respirator with escape cylinder or a closed circuit SCBA should be used. The choice will depend on whether the inspector can tolerate the trailing air line or prefers to carry 35 pounds of breathing apparatus on his back. An oxygen-generating closed circuit SCBA could be used, but its useful lifetime is only one hour and once started it cannot be shut off. For less than a half hour, an open circuit SCBA could be used, as well as the device just mentioned.

This example illustrates that a simple oxygen-deficiency hazard is relatively easy to deal with. However, it must be classified as being immediately hazardous to life and the OSHA requirements for communications, standby men, lifelines, etc. during respirator use in such atmospheres must be met.

Although the rationale for use of demand type atmosphere supplying units is reviewed, they would not be allowed. Section III A states specifically that in concentrations immediately dangerous to life or health you must eliminate all but the positive pressure self-contained breathing apparatus.

We hope that these examples of respirator selection indicate the fundamental thought processes involved. Without a knowledge of the degree and extent of the respiratory hazard and other possible physiological hazards, choosing the proper respirator can deteriorate into a potentially dangerous guessing game. The fact that the person selecting the respirator may not be an industrial hygienist or other knowledgeable individual is no excuse. The OSHA requirements state that the respirator "shall be selected on the basis of hazards to which the worker is exposed," which, freely translated, means by hazard evaluation.

CHAPTER SEVEN

RESPIRATOR USE

LEGAL REQUIREMENTS

OSHA 1910.134 states that the correct respirator shall be specified for each job and that a qualified individual supervising the respirator program usually specifies the respirator. Also, the person who issues respirators shall be adequately instructed to ensure he issues the correct respirator.

PRACTICALITIES OF RESPIRATOR ISSUE

Issuance of respirators seems simple, but issue of an incorrect respirator may injure or even kill a worker, so the matter cannot be treated lightly. The person responsible for issuing respirators must be adequately trained to make sure that he issues the correct respirator for each job. Some firms have developed an elaborate system wherein each wearer is issued a card that specifies what type of respirator he can be issued for protection against a particular hazard. He is required to show this card to the issuer, who can issue only the type of respirator listed. Often, such a card lists a particular brand of respirator on the basis of fitting tests.

When practical, a respirator should be assigned to each worker for his exclusive use, and should be permanently marked to indicate to whom it is assigned. Care must be taken to ensure that the marking does not hurt the respirator performance. If possible, records should be kept on the issuance and use of each respirator. To do so, each must be permanently identified. Records should include the date of initial issue, the dates of reissue, and a listing of repairs.

SUPERVISION OF RESPIRATOR USE

Random Inspection

Respirators in use shall be randomly inspected frequently to ensure that those selected for the job are being used and that they are in good condition. Respiratory protection is no better than the respirator in use. Periodic monitoring of respirator use should include:

- Determination that the proper respirators are being used.
- Determination that respirators are being worn properly.
- Consultation with wearers about:
 - Discomfort
 - Resistance to breathing
 - Fatigue
 - Interference with vision
 - Interference with communications
 - Restriction of movement
 - Interference with job performance
 - Confidence in the respirator
- Problems discovered during the random inspections must be rectified.

Employee Responsibility

Proper supervision of respirator use should ensure that each worker understands that he has the following responsibilities.

- He shall use the respirator as instructed.
- He shall guard against damaging the respirator.
- He shall go immediately to an area having respirable air if the respirator fails to provide proper protection.
- He shall report any respirator malfunction to a person responsible for the respirator program.

Determination of Wearer's Exposure to Hazards

Appropriate surveillance of work area conditions and of worker exposure to respiratory hazards shall be carried out. This means that the concentration of the respiratory hazard to which workers are exposed shall be determined periodically and records shall be kept. The monitoring must cover conditions throughout a full work shift as activities in the work area vary during the shift and change the hazard concentration. The time-weighted average concentration and ceiling (peak) concentration of the hazard during the work shift must be determined. Preferably, the air in the work area should be sampled in the workers' breathing zones.

Fit Testing Before Use

Respirator facepieces shall be checked for fit each time they are worn. The wearer can make either the positive- or the negative-pressure test, discussed in Chap. Eight, before entering a hazardous atmosphere, but a qualitative check using either isoamyl acetate or irritant smoke is much preferred.

FUNCTIONAL AND PHYSICAL CHARACTERISTICS AND USE LIMITATIONS OF RESPIRATORS

The various types of respirators and their functional and physical characteristics and use limitations are discussed in Chap. Five. As these factors are most important in respirator use, additional information is given here.

Limitations of Particulate-Filter Elements

As discussed in Chap. Five, the air flow resistance of a particulate-removing respirator filter element increases as the quantity of particles it retains increases. This resistance increases the breathing resistance offered by a nonpowered respirator and may reduce the rate of air flow in a powered respirator. Filter element plugging by retained particles may also limit the continuous use time of a particulate-filter type respirator. Rapid plugging means that the element must be replaced frequently. Elements should be replaced at least daily or more often if necessary. Filter elements designed to be cleaned and reused also should be cleaned at least daily.

Performance of some fibrous filter materials (electrostatic felts) is hurt by storage in very humid atmospheres, so care should be taken in storing filter elements. Performance also may deteriorate during use because of water vapor in the workplace atmosphere. Airborne liquid particles (aqueous and nonaqueous) and extremely small solid particles may deteriorate the functioning of these materials. Solid particles plug fibrous filter materials (including electrostatic felts), and, although this plugging increases the resistance to air flow, significant plugging increases the materials' efficiency in removing particles from air.

Limitations of Vapor- and Gas-Removing Cartridges and Canisters

It has been stated that if a vapor or gas lacks adequate warning properties (odor, taste, irritation) in a

concentration above the established breathing time-weighted average concentration, a vapor- and gas-removing air-purifying respirator should not be used. Another limitation is limited capacity of the cartridges and canisters in these respirators to remove vapors and gases from air, or to catalyze a reaction converting toxic vapors or gases to nontoxic products or products that can be removed from air. Theoretically, cartridges and canisters containing sorbents are totally efficient against vapors and gases until their capacity for adsorption or catalysis is exhausted. Then, the vapor or gas passes through the sorbent bed of the cartridge or canister and into the respirator. If the wearer detects an odor or taste of gas in the inspired air, or feels eye or throat irritation, he should leave the hazardous area immediately and go to a safe area that contains respirable air. Then, he should replace the cartridge or canister. Because of the limited useful service time of canisters and cartridges, they should be replaced daily or after each use, or even more often if the wearer detects odor, taste, or irritation.

If a respirator wearer detects an odor, taste, or irritation for a very short time and then the sensation disappears, penetration of an air contaminant into the respiratory-inlet covering has not necessarily ceased. The nerve endings that cause a sensation of odor, taste, or irritation often are fatigued or their response is dulled by low concentrations of substances. Thus, one may fail to detect low concentrations of some substances in air. This often happens when the concentration increases very slowly.

Some sorbents used in cartridges and canisters are harmed by high humidity, whereas others are harmed by very dry atmospheres. Therefore, when replacing these elements, never use an unsealed one and remember that if the hazardous atmosphere is very moist or dry, the useful service time may be markedly reduced.

Advantages and Limitations of Nonpowered Air-Purifying Respirators

In addition to those limitations imposed by respiratory-inlet coverings (see Chap. Five), particulate-filter elements, and sorbent cartridges and canisters, further limitations of nonpowered air-purifying respirators should be considered.

An important disadvantage is the negative air pressure created inside the respiratory-inlet covering during inhalation which can cause air contaminants to penetrate the covering if it fits poorly. Care should be taken to provide each wearer with a respirator that fits him. This can best be accomplished by individual fittings.

Other disadvantages of nonpowered air-purifying respirators include resistance to breathing, need for frequent replacement of air-purifying elements, and need for continual maintenance (except for single-use respirators).

Advantages and Limitations of Powered Air-Purifying Respirators

In addition to those imposed by respiratory inlet coverings, particulate-filter elements, and cartridges containing sorbents, other limitations of powered air-purifying respirators should be considered.

A powered respirator's battery must be recharged periodically to ensure that the blower will deliver enough respirable air to the respiratory-inlet covering. A battery has a limited useful life and cannot be recharged indefinitely. Battery replacement can be expensive.

The blower in most powered respirators has a high-speed motor whose parts eventually wear out. Therefore, the blower will have to be replaced periodically. If the blower fails, the wearer of a powered respirator must go to the nearest safe area immediately.

Other disadvantages include weight, bulk, complex design, the need for continual maintenance, high initial cost, cost of at least daily replacement of air-purifying elements, and cost of periodic replacement of batteries and blowers. Out-of-doors use presents a special problem of hot air being supplied to the respiratory-inlet covering.

The great advantage of the powered air-purifying respirator is that the air inside the respiratory-inlet covering is normally at positive pressure which reduces the possibility of contaminated air entering, and that the wearer is continually being supplied with fresh air with no breathing resistance.

Advantages and Limitations of Airline Supplied-Air Respirators

Loss of the source of respirable air supplied to the respiratory-inlet covering of the airline supplied-air respirator eliminates any protection to the wearer. Such loss may be caused by cutting, burning, kinking, or crushing the supply air hose, by air compressor failure, or by depletion of the respirable air in a storage tank. Possible loss of respirable air prohibits airline respirator use in atmospheres immediately dangerous to life or health. However, an airline respirator with an auxiliary self-contained air supply can be used in such atmospheres because the auxiliary self-contained air supply always can be used in escape. The trailing air supply hose of the

airline respirator severely restricts the wearer's mobility. This may make the airline respirator unsuitable for those who must move frequently between widely separated work stations. A combination airline and self-contained breathing respirator may be suitable if the supply of self-contained breathing air is adequate for the time required to move from place to place.

