CHAPTER 1

NIOSH AND RESPIRATORY PROTECTION

This report is intended to provide respirator users with a single source of respirator information. It covers the selection, use, and maintenance of respiratory protective devices available in 1987, and therefore serves as an update to the 1976 ***Guide to Industrial Respiratory Protection.***

When the National Institute for Occupational Safety and Health (NIOSH) was established in 1971, the professional staff recognized the crucial need for establishing the correct role of respiratory protection in workplaces. While dedicating the majority of its resources to the fundamental concepts of industrial health and safety, NIOSH has devoted a significant part of those resources to three areas of respiratory protection--research, training, and certification.

NIOSH has had an ongoing respirator research program since the early 1970s. Most of the recent research has been dedicated toward improving the quality and reliability of respirators through development of new and revised performance requirements for respirator certification.

Respirator training has been a focal point of the NIOSH activities in respiratory protection. The basic respirator training courses which are available from several sources today are based on the respirator course developed by NIOSH personnel.

NIOSH and OSHA established a Joint Respirator Committee in 1973, for the purpose of developing standard respirator selection criteria and tables for the approximately 400 hazardous materials regulated by OSHA. This committee, assisted by contractors from Los Alamos Scientific Laboratory and Arthur D. Little, Inc., developed the respirator selection tables that appear in NIOSH criteria documents and in the initial ***NIOSH/OSHA Pocket Guide to Chemical Hazards***. The committee also participated in development of the initial ***Respirator Decision Logic***, which has been revised for this publication.

The respirator certification work of NIOSH is a direct offshoot of the approval of mine rescue breathing apparatus by the Bureau of Mines. Under authorization of the Coal Mine Health and Safety Act of 1969 and the Federal Mine Safety and Health Act of 1977, NIOSH has established an evaluation and certification program for respirators. All certifications are issued jointly with the Mine Safety and Health Administration (MSHA).

The goal of the certification program is to help increase worker protection from airborne contaminants by certifying respirators that meet the minimum

performance requirements which appear in Title 30, Code of Federal Regulations, Part 11 (30 CFR 11). NIOSH certification evaluations include a laboratory evaluation of the respirator, an evaluation of the manufacturer's quality control (QC) plan, audit testing of certified respirators, and investigations of problems with MSHA/NIOSH certified respirators.
In accordance with 30 CFR 11, MSHA/NIOSH certifications are issued for respirators specifically for use in mines and mining. However, the wide variety of respirators used in mines and mining ensures the availability of certified respirators for most other applications.

NIOSH has proposed significant revisions to 30 CFR 11. Once revised regulations are in effect, NIOSH expects to push vigorously for other improvements in respirator performance standards over the ensuing several years.

NIOSH also monitors respirators over the lifetime of their certification. Samples of "off the shelf" respirators are evaluated in NIOSH laboratories to see if they continue to meet applicable minimum performance requirements. In addition, NIOSH performs in-plant QC audits in order to determine if manufacturers are complying with the QC plans submitted in their approval applications. Reports of problems received from regulatory agencies, labor organizations, respirator users, and respirator manufacturers are investigated and resolved.

CHAPTER 2

TYPES OF RESPIRATORS

The basic purpose of any respirator is, simply, to protect the respiratory system from inhalation of hazardous atmospheres. Respirators provide protection either by removing contaminants from the air before it is inhaled or by supplying an independent source of respirable air. The principal classifications of respirator types are based on these categories.

A respirator that removes contaminants from the ambient air is called an **air-purifying respirator.** A respirator that provides air from a source other than the surrounding atmosphere is an **atmosphere-supplying respirator.** Both types can be further subclassified by the type of inlet covering and the mode of operation. Figures 2-1 through 2-6 detail the subclassifications of respirators that will be discussed in this chapter.

I. Respiratory Inlet Coverings

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

A. Tight-fitting coverings

Tight-fitting coverings, usually called "facepieces," are made of flexible molded rubber, silicone, neoprene, or other materials. Present designs incorporate rubber or woven elastic headstraps that are attached at two to six points. They buckle together at the back of the head, or may form 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. 2-7). Good protection may be obtained with a quarter-mask, but it is more easily dislodged than other types. Quarter-masks are most commonly found on dust and mist respirators.