Airline respirators that operate in the demand mode have negative air pressure inside the respiratory-inlet covering during inhalation which permits the contaminated atmosphere to leak into the respiratory-inlet covering if it fits poorly. However, airline respirators that operate in the continuous-flow or pressure-demand mode always have positive air pressure inside the respiratory-inlet covering which keeps contaminated air from leaking in. Thus, an airline respirator operating in the continuous-flow or pressure-demand mode provides much better protection than one that operates in the demand mode.

A great advantage of the airline respirator is that it can be used for long continuous periods. Other advantages are minimal breathing resistance and discomfort, light weight, low bulk, moderate initial cost, and relatively low operating cost.

Advantages and Limitations of Hose Mask Type Supplied-Air Respirators

Obviously, air pressure inside the respiratory-inlet covering of the hose mask with no blower is negative during inhalation, so contaminated air can leak in if the covering fits poorly. Presently 30 CFR Part 11 allows a hose mask with a blower that supplies respirable air at a relatively low (50-lpm) flow rate to be approved for atmospheres immediately dangerous to life and health. Hose mask type supplied-air respirators, with and without blower, are not recommended in atmospheres immediately dangerous to life or health.

The trailing air supply hose of the hose mask also severely limits mobility, so it may be unsuitable for those who must move frequently among widely separated work stations.

A severe restriction of the hose mask without blower is that it is limited to a maximum hose length of only 75 ft. Also, it requires the wearer to inhale against the resistance to air flow offered by the air hose which may become significant during heavy work. Inhaling against this resistance strains the wearer and may cause fatigue.

Advantages of the hose mask without blower are its theoretically long use periods and its simple construction, low bulk, easy maintenance, low initial cost, and minimal operating cost. An advantage of

the hose mask with blower is its minimal resistance to breathing.

Advantages and Limitations of Self-Contained Breathing Apparatus

The bulk and weight of most SCBAs make them unsuitable for strenuous work or use in a very confined space. The limited service life makes them unsuitable for routine use for long continuous periods. The especially short service life of open-circuit type devices may limit them to use where the wearer can go conveniently and quickly from a hazardous atmosphere to a safe atmosphere to change the tank of supply air.

The demand type open-circuit SCBA and most closed-circuit SCBAs have negative air pressure inside the respiratory-inlet covering during inhalation so contaminated air can leak in if they fit poorly. The pressure-demand type open-circuit SCBA and those closed-circuit SCBAs that are positive-pressure devices provide very good protection because the air inside the respiratory-inlet covering is always at positive pressure which keeps the contaminated atmosphere from leaking in.

Because the SCBA wearer carries his own supply of respirable air, he is independent of the surrounding atmosphere. A great advantage of such apparatus is that it allows comparatively free movement over an unlimited area.

RESPIRATOR USE UNDER SPECIAL CONDITIONS

In Dangerous Atmospheres

Written procedures shall be prepared for safe respirator use in dangerous atmospheres that may occur in normal operations or emergencies. Personnel shall be familiar with these procedures and respirators. At least one standby man, equipped with proper rescue equipment including a SCBA shall be present in the nearest safe area for emergency rescue of those wearing respirators in a dangerous atmosphere. Communications (visual, voice, signal line, telephone, radio, or other suitable type) shall be maintained among all persons present (those in the dangerous atmosphere and the standby man or men). The respirator wearers shall be equipped with safety harnesses and safety lines to permit their removal from the dangerous atmosphere if they are overcome.

In Confined Spaces

Confined spaces are enclosures that are difficult to get out of, such as storage tanks, tank cars, boilers, sewers, tunnels, pipelines, pits, and tubs. The atmosphere in a confined space may be immediately dangerous to life or health because of toxic air contaminants or lack of oxygen. Before anyone enters a confined space, tests should be made to determine the presence and concentration of any flammable vapor or gas, or any toxic airborne particulate, vapor, or gas, and to determine the oxygen concentration.

The confined space must be force-ventilated to keep the concentration of a flammable substance at a safe level. No one shall enter if a flammable substance exceeds the lower explosive limit. No one shall enter without wearing the proper type of respirator if any air contaminant exceeds the established breathing time-weighted average limit or if there is an oxygen deficiency. Even if the contaminant concentration is below the established breathing time-weighted average limit and there is enough oxygen, the safest procedure is to ventilate the entire space continuously and to monitor the contaminant and oxygen concentrations continuously if people are to work in the confined space without respirators.

Air-purifying respirators and airline and hose mask type supplied-air respirators may be worn in a confined space only if tests show that the atmosphere contains adequate oxygen and that air contaminants are well below levels immediately dangerous to life or health. While people wearing these types of respirators are in a confined space, its atmosphere must be monitored continuously.

If the atmosphere in a confined space is immediately dangerous to life or health owing to a high concentration of air contaminant or oxygen deficiency, those who must enter the space shall wear a SCBA or a combination airline and self-contained breathing respirator that always maintains positive air pressure inside the respiratory-inlet covering. This is the best safety practice for confined spaces.

While personnel are in a confined space, at least one standby man with proper rescue equipment, including a SCBA, must be present outside for emergency rescue. He must maintain communications (visual, voice, signal line, telephone, radio, or other suitable type) with those inside. Also, those inside the space must be equipped with safety harnesses and safety lines to allow their removal in case they are overcome.

In Low and High Temperatures

Low temperatures will fog respirator lenses. Coating the inner surface of the lens with an anti-fogging compound will prevent fogging down to 32°F, but severe fogging may occur below 0°F. Full facepieces with nose cups that direct the warm, moist exhaled air through the exhalation valve without its touching the lens are available. They should provide satisfactory vision at as low as -30°F. At very low temperatures, exhalation valves may freeze owing to moisture. Dry respirable air should be used with airline respirators and with the type of SCBA that has an air tank when they are used in low temperatures.

A person working in high-temperature air is under stress. Wearing a respirator causes additional strain which should be minimized by using a light-weight respirator with low breathing resistance. The airline type supplied-air respirator is recommended. Such a respirator used in low- or high-temperature atmospheres may be equipped with a vortex tube to either warm or cool the air supplied.

SPECIAL PROBLEMS IN RESPIRATOR USE

Facial Hair

Facial hair lying between the sealing surface of a respirator facepiece and the wearer's skin will prevent a good seal. If the respirator permits negative air pressure inside the facepiece during inhalation, there will be excessive penetration by an air contaminant. Even a few days growth of stubble will permit excessive contaminant penetration.

Respirators shall not be worn when conditions prevent a good seal of the facepiece to the face. Items such as beards and sideburns prevent satisfactory sealing. Therefore, anyone who has stubble, a moustache, sideburns, or a beard that passes between his face and the sealing surface shall not wear a respirator that allows negative pressure inside the facepiece during inhalation.

Corrective Lenses

Those who must wear spectacles present a problem in respiratory protection. Spectacle temple bars or straps that pass between the sealing surface of a full facepiece and the wearer's face prevent a good seal. Therefore, spectacles that have temple bars or straps shall not be used when a full-facepiece respirator must be worn. Spectacles with short temple bars that do not protrude between the sealing surface and the wearer's face, or spectacles without temple bars which are taped to the wearer's face may be used temporarily. Special corrective lenses to be mounted inside full facepieces are available and should be used by those who need them. These lenses shall be mounted in the full facepiece only by qualified persons to ensure good vision, comfort, and proper sealing of the facepiece.

Spectacles or goggles may also interfere with quarter- or half-masks. They shall be worn so as not to interfere with the seal of the facepiece. If there is interference, a full facepiece respirator should be worn to avoid sealing problems.

Contact lenses shall not be worn while wearing a respirator in a contaminated atmosphere. Contaminants that penetrate the respirator may get into the eyes and cause severe discomfort because of the contact lenses.

Miscellaneous Sealing Problems

Scars, hollow temples, very prominent cheekbones, deep skin creases, and lack of teeth or dentures may cause respirator facepiece sealing problems. Dentures or missing teeth may cause problems in sealing a mouthpiece in a person's mouth. Full dentures should be retained when wearing a respirator, but partial dentures may or may not have to be removed, depending upon the possibility of swallowing them. With full lower dentures, problems in fitting quarter-masks can be expected, as the lower part of the mask tends to unseat the denture.

CHAPTER EIGHT

TRAINING AND FITTING

ELEMENTS OF AN ADEQUATE TRAINING PROGRAM

Selecting the respirator appropriate to a given hazard is important, but equally important is using the selected device properly. Proper use can be ensured by carefully training both supervisors and workers in selection, use, and maintenance of respirators. This implies that there should be a training program.

Like the overall respirator program, the content of the training program can vary widely, depending on circumstances. However, OSHA 1910.134 requires that training of both workers and supervisors include the following, no matter what the circumstances:

- An opportunity to handle the respirator,
- Proper fitting,
- Test of facepiece-to-face seal,

A long familiarizing period of wear in normal air. Furthermore, OSHA requires that the wearer receive fitting instructions including demonstrations and practice in wearing, adjusting, and determining the fit of the respirator. These requirements originated in ANSI Standard Z88.2-1969. Section 7.4 of that Standard gives more details.

Training of supervisors and workers also should include:

- Discussion of the engineering and administrative controls in use and why respirators also are needed,
- Explanation of the nature of the respiratory hazard and what happens if the respirator is not used properly,
- Explanation of why a particular type of respirator has been selected,
- Discussion of how to recognize and handle emergencies.

Unfortunately, these training requirements apply to large and small organizations, with no differentiation to meet individual needs. The training the supervisor needs may differ from that for the individual worker, and both may differ markedly from that needed by members of emergency response teams. This chapter summarizes methods for satisfying the OSHA requirements and suggests ways that respiratory protection training may be tailored to individual needs based on job function.