A second type, the "half-mask," fits over the nose and under the chin (Fig. 2-8). Half-masks are designed to seal more reliably than quarter-masks, so they are preferred for use against more toxic materials.

A third type, the "full-facepiece," covers from roughly the hairline to below the chin (Fig. 2-9). On the average they provide the greatest protection, usually seal most reliably, and provide some eye protection

AIR-PURIFYING RESPIRATORS

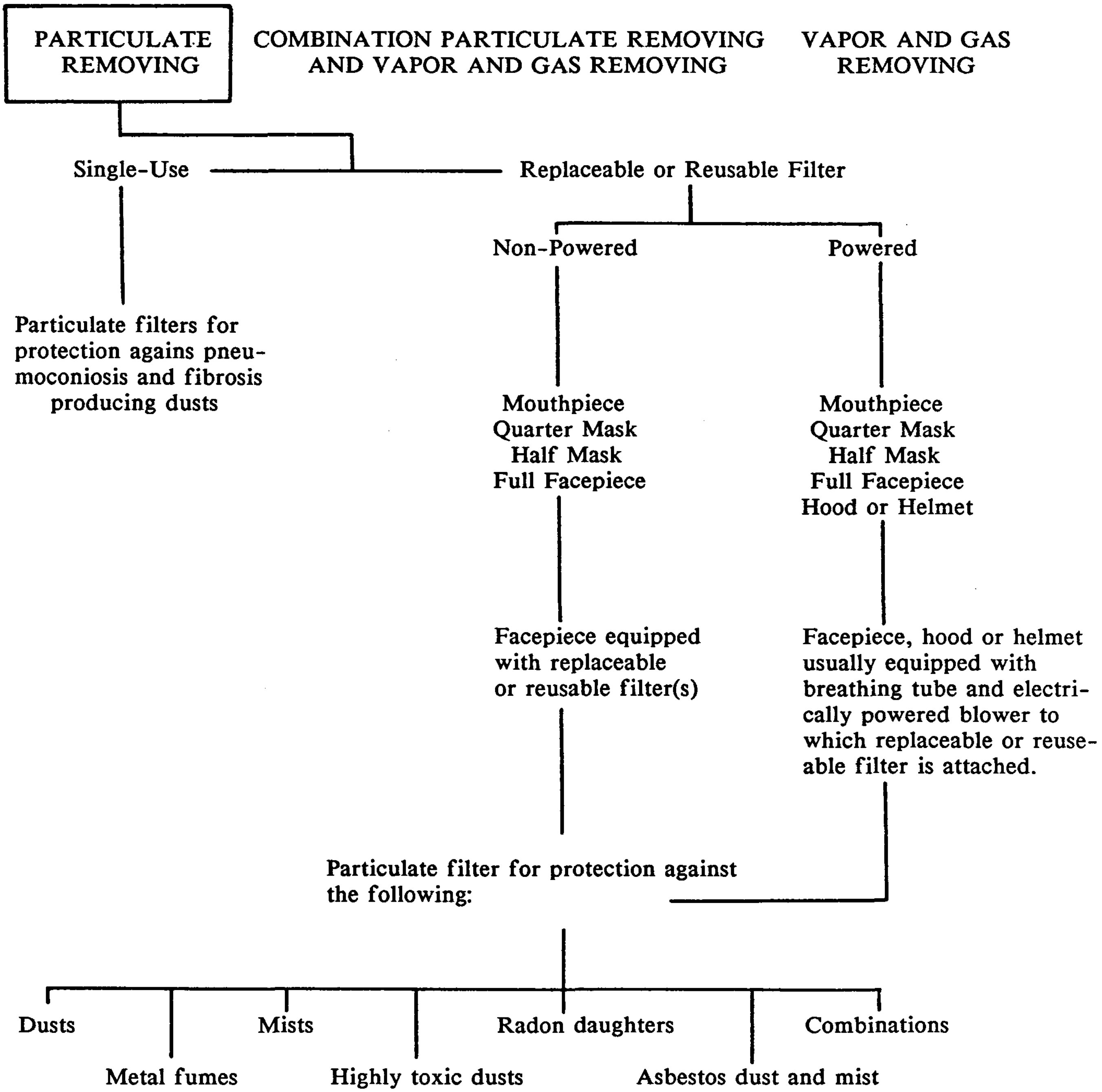

Figure 2-1. **Particulate removing respirators**

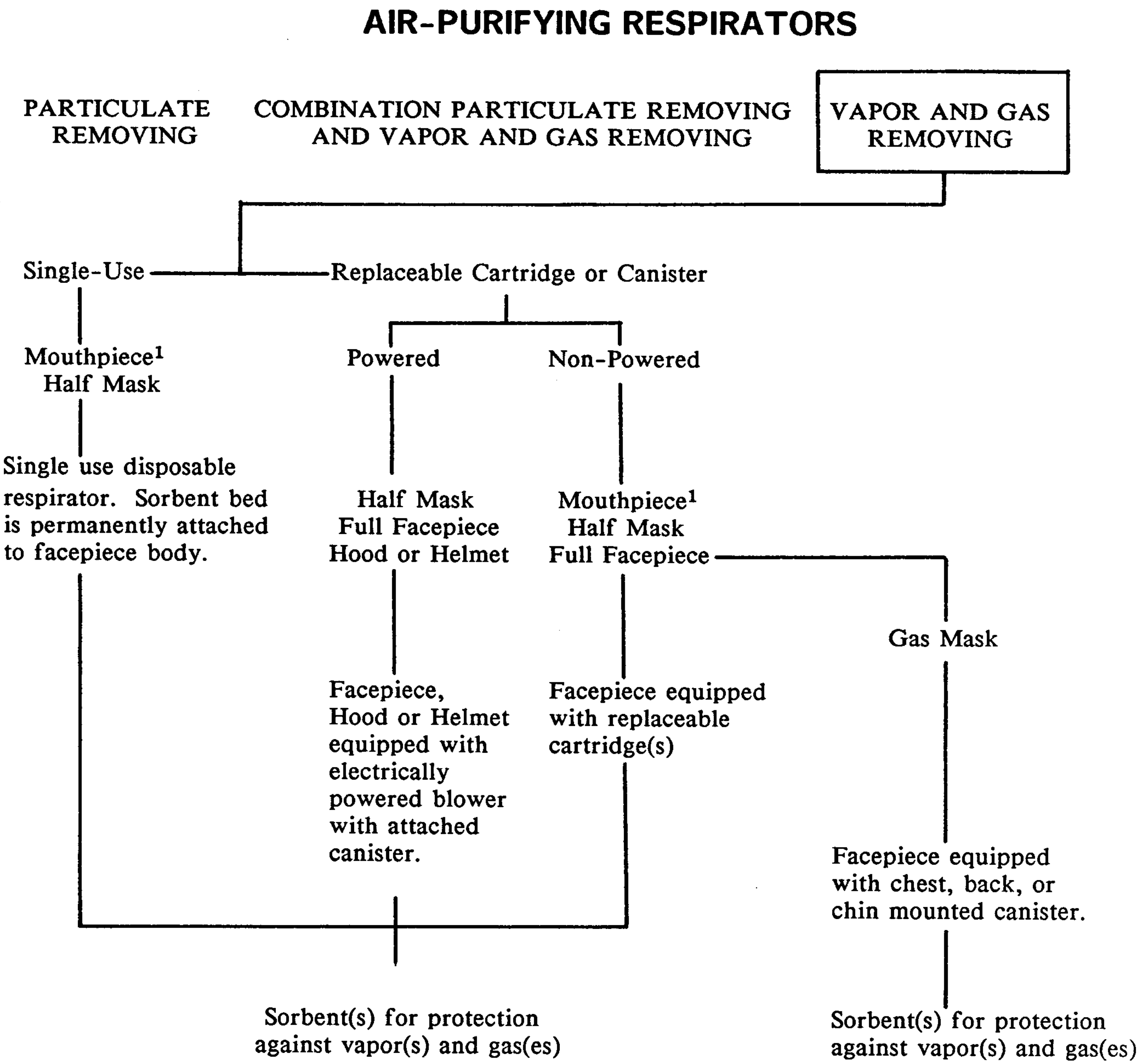

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Figure 2-2. **Vapor and gas removing respirators**