The exact format of the training program will vary widely, depending upon the organization. The large user may need a full-time professional instructor. At the other extreme is the very small user who may be forced into a do-it-yourself training program. It must be emphasized again, however, that the OSHA requirements apply to large and small users alike.

Supervisor Training

Supervisors, those who oversee the daily activities of one or more workers who wear respirators frequently, should have a reasonably comprehensive knowledge of respirators and respiratory protection practices. Their training should include, but not necessarily be limited to, knowledge of the following.

- Basic respiratory protection practices,
- Selection and use of respirators to protect each worker against every respiratory hazard to which he may be exposed,
- The nature and extent of the respiratory hazards to which the workers may be exposed,
- The structure and operation of the entire respirator program. The supervisor should understand his responsibility to facilitate functioning of the program, including maintenance that the worker may be expected to do himself, issuance of respirators, control of their use, and evaluation of the program's effectiveness.
- The legal requirements pertinent to use of respirators in his situation.

These suggestions obviously apply to the large organization. A smaller organization may have to combine the supervisor training with that of the workers. This benefits the workers as they receive more comprehensive training.

Worker Instruction and Training

The extent and frequency of the workers' training depends primarily on the nature and extent of the hazard. If the hazard is a nuisance particulate, for example, the danger from misuse of the respirator is not likely to be serious. However, against highly toxic particulates, a single misuse may have serious

consequences. The same holds true, of course, for gases and vapors. If the respirator is to be used in an emergency, training in its use should be very thorough and complete. In any case, the worker shall be given some instruction and training in respiratory protection practices.

As a bare minimum, both worker and supervisor should be trained in basic respiratory protection practices. Also each should be trained in use of the respirator selected for his particular situation. Because proper respirator use depends especially upon the wearer's motivation, it is important that the need for the respirator be explained fully. ANSI Standard Z88.2, Sec. 7.4 lists the following points to be included in a minimal acceptable respirator program.

- (1) Instruction in the nature of the hazard, whether acute, chronic, or both, and an honest appraisal of what may happen if the respirator is not used.

- (2) Explanation of why more positive control is not immediately feasible. This should include recognition that every reasonable effort is being made to reduce or eliminate the need for respirators.

- (3) Discussion of why this is the proper type of respirator for the particular purpose.

- (4) Discussion of the respirator's capabilities and limitations.

- (5) Instruction and training in actual use of the respirator (especially one for emergency use) and close, frequent supervision to ensure that it continues to be used properly.

- (6) Classroom and field training in recognizing and coping with emergencies.

- (7) Other special training as needed.

A major thrust is toward explaining as much as possible about the reasons for wearing a respirator. This, of course, is to motivate the user to accept the fact that protection is necessary, and to instill in him the desire to wear and maintain his respirator properly. Just throwing a respirator at a worker with orders that he wear it because OSHA says so is one of the easiest ways to ensure its misuse.

At best, a respirator may cause discomfort and inconvenience, so there is a natural resistance toward wearing it conscientiously. Recent field studies have pointed this out. Much of this natural resistance can be overcome by taking the time and effort to inform the wearer as thoroughly as possible why he needs the respirator. This effort will create easier acceptance of respirators and contribute to subsequent correct use.

RESPIRATOR FITTING METHODS

All the care that went into design and manufacture of a respirator to give maximum efficiency will not protect the wearer if there is an improper match between facepiece and wearer or improper wearing practices. The problem is twofold. Assuming that more than one brand of a particular type of facepiece is available, the first problem is to determine which fits best. The second problem is to ensure that the user knows when the respirator fits properly. Both problems can be solved by use of some sort of fitting test, which is one of the OSHA requirements.

Respirator Fitting Tests

Determination of facepiece fit could involve both qualitative and quantitative tests. A qualitative test relies on the wearer's subjective response. A quantitative test uses some other means of detecting facepiece leakage. The general advantages and disadvantages are as follows.

Qualitative Tests

Advantages

Usually, qualitative tests are fast, require no complicated, expensive equipment, and are easily performed in the field.

Disadvantages

Qualitative tests rely on the wearer's subjective response, so they are not entirely reliable.

Quantitative Tests

Advantages

The greatest advantage of a quantitative test is that it indicates respirator fit numerically, and does not rely on a subjective response. The quantitative test is highly recommended when facepiece leakage must be minimized for work in highly toxic atmospheres or those immediately dangerous to life or health.

Disadvantages

Quantitative fitting tests require expensive (up to \$10,000) equipment that can be operated only by highly trained personnel and is unsuitable for field use because of its complexity and bulk. Each test respirator must be equipped with a sampling probe to allow removal of a continuous air sample

from the facepiece, so the same facepiece cannot be worn in actual service.

Selection of a qualitative or quantitative fitting test depends upon circumstances such as the severity and extent of the respiratory hazard and the size of the organization. Ideally, both qualitative and quantitative tests should be used. A quantitative test can be used in selecting the best respirator for each worker during training. To supplement the periodic quantitative fitting, a qualitative test can be used before each entry into a contaminated atmosphere. Again, this is only a suggested procedure that can be modified on the basis of an objective professional evaluation of the circumstances.

As mentioned in Chap. Five, quarter- and half-masks, and full facepieces have inherently different fitting characteristics. Moreover, several brands of each are marketed, each brand manufactured in only one size and style and each having slightly different fitting characteristics. Although every manufacturer designs his facepieces to fit as broad a section of the working population as possible, no respirator marketed will fit everyone. Therefore it is strongly suggested that many brands of a given type of respirator be purchased to take advantage of the different fitting characteristics of each. In this way, the chances of properly fitting all workers are increased. Equally important is the fact that having more than one facepiece to choose from gives the worker a better chance of finding a respirator that is reasonably comfortable while providing good protection. It is in this process of matching the respirator to the individual user that the fitting test, particularly the qualitative test, has the greatest impact.

Respirator Fitting Procedures

One point must be kept in mind throughout the following discussions. The OSHA regulations require that workers be allowed to test the facepiece-to-face seal of the respirator and to wear it in a test atmosphere.

NOTE: During any fitting test, the respirator headstraps must be as comfortable as possible. Tightening the straps will sometimes reduce facepiece leakage, but the wearer may be unable to tolerate the respirator for any length of time.

Qualitative Fitting Tests

Negative Pressure Test. The wearer can perform this test by himself in the field. It consists merely of closing off the inlet of the canister, cartridge(s), or filter(s) by covering with the palm(s) or replacing

the seal(s), or of squeezing the breathing tube so that it does not pass air; inhaling gently so that the facepiece collapses slightly; and holding the breath for 10 seconds. If the facepiece remains slightly collapsed and no inward leakage is detected, the respirator is probably tight enough. This test, of course, can be used only on respirators with tight-fitting facepieces.

Although this test is simple, it has severe drawbacks, primarily that the wearer must handle the respirator after it has supposedly been positioned on his face. This handling can modify the facepiece seal. It is strongly recommended that this test be used only as a very gross determination of fit when the respirator is to be used in relatively toxic atmospheres. The wearer should use this test (Fig. 8-1) just before entering any toxic atmosphere.

Positive Pressure Test. This test is very like the negative pressure test, and it has the same advantages and limitations. It is conducted by closing off the exhalation valve and exhaling gently into the facepiece. The fit is considered satisfactory if slight positive pressure can be built up inside the facepiece without any evidence of outward leakage. For some



Figure 8-1.
Negative pressure test.

respirators, this method requires that the wearer remove the exhalation valve cover and then carefully replace it after the test, often a most difficult task. Removing and replacing the exhalation valve cover often disturbs the respirator fit even more than does the negative pressure test. Therefore, this test should be used sparingly if it requires removing and replacing a valve cover. The test is easy for respirators whose valve cover has a single small port that can be closed by the palm or a finger. The wearer should perform this test (Fig. 8-2) just before entering any hazardous atmosphere.

Isoamyl Acetate Vapor (Banana Oil) Test. Anyone who has ever built flying model airplanes has smelled banana oil, widely used in the dope for coating their fabric coverings. This chemical, isoamyl acetate, has a pleasant, easily detectable odor, so it also is used widely in qualitatively checking respirator fit.

This is the first test mentioned that gives the user the required opportunity to wear the respirator in a test atmosphere. Generally it consists of creating an atmosphere containing banana oil around the wearer of an atmosphere-supplying or air-purifying respirator with an organic vapor-removing car-

tridge(s) or canister. If the hazard is particulate matter or a nonorganic vapor or gas, the organic vapor cartridge(s) or canister must be replaced with a particulate filter(s) or proper cartridge(s) or canister after this test.

There are several versions of the banana oil test. The simplest is to saturate a piece of cotton or cloth with the liquid and pass it close to the respirator near the sealing surface, taking care to avoid the skin. A second method is to use a stencil brush (Fig. 8-3) filled with isoamyl acetate in the same manner as the cotton or cloth.

A more complex, and better, version of the test uses a room or small booth or a hood covering the respirator wearer's head and shoulders. In this enclosure is generated a known concentration of vapor, usually 100 ppm, created by vaporizing 17.3 ml of isoamyl acetate liquid for each 1000 ft³ (or about 28 m³) of enclosure volume. Use of a fixed enclosure decreases the test's flexibility but provides a known vapor concentration that reduces the number of variables involved. Most people can smell 1-10 ppm of isoamyl acetate; the permissible exposure limit is 100 ppm.

In general, the isoamyl acetate fitting test should be performed as follows.



Figure 8-2.
Positive pressure test.



Figure 8-3.
Banana oil test.

- The wearer puts on the respirator in a normal manner. If it is an air-purifying device, it must be equipped with a cartridge(s) or canister specifically designed for protection against organic vapors.
- The wearer enters the test enclosure, or the saturated cloth or stencil brush is passed close to the respirator sealing surfaces.
- If the wearer smells banana oil, he returns to clean air and readjusts the facepiece and/or adjusts the headstraps without unduly tightening them.
- The wearer repeats the second step. If he does not smell banana oil, he is assumed to have obtained a satisfactory fit. If he smells the vapor, an attempt should be made to find the leakage point. If the leak cannot be located, another respirator of the same type and brand should be tried. If this leaks, another brand of respirator with a facepiece of the same type should be tried.
- After a fit is obtained, if the respirator is an air-purifying device it must be equipped with the correct filter(s), cartridge(s), or canister for the anticipated hazard.

During the test, the subject should make movements that approximate a normal working situation. These may include, but not necessarily be limited to, the following.

- Normal breathing.
- Deep breathing, as during heavy exertion. This should not be done long enough to cause hyperventilation.
- Side-to-side and up-and-down head movements. These movements should be exaggerated, but should approximate those that take place on the job.
- Talking. This is most easily accomplished by reading a prepared text loudly enough to be understood by someone standing nearby.
- Other exercises may be added depending upon the situation. For example, if the wearer is going to spend a significant part of his time bent over at some task, it may be desirable to include an exercise approximating this bending.

If the test is used in training the worker and selecting the respirator that fits him best, he should perform the complete set of exercises. However, the number of exercises may be reduced when the test is used as a quick field check before routine entry into a contaminated atmosphere.

The major drawback of the isoamyl acetate test is that the odor threshold varies widely among individuals. Furthermore, the sense of smell is easily dulled and may deteriorate during the test so that the wearer can detect only high vapor concentrations. Another disadvantage is that isoamyl acetate smells pleasant, even in high concentrations. Therefore, a wearer may say that the respirator fits although it has a large leak. This is usually because

he likes the comfort of the particular respirator or is following the lead of someone else and selecting the same respirator. Conversely, a wearer may claim that a particular respirator leaks if it is uncomfortable, etc. Therefore, unless the worker is highly motivated toward wearing respirators, the results of this test must sometimes be suspect.

Irritant Smoke Test. This qualitative test is similar to the isoamyl test in concept. It usually involves exposing the respirator wearer to an irritating aerosol produced by commercially available smoke tubes normally used to check the quality of ventilation systems. These are sealed glass tubes, approximately 12 cm long by 1 cm in diameter (Fig. 8-4), filled with pumice impregnated with stannic chloride or titanium tetrachloride. When the tube ends are broken and air is passed through it, the material inside reacts with the moisture in the air to produce a dense, highly irritating smoke, consisting of hydrochloric acid adsorbed on small solid particles.

As a qualitative means of determining respirator fit, this test has a distinct advantage in that the wearer usually reacts involuntarily to leakage by coughing or sneezing. The likelihood of his giving a false indication of proper fit is reduced. On the other



Figure 8-4.
Irritant smoke test.

hand, the aerosol is very irritating and must be used carefully to avoid injury. Also, it is advisable to have exhaust ventilation behind the subject to protect the person doing the testing.

This test can be used for both air-purifying and atmosphere-supplying respirators, but an air-purifying respirator must have a high-efficiency filter(s). After the test, it may be necessary to replace the high-efficiency filter(s) on the air-purifying respirator with another type of air-purifying element(s), depending upon the hazard to which the respirator wearer is to be exposed. This test can be used for worker training or respirator selection.

The irritant smoke test must be performed with proper safeguards because the aerosol is highly irritating. A suggested procedure is as follows.

- The wearer puts on the respirator normally, taking care not to tighten the headstraps uncomfortably. He stands with his back to a source of exhaust ventilation, such as a chemical fume hood.
- The tester tells the wearer to close his eyes, even if he is wearing a full facepiece respirator, and to keep them closed until told to open them.
- The tester lightly puffs smoke over the respirator, holding the smoke tube at least 2 ft from it. At this time, he should keep the amount of smoke minimal and pause between puffs to note the wearer's reaction.
- If the wearer detects no leakage, the tester may increase the smoke density and move the smoke tube progressively closer to the subject, still remaining alert to his reactions.
- When the smoke tube has been brought to within about 6 in. of the respirator with no leakage detected, the tester may start to direct smoke specifically at the potential sources of leakage, around the sealing surface and exhalation valve, while the subject holds his head still.
- At this point, if no leakage has been detected, the wearer may cautiously begin the head movements mentioned in the isoamyl acetate test. The tester should remain especially alert and be prepared to stop producing smoke immediately.
- If leakage is detected at any time, the tester should stop the smoke and let the wearer readjust the facepiece or headstrap tension. The tester should then start the test at the second step.

In all fairness, this test is not so time-consuming as it sounds. Also, because of its greater sensitivity and lesser reliance on subjective response, it is considered more reliable than the isoamyl acetate vapor test. If the wearer keeps his eyes closed and the smoke is increased gradually, there is little danger or discomfort.

Other Qualitative Tests. Other qualitative fitting tests have been used, although not so extensively as those just described. Among these are tests in which a stream of talcum powder or coal dust is directed around the respirator sealing surface. The wearer then removes the respirator and any leakage is revealed by telltale streaks of the powder or dust. These tests have been used almost exclusively for investigative purposes rather than routine fitting.

Another similar test, used very infrequently, involves spraying fluorescein dye (uranine) around the sealing surface. The respirator is then removed, and the sources of leakage are detected with ultraviolet light. Obviously, this test is more for research than for routine fitting.

In summary, qualitative fitting tests are quick, easily performed with a minimum of special equipment, and generally adequate for checking respirator fit before entering a contaminated area. However, they have limitations that make them less useful than quantitative tests for initial selection of a brand of respirator that fits best. For that purpose, the following tests are preferred.

Quantitative Fitting Tests. All quantitative respirator performance tests involve placing the wearer in an atmosphere containing an easily detectable, relatively nontoxic gas, vapor, or aerosol. The atmosphere inside the respirator is sampled continuously through a probe in the respiratory-inlet covering. The leakage is expressed as a percentage of the challenge atmosphere outside the respirator, called "per cent of penetration," or simply "penetration."

The procedures are relatively independent of the type of aerosol or gas. Appendix D details standardized test procedures and shows a typical strip chart recording of a quantitative fitting test and a suggested format for recording and evaluating the data.

Sodium Chloride (NaCl) Test. In the NaCl aerosol quantitative respirator fitting test, a liquid aerosol is generated continuously from an aqueous solution, (salt water) using a nebulizer, dried to produce discrete submicron salt particles, and dispersed into a test chamber or hood. The resultant NaCl aerosol is called polydisperse because the particles vary in size. A means is provided for sampling the atmosphere in the chamber or hood and that inside the respirator. These samples are fed to the analyzing section where the aerosol's penetration inside the respirator is determined. The amount of penetration is displayed on a meter or recorder. Figure 8-5 shows

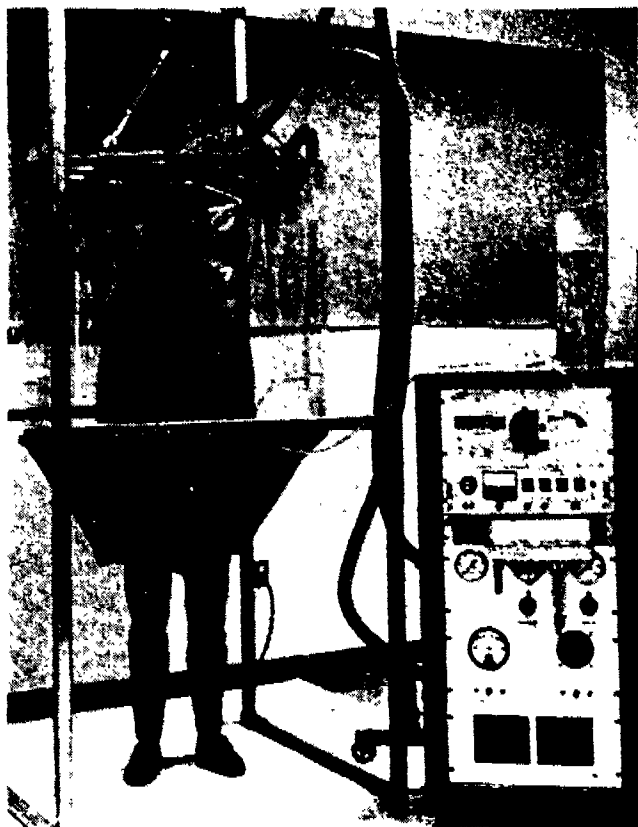


Figure 8-5.
NaCl quantitative respirator-fitting test system.

a NaCl quantitative respirator fitting test system. See Appendix E for details of the test system. Appendix D gives the procedures for conducting the NaCl quantitative test.

Diethyl Phthalate (DOP) Test. The diethyl phthalate (DOP) quantitative fitting test, that uses an air-generated DOP aerosol, differs from the NaCl test only in that the aerosol particle is liquid (see Appendix D). The aerosol is generated using a nozzle-type atomizer, but, being an oil, DOP does not dry into solid particles when injected into a diluting air stream. Figure 8-6 shows a DOP test system, and Appendix D gives a more detailed description.

A second type of DOP system uses a thermally generated liquid aerosol. Liquid DOP is heated to boiling, and the vapor is passed to a cooling chamber

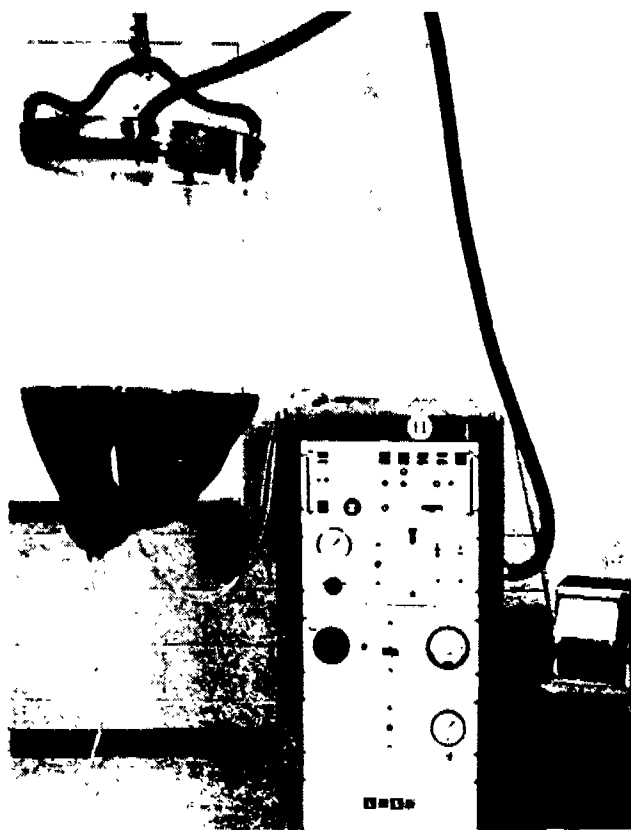


Figure 8-6.
DOP quantitative respirator-fitting test system.

where it condenses at a very closely controlled temperature, to produce a $0.3\text{-}\mu\text{m}$ monodisperse aerosol. That is, all the particles are $0.3\text{ }\mu\text{m}$ in diameter. This aerosol has been used widely for quality control of high-efficiency respirator filters and for basic research on aerosol filtration. It was also used for quantitative fitting tests but has fallen into disfavor because the boiling produces aerosol particles that have a disagreeable odor and an unknown toxicity.

Freon 12 Test. Freon 12, normally a refrigerant gas, has been used in quantitative respirator fitting tests. It is not so useful as NaCl or DOP because slow response time of the analyzing instrumentation prevents following the fluctuations in concentration of the gas that penetrates the respirator.

CHAPTER NINE

RESPIRATOR INSPECTION, CLEANING, MAINTENANCE, AND STORAGE

ELEMENTS OF AN ADEQUATE RESPIRATOR INSPECTION, CLEANING, MAINTENANCE, AND STORAGE PROGRAM

Scrupulous respirator maintenance must be made an integral part of the overall respirator program. Wearing poorly maintained or malfunctioning respirators is, in one sense, more dangerous than not wearing a respirator at all. The worker wearing a defective device thinks he is protected when, in reality, he is not. Emergency escape and rescue devices are particularly vulnerable to poor maintenance as they generally are used infrequently, and then in the most hazardous and demanding circumstances. The possible consequences of wearing a defective emergency escape and rescue device are lethal.

The OSHA standards strongly emphasize the importance of an adequate maintenance program, but permit its tailoring to the type of plant, working conditions, and hazards involved. However, all programs are required to include at least:

- Inspection for defects (including a leak check),
- Cleaning and disinfecting,
- Repair,
- Storage.

A proper maintenance program ensures that the worker's respirator remains as effective as when it was new.

INSPECTION FOR DEFECTS

Probably the most important part of a respirator maintenance program is continual inspection of the devices. If conscientiously performed, inspections will identify damaged or malfunctioning respirators before they can be used. The OSHA requirements outline two primary types of inspection, that while the respirator is in use and that while it is being cleaned. In a small operation where the worker probably maintains his own respirator, the two types of inspection become essentially one and the same. In a large organization with a central respirator maintenance facility, the inspections differ.

Frequency of Inspection

OSHA requires that "all respirators be inspected before and after each use," and that those not used routinely, i.e. emergency escape and rescue devices, "shall be inspected after each use and at least monthly..." In one case, the respirator is to be inspected both before and after each use, in the other case, only after use. However, it is highly unlikely that anyone needing a respirator in a hurry, as during an emergency, is going to inspect it. In fact, it could be dangerous to take time to do so.

Inspection Procedures

Here we will divide inspection procedures into those for "field" inspection and those for use during routine cleaning, as well as into those for air-purifying and atmosphere-supplying devices.

The OSHA standards state only that respirator inspection shall include:

- A check of the tightness of the connections
- A check of the facepiece, valves, connecting tube, canisters.

The standards also state that the regulator and warning devices on SCBAs shall be checked for proper functioning.

FIELD INSPECTION

Air-Purifying Respirators

Routinely used air-purifying respirators should be checked as follows before and after each use.

(a) Examine the facepiece for:

- Excessive dirt,
- Cracks, tears, holes, or distortion from improper storage,
- Inflexibility (stretch and massage to restore flexibility),

- Cracked or badly scratched lenses in full facepieces,
- Incorrectly mounted full facepiece lens or broken or missing mounting clips,
- Cracked or broken air-purifying element holder(s), badly worn threads, or missing gasket(s) (if required).
- (b) Examine the headstraps or head harness for:
 - Breaks,
 - Loss of elasticity,
 - Broken or malfunctioning buckles and attachments,
 - (Full facepieces only) Excessively worn serrations on the head harness which might permit slippage.
- (c) Examine the exhalation valve for the following after removing its cover:
 - Foreign material, such as detergent residue, dust particles, or human hair under the valve seat,
 - Cracks, tears, or distortion in the valve material,
 - Improper insertion of the valve body in the facepiece,
 - Cracks, breaks, or chips in the valve body, particularly in the sealing surface,
 - Missing or defective valve cover,
 - Improper installation of the valve in the valve body.
- (d) Examine the air-purifying elements for:
 - Incorrect cartridge, canister, or filter for the hazard,
 - Incorrect installation, loose connections, missing or worn gaskets, or cross-threading in holder,
 - Expired shelf-life date on cartridge or canister,
 - Cracks or dents in outside case of filter, cartridge, or canister,
 - Evidence of prior use of sorbent cartridge or canister, indicated by absence of sealing material, tape, foil, etc., over inlet.
- (e) If the device has a corrugated breathing tube, examine it for:
 - Broken or missing end connectors,
 - Missing or loose hose clamps,
 - Deterioration, determined by stretching the tube and looking for cracks.
- (f) Examine the harness of a front- or back-mounted gas mask for:
 - Damage or wear to the canister holder which may prevent its being held securely in place,
 - Broken harness straps or fastenings.

Atmosphere-Supplying Respirators

For a routinely used atmosphere-supplying device, use the following procedures.

- (a) If the device has a tight-fitting facepiece, use the procedures outlined above for air-purifying respirators, except those pertaining to the air-purifying elements.
- (b) If the device is a hood, helmet, blouse, or full suit, use the following procedures.
 - Examine the hood, blouse, or full suit for rips and tears, seam integrity, etc.,
 - Examine the protective headgear, if required, for general condition, with emphasis on the suspension inside the headgear,
 - Examine the protective faceshield, if any, for cracks or breaks or impaired vision due to rebounding abrasive particles,
 - Make sure that the protective screen is intact and secured correctly over the faceshield of abrasive blasting hoods and blouses.
- (c) Examine the air supply system for:
 - Integrity and good condition of air supply lines and hoses, including attachments and end fittings,
 - Correct operation and condition of all regulators, valves, or other air-flow regulators.

On SCBAs, determine that the high-pressure cylinder of compressed air or oxygen is sufficiently charged for the intended use, preferably fully charged (mandatory on an emergency device). On closed-circuit SCBAs, make sure that a fresh canister of CO sorbent is installed before use, or that the total use time on the canister is known. On open-circuit SCBAs, recharge the cylinder if less than 25% of the useful service time remains. All these SCBAs are required to have a warning device that indicates when this point is reached. However, it is much preferred that an open-circuit SCBA be fully charged before use.

When an air-purifying or atmosphere-supplying device is used nonroutinely, all the above procedures should be followed after each use. OSHA requires that devices for emergency use be inspected once a month and that "a record shall be kept of inspection dates and findings for respirators maintained for emergency use."

If defects are found during any field inspection, two remedies are possible. If the defect is minor, repair and/or adjustment may be made on the spot. If it is major, the device should be removed from service until it can be repaired. *Under no circumstances should a device that is known to be defective be used.*

Inspection During Cleaning

Because respirator cleaning usually involves some disassembly, it presents a good opportunity to examine each respirator thoroughly. The procedures outlined above for a field inspection should be used, but a precleaning check would not normally include an operational check, which obviously should be done just before the device is returned to service. Therefore, it is suggested that the inspection be made *after* the respirator is cleaned.

During this inspection, the respirator should be leak checked, as OSHA requires. The exact meaning of "leak check" has been much discussed, but no universal definition has emerged. Generally, a "leak check" is an examination of the freshly cleaned and reassembled respirator to determine that the complete assembly is gastight.

Several methods could be devised for meeting this requirement. One is worthy of mention as it is being used in several extensive respirator programs. It involves use of a machined metal head form with an inflated sealing surface over which a full facepiece may be placed. The respirator facepiece is placed over the headform, the straps are fastened down, and the inflatable seal built into the headform is pressurized to provide a gastight seal between the headform and the facepiece. A continuous air sample is withdrawn from inside the facepiece through the headform and passed through an aerosol detector like that described in Chap. Eight. An aerosol stream is directed through a small-diameter tube around the potential leak points in the facepiece. Any leaks are shown by the penetration meter or recorder of the aerosol analyzing system, if it is set on the most sensitive scale.

This procedure will detect leak sources and indicate the magnitude of the leak. However, it must be considered a qualitative, rather than quantitative, test. Some installations have built a small test chamber around the headform. Instead of the aerosol being passed around the facepiece, the chamber contains an aerosol-laden atmosphere that permits actual quantitative determination of leakage in a manner similar to a quantitative fitting test.

This test requires use of the expensive aerosol system which is practical only for large organizations. The small respirator user is in a difficult position as he cannot afford this sophisticated equipment but is bound by the same requirements as the large user. The best advice for the small user, which is of little help, is to use his ingenuity and devise a method that will satisfy the basic purpose of the leak check, assurance that the reassembled respirator is leak-free.

CLEANING AND DISINFECTING

The OSHA requirements are not specific about cleaning and disinfecting procedures, stating that "routinely used respirators shall be collected, cleaned, and disinfected as frequently as necessary to insure that proper protection is provided..." and that emergency use respirators "shall be cleaned and disinfected after each use."

In a large respirator program in which respirators are used routinely, they should be exchanged daily for cleaning and inspection. In a small program involving only occasional respirator use, this period could be weekly or monthly. If each worker is to maintain his own respirator, he should be thoroughly briefed on its cleaning and disinfecting. Although a worker may not be required to maintain his own respirator, briefings on the cleaning procedure will encourage his acceptance of the respirator by providing assurance that he always receives a clean, disinfected, properly maintained device. This is particularly important where respirators are not individually assigned. Where respirators are individually assigned, a practice to be encouraged, they should be durably identified to ensure that the worker always receives the same device. Identification markers must not penetrate the facepiece or block filter or cartridge ports or exhalation valves.

In a small respirator program, or where each worker cleans his own respirator, washing with detergent in warm water using a brush, thorough rinsing in clean water, and air drying in a clean place is generally accepted as sound procedure. Precautions should be taken to prevent damage from rough handling during this procedure.

In a large program, there may be a centralized cleaning and maintenance facility with specialized equipment and personnel trained in respirator maintenance. Figure 9-1 shows a typical, hypothetical, large respirator maintenance facility. Good features are the separate areas for disassembly of used respirators and assembly of freshly cleaned and maintained devices which ensure that the clean respirators do not become contaminated. Also, there is ample storage space for the clean respirators, and spare parts (filters, exhalation valves, headbands, etc.) are readily available. There is also a test bench for checking the operation of SCBA regulators as well as a leak test system. A facility of this type would take up about 500 ft².

In the following discussion of cleaning and maintenance procedures, reference to Fig. 9-1 should help in understanding the overall process. The following procedure may be used:

which has some disadvantages, because its concentration must be adjusted to the composition of the local water to provide a constant degree of disinfection. Also, there is a possibility of dermatitis if the quaternary ammonium salts are not completely rinsed from the respirator.

An alternative is to wash the respirators in detergent, followed by a disinfecting rinse. Disinfection is not absolutely necessary if the respirator is reused by the same worker. However, where individual issue is not practiced, disinfection is strongly recommended. Reliable, effective disinfectants may be made from readily available household solutions, including:

- Hypochlorite solution (50 ppm of chlorine) made by adding approximately 2 ml of Clorox to 1 liter of water or, in kitchen language, 2 tablespoons per gallon. A 2-min immersion disinfects the respirators.
- Aqueous solution of iodine (50 ppm of iodine) made by adding approximately 0.8 ml tincture of iodine per liter of water. The iodine is approximately 7% ammonium and potassium iodide, 45% alcohol, and 48% water. An equivalent expression is approximately 1 teaspoon of tincture of iodine per gallon of water. Again, a 2-min immersion is sufficient.

If the respirators are washed by hand, a separate disinfecting rinse may be provided. If a washing machine is used, the disinfectant must be added to the rinse cycle, and the amount of water in the machine at that time will have to be measured to determine the correct amount of disinfectant.

To avoid damaging the rubber and plastic in the respirator facepieces, the cleaner and disinfectant temperatures should not exceed 140°F, but they should not be less than 120°F to ensure adequate cleaning.

Rinsing

The cleaned and disinfected respirators should be rinsed thoroughly in clean water (140°F. maximum) to remove all traces of detergent, cleaner and sanitizer, and disinfectant. This is very important to prevent dermatitis.

Drying

The respirators may be allowed to dry by themselves on a clean surface. They also may be hung from a horizontal wire, like drying clothes, but care must be taken not to damage the facepieces. A better method is to equip a standard steel storage cabinet, Fig. 9-1 (E), with an electric heater that has

a built-in circulating fan, and to replace the solid shelves with steel mesh. Appendix C gives instructions for these modifications.

Reassembly and Inspection

The clean dry respirator facepieces should be reassembled and inspected in an area, Fig. 9-1 (F), separate from the disassembly area to avoid contamination. The inspection procedures have been discussed, but there may be more things to look for because of the cleaning. The most common is detergent or soap residue left by inadequate rinsing. This appears most often under the seat of the exhalation valve, and can cause valve leakage or sticking.

At this time, the respirators should be thoroughly inspected and all defects corrected. New or retested filters, or new cartridges and canisters should be installed, and the completely reassembled respirator should be tested for leaks, Fig. 9-1 (M).

The facepiece of a SCBA can now be combined with the tested regulator from (I) and a fully charged cylinder from the storage rack (K), and an operational check can be performed.

MAINTENANCE AND REPAIR

The OSHA standards state that "replacement or repairs shall be done by experienced persons with parts designed for the respirator." Besides being contrary to OSHA requirements, *substitution of parts from a different brand or type of respirator invalidates approval of the device*. Therefore, the user would be wearing an unapproved device, in violation of the OSHA requirement.

Maintenance personnel must be thoroughly trained. They must be aware of their limitations and never try to replace components or make repairs and adjustments beyond manufacturer's recommendations, unless they have been especially trained by the manufacturer.

These restrictions apply primarily to maintenance of the more complicated devices, especially closed- and open-circuit SCBAs, and even more specifically their reducing or admission valves (regulators) which "...shall be returned to the manufacturer or to a trained technician for adjustment or repair." The words "trained technician" permit on-site repair if the maintenance personnel are trained. There should be no problems in repairing and maintaining most other respirators, particularly the most commonly used air-purifying types.

An important aspect of any maintenance program is having enough spare parts on hand. Only continual surveillance of replacement rate will determine what parts in what quantities must be kept in stock. It is desirable to have some sort of record-keeping system to indicate spare parts usage and the inventory on hand.

STORAGE

All the care that has gone into cleaning and maintenance of a respirator can be negated by improper storage. OSHA requires that respirators be stored to protect against:

- Dust,
- Sunlight,
- Heat,
- Extreme cold,
- Excessive moisture,
- Damaging chemicals.

What is omitted, though implied in a later statement, is protection against mechanical damage. Leaving a respirator unprotected, as on a workbench, or in a tool cabinet or tool box among heavy wrenches etc., may damage it.

It is strongly recommended that freshly cleaned respirators be placed in heat-sealed or reusable plastic bags until reissue. They should be stored in a clean, dry location away from direct sunlight. They should be stored in a single layer with the facepiece and exhalation valve in a more or less normal position to prevent the rubber or plastic from taking a permanent distorted "set."

Air-purifying respirators kept ready for nonroutine or emergency use should be stored in a cabinet in individual compartments. A steel wall-mounted cabinet, with six compartments is shown in Fig. 9-3. Note that each compartment is clearly labeled with the user's name and that the respirators are in plastic bags. Note also that the respirator in the lower right compartment is stored improperly. Another acceptable method of storage in a standard steel storage cabinet is shown in Fig. 9-4. Note that the respirators are stored in a single layer.

The storage cabinet should be readily accessible, and all workers should be made aware of its location, as is done for fire extinguishers. Avoidance of serious injury from inhalation of a toxic substance may depend entirely on how quickly workers can get to the emergency respirators. This type of storage should be encouraged for routinely used respirators if it does not interfere with the normal work routine. A little inconvenience here is justified to prevent use of a respirator damaged by improper storage.

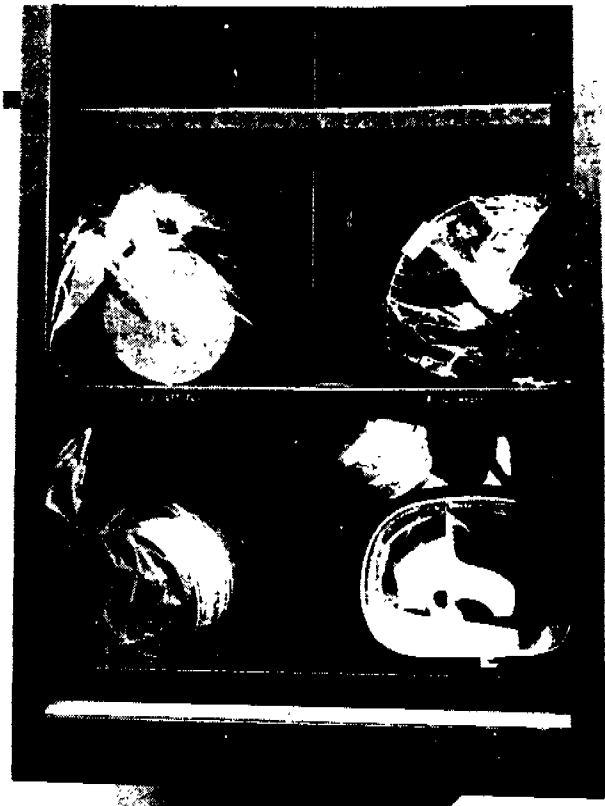


Figure 9-3.
Air-purifying respirator storage.

A chest, Fig. 9-5, or wall-mounted case, Fig. 9-6, may be purchased from the respirator manufacturer for storing a SCBA for use in emergencies. Again, the locations of SCBAs should be well known and clearly marked. Unlike fire extinguishers, however, they should be located in an area that will predictably remain uncontaminated. Even highly trained workers take 30 seconds to 1 min to put on these devices. In a highly contaminated atmosphere such as might be created by massive release of a toxic material, this may be too long a time to stay safely in the area. Therefore, the first reaction should be to escape to an uncontaminated area, then put on the SCBA which should be located there and re-enter the hazardous area for whatever task must be done. There are undoubtedly exceptions to this general rule, and only thorough evaluation of the potential hazard, taking into account the physical configuration of the work area, will permit a final decision about the correct storage location for a SCBA.

Routinely used respirators may be stored in a variety of ways if they are protected against the substances and conditions listed at the beginning of this section. This means that when a respirator is not in

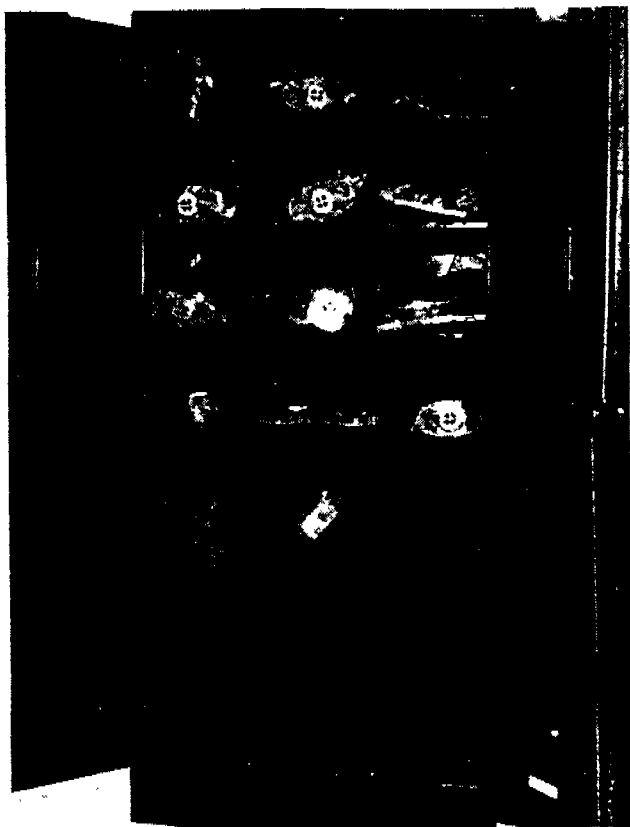


Figure 9-4.
Standard storage cabinet used for respirator storage.

use, it should be stored in a plastic bag inside a rigid container. The OSHA requirements suggest that respirators be stored in the cartons in which they came, but these usually would provide only minimal protection from mechanical damage.

If the worker is trained adequately, he should develop a respect for his respirator which will automatically give him incentive to protect it from damage. Besides providing better assurance of adequate protection, this training will lower maintenance costs because of decreased damage.



Figure 9-5.
Storage chest for a SCBA.



Figure 9-6.
Wall-mounted storage cabinet for a SCBA.

CHAPTER TEN

PHYSIOLOGICAL AND PSYCHOLOGICAL LIMITATIONS ON RESPIRATOR USE

PHYSIOLOGICAL LIMITATIONS

Wearing any type of respirator imposes some physiological stress on the wearer. Air-purifying respirators resist inhalation because the filter or cartridge restricts free air flow, and also resist exhalation because the expired air must force open a valve. The special exhalation valve on an open-circuit pressure-demand SCBA, designed to ensure that the air pressure inside the facepiece is always positive, requires the wearer to exhale against significant resistance. The bulk and weight (up to 35 lb) of some SCBAs are a significant burden. Wearers of airline respirators and hose masks must drag around up to 300 ft of air supply hose.

Any or all of these factors significantly increase the work load. If the worker's cardiovascular or pulmonary function is significantly impaired, wearing a respirator could constitute an unacceptable risk. The OSHA standards suggest that the local physician determine whether a worker can wear a respirator and perform useful work safely. As there is so little information on the physiological effects, it may be difficult for the local physician to determine whether or not a worker should wear a specific type of respirator.

How is the person responsible for overseeing the physical well-being of those who must wear respirators supposed to make decisions? The only practical approach is to treat each case individually, using the best medical advice available, and to consider the physical burdens imposed by the various types of respirators.

Pulmonary

The individual should be examined for evidence of respiratory impairment such as emphysema, chronic pulmonary obstructive disease, or bronchial asthma. Historical and x-ray evidence of significant pulmonary disease, if substantiated by reduced vital capacity or reduced forced expiratory volume may justify forbidding a person to wear a respirator that restricts inhalation and exhalation, and limiting him to powered air-purifying or continuous flow airline

respirators. Breathing difficulties should not necessarily prohibit a worker from wearing air-purifying respirators, if he is reasonably comfortable, because such prohibition might deprive him of his livelihood.

Workers in occupations, such as installing asbestos insulation, coal mining, and sand blasting, which cause high incidence of pulmonary diseases, should be given particular attention. In any case, if difficulties are experienced, the local physician shall make the final determination.

Cardiovascular

Cardiovascular impairment must be treated with much more concern than pulmonary impairment because of its potentially catastrophic consequences. Workers who have indications of coronary artery disease or angina pectoris, probably should not wear nonpowered air-purifying respirators or the heavy (35-lb) SCBAs. The same restrictions are recommended for those who have myocardial infarction or progressive or severe hypertension.

Those whose duty is to respond to emergencies should not wear any type of respirator if they have any cardiovascular deficiency. Or, if emergency response duty absolutely requires use of respirators, those wearing them should be completely free of cardiovascular impairment. Such people include firemen and mine rescue team members, who might have to rescue an unconscious 200-lb man from an extremely hazardous environment while wearing 35 lb of self-contained breathing apparatus.

Other Physiological Considerations

Other physical conditions such as diabetes, or grand mal epilepsy may limit wearing of respirators. Skin sensitivity to certain organic compounds may prevent some workers from entering certain environments at all, let alone wearing respirators in them. A perforated eardrum, allowing air passage through the eustachian tube into the respiratory

tract, may keep a person from working in a toxic environment unless he wears a respirator with a full head enclosure, such as a supplied-air hood, helmet, or suit.

Deep facial scars or blemishes, hollow temples, or an abnormally receding chin may spoil the seal of certain types of respirator facepieces. Also, full or partial dentures may prohibit wearing of certain types of facepieces or mouthpieces.

In summary, physiological conditions that may determine whether an individual should wear a respirator or not are varied. Pending more research on this problem, specific guidelines cannot be stated, and one must rely on the best judgment of the local physician.

PSYCHOLOGICAL LIMITATIONS

Psychological conditions that may prevent a worker from wearing a respirator are, if anything, less clearly defined than physical limitations. However, those who experience claustrophobia or anxiety when confined in a small space should not be given jobs that require respirators. In this category are firefighting, which frequently requires entering smoke-filled rooms with poor visibility, and mine rescue, which necessitates crawling through small passages containing highly toxic gases.

A more subtle psychological consideration is comfort. Obviously, if a respirator with an ill-fitting or irritating facepiece causes continual discomfort, it is bound to have an adverse psychological effect.

CHAPTER ELEVEN

PROGRAM ADMINISTRATION

Unfortunately, respirators generally are misused or taken too much on faith, primarily because of lack of knowledge. Such misuse can be avoided by establishing written procedures for respirator selection and use and through proper supervision of all aspects of the respirator program. This chapter presents detailed methods for ensuring that a respirator program remains effective.

WRITTEN STANDARD OPERATING PROCEDURES

The importance of written standard operating procedures is emphasized in OSHA Part 1910.134 which gives the first requirement for a "minimal acceptable (respirator) program" as establishment of "written standard operating procedures governing the selection and use of respirators." Part 1910.134 does not provide any guidance on preparation of these procedures and does not differentiate between large and small users. However the general content of written procedures can be established, and from that information, any user, large or small, can formulate procedures for his own circumstances.

General Content

The written standard operating procedures should contain all information needed to maintain an effective respirator program to meet the user's individual requirements. They should be written so as to be useful to those directly involved in the respirator program, the program administrator, those fitting the respirators and training the workers, respirator maintenance workers, and the supervisors responsible for overseeing respirator use on the job. It is not necessary that the operating procedures be written for the wearer himself, although in a very small program it may be desirable to direct their content to the wearer. Only analysis of the individual program will show to what extent information for the wearer should be included.

The procedures should contain all information needed to ensure proper respiratory protection of a specific group of workers against a specific hazard or

several particular hazards. The hazard(s) must have been assessed thoroughly; otherwise the written procedures will have only limited validity. Generally, the procedures should contain the following.

- Guidance for selection of the approved respirator(s) for protection against particular hazard(s).
- Detailed instructions for training workers in proper use of the respirator(s), including respirator fitting.
- Detailed maintenance procedures for:
 - Cleaning and disinfecting,
 - Drying,
 - Inspection,
 - Repair or replacement of worn or defective components,
 - Storage.
- Administrative procedures for:
 - Purchase of approved or accepted respirator(s),
 - Control of inventory of spare parts, new respirators, and respirators ready for reissue after maintenance,
 - Issuance of respirators to ensure use of the proper one for a given hazard,
 - Guidance of supervisory personnel in continued surveillance of respirator use and determination of workers' exposure to respiratory hazards.
- Instructions for respirator use during emergencies, including fire, which can create an atmosphere immediately hazardous to life and health.
- Guidelines for medical surveillance of workers, including pre-employment physical examinations to eliminate those physically or psychologically unfit to wear respirators, and periodic physical examinations to review the overall effectiveness of the respirator program on the basis of physiological factors.
- Procedures for evaluating the respirator program's effectiveness.

Obviously, the above essentially restates the OSHA requirements for a minimal acceptable respirator program. The point is that all the information needed to establish and maintain an adequate respirator program must be written down.

The exact format of written standard operating procedures may vary widely. The large user who has many workers wearing respirators and, perhaps,

several respiratory hazards to consider may formulate separate procedures for selection and use of respirators for each hazard. For a small user, who has only a few workers to protect from only one or very few hazards, a much simplified document may serve; but it must cover the same subjects. In general, the complexity of the procedures increases as respirator use increases. The procedures also become more extensive as the toxicity of the respiratory hazard(s) increases, demanding better and more reliable protection. It is better to be overly detailed in developing written operating procedures than not detailed enough.

Particularly important are procedures for respirator use during emergencies such as fire, large spillage of toxic material, accidental release of a potentially lethal substance, or failure of a ventilation system. All possible emergencies must be considered in advance and prepared for in the written procedures because in the stress of an emergency memories may be faulty. Furthermore, these emergency procedures should be used in training emergency response teams.

THE PROGRAM ADMINISTRATOR

Without a definite chain of supervision, there is no assurance that written standard operating procedures will be followed. Therefore, responsibility for the entire respirator program should be assigned to one person.

The large user may find it practical and economical to have a staff of personnel involved in the respirator program, each with his own area of responsibility as shown in Fig. 11-1. Each of these people should report to the one administrator who has overall responsibility for the program. The administrator's technical and professional background should enable him or her to make sound judgments based on hazard evaluation input from the workplace. She or he may be a safety engineer, industrial hygienist, health physicist, or physician. He or she should have the full support of higher level management; without it, an effective respirator program is difficult to initiate and maintain.

It may seem strange that respirator purchasing should be controlled by the program administrator.

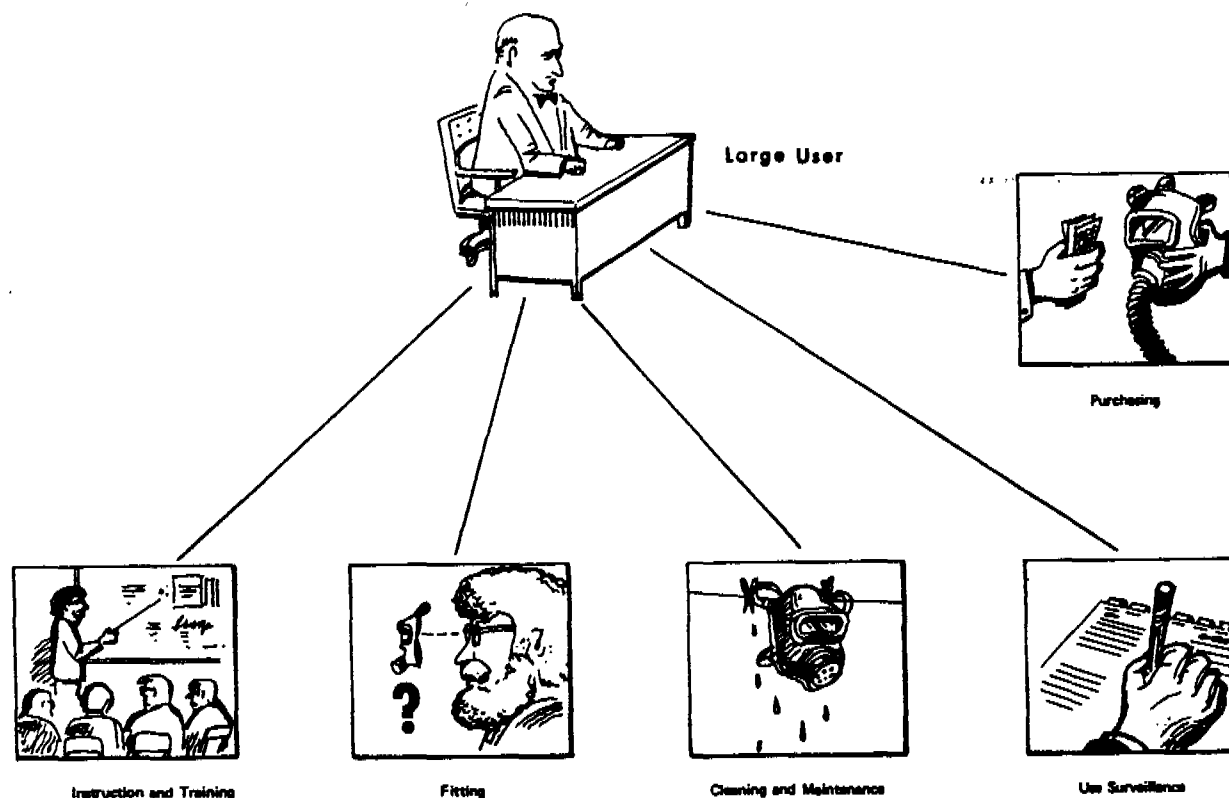


Figure 11-1.
Respirator program administration.

There are good reasons related to respirator fitting and selection. Several respirator manufacturers produce a wide variety of devices for protection against specific hazards. Unfortunately, the facepiece of each device generally is made in only one size that may fit only 50-75% of a group of workers. However, if more than one brand of respirator is purchased, thus providing a variety of facepiece sizes, it is possible to fit over 95% of a working population. Sometimes more than one type of respirator may be adequate against a particular hazard. The program administrator should select what he considers to be the best types of devices and ensure that they are purchased. As the price spread among the various brands of respirators for a particular type of hazard is not great, it is foolish to select a respirator on the basis of price alone. The program administrator, with his comprehensive knowledge, should have a strong influence on, if not absolute control over, respirator purchases.

What about the small user who cannot afford (and may not need) to involve several people specifically in a respirator program? Does he not have to meet the same requirements that the program administrator does for the large user? Because the OSHA regulations do not differentiate between large and small users, the answer is yes! In a small firm, where only a few workers must wear respirators for protection against one or very few different hazards, the program administrator may be a foreman or other supervisor. Where only one or two workers wear respirators, the entire program may be the responsibility of the company owner. In an extremely small operation, the entire program may be the responsibility of the worker himself, if he is the only person who must wear a respirator.

In summary, the program administrator can be a highly trained professional who oversees several employees responsible for specific phases of the respirator program, or a single employee responsible for his own respirator. Like the written operating procedures, the exact administration of the respirator program must be tailored to the individual situation.

THE DUTIES OF THE PROGRAM ADMINISTRATOR

The program administrator is generally a supervisor and coordinator. He receives workplace hazard evaluations, medical information, reports on worker acceptance of particular devices, etc., which he uses for guidance.

The administrator should keep the respirator program as flexible as possible. Although the written operating procedures meet today's situation, they may not meet tomorrow's. New hazards are continually being identified, and allowable exposure limits often are revised as more knowledge becomes available. The program administrator must stay abreast of these changes by subscribing to pertinent publications, and must not hesitate to modify his program to meet changing conditions.

Thus, the administrator, of a large or small program, must establish a respirator program that meets current needs, ensure that it is carried out satisfactorily, and ensure that it remains effective by continual examination and modification to meet changing conditions.

CHAPTER TWELVE

SURVEILLANCE AND PROGRAM EVALUATION

SURVEILLANCE

Surveillance of Work Area Conditions and Worker Exposure

OSHA 1910.134 and Sec. 3.5.8 of ANSI Z88.2 state that surveillance of conditions in the work area and of worker exposure to respiratory hazards shall be maintained. This necessitates periodic monitoring of the air contaminant concentration to which the respirator wearer is exposed. Many things such as changes in the operation or process, air movement, temperature, or humidity, affect the concentration of a substance in the work area atmosphere. Therefore, the air contaminant should be sampled. Preferably, sampling should be in the respirator wearer's breathing zone. Both the time-weighted average and peak concentrations of the contaminant should be determined. Comparing the measured time-weighted average concentration with the maximum use concentration determined for the type of respirator being used is a means of checking that the proper respirator has been selected.

Medical Surveillance

OSHA 1910.134 and Sec. 3.7 of ANSI Z88.2 state that no one should be assigned to tasks requiring use of respirators unless he has been found physically able to do the work while wearing the respirator. Both standards declare that a physician shall determine what health and physical conditions are pertinent, and that respirator wearers' medical status should be reviewed periodically.

Pre-employment medical examinations should screen out those who are physically or psychologically unfit to wear respirators. As another part of this examination, medical tests pertinent to the respiratory hazards that workers may encounter should be made to get baseline data against which to assess physiological changes in respirator wearers.

Periodic routine medical examinations shall be made to determine whether respirator wearers have been exposed to harmful levels of respiratory hazards. Examination frequency should be tailored

to particular situations. Tests to determine whether harmful amounts of hazardous substances have been taken into the body should be used. The results of the periodic examinations should be compared with those of the pre-employment examinations and previous periodic examinations to determine whether the respirators used are adequate. If possible, periodic biochemical tests of body tissues and wastes should be made to measure respirator wearers' exposures to respiratory hazards.

EVALUATION OF RESPIRATOR PROGRAM EFFECTIVENESS

OSHA 1910.134 and Sec. 3.5.9 of ANSI Z88.2 state that respirator program effectiveness shall be inspected and evaluated regularly. Periodic monitoring is necessary to ensure that workers are adequately protected. The program should be evaluated at least annually, and the written operating procedures should be modified to reflect the evaluation results if necessary.

Frequent inspection of respirator use will determine whether the correct respirators are being used and worn properly. Examination of respirators in use and in storage will indicate how well they are maintained. Wearers should be consulted periodically about their acceptance of respirators, including the discomfort, resistance to breathing, fatigue, interference with vision and communication, restriction of movement, and interference with job performance, and their confidence in the respirator's effectiveness.

The results of periodic inspections of respirator use, consultations with wearers, measurements of hazard levels in work areas, and medical surveillance of wearers should be reviewed, studied, and analyzed to determine the effectiveness of the respirator program. Evidence of excessive exposure to hazards should be followed up to determine why inadequate protection was provided, and action should be taken to remedy the problem. The results of the program evaluation should be presented in a written report that should list plans to correct faults and the target dates for their implementation.