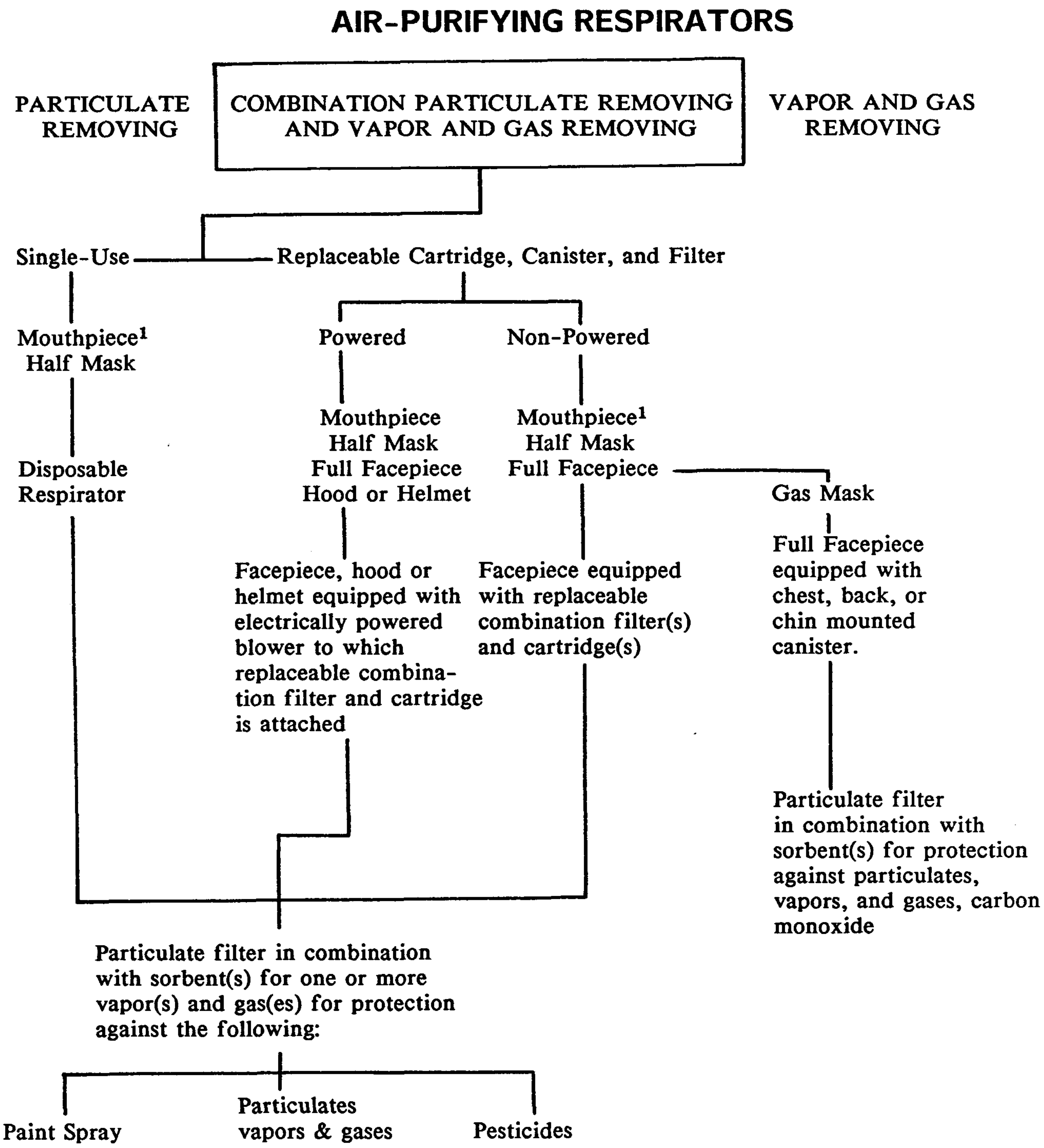

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Figure 2-3. **Combination particulate and vapor and gas removing respirators**

ATMOSPHERE-SUPPLYING RESPIRATORS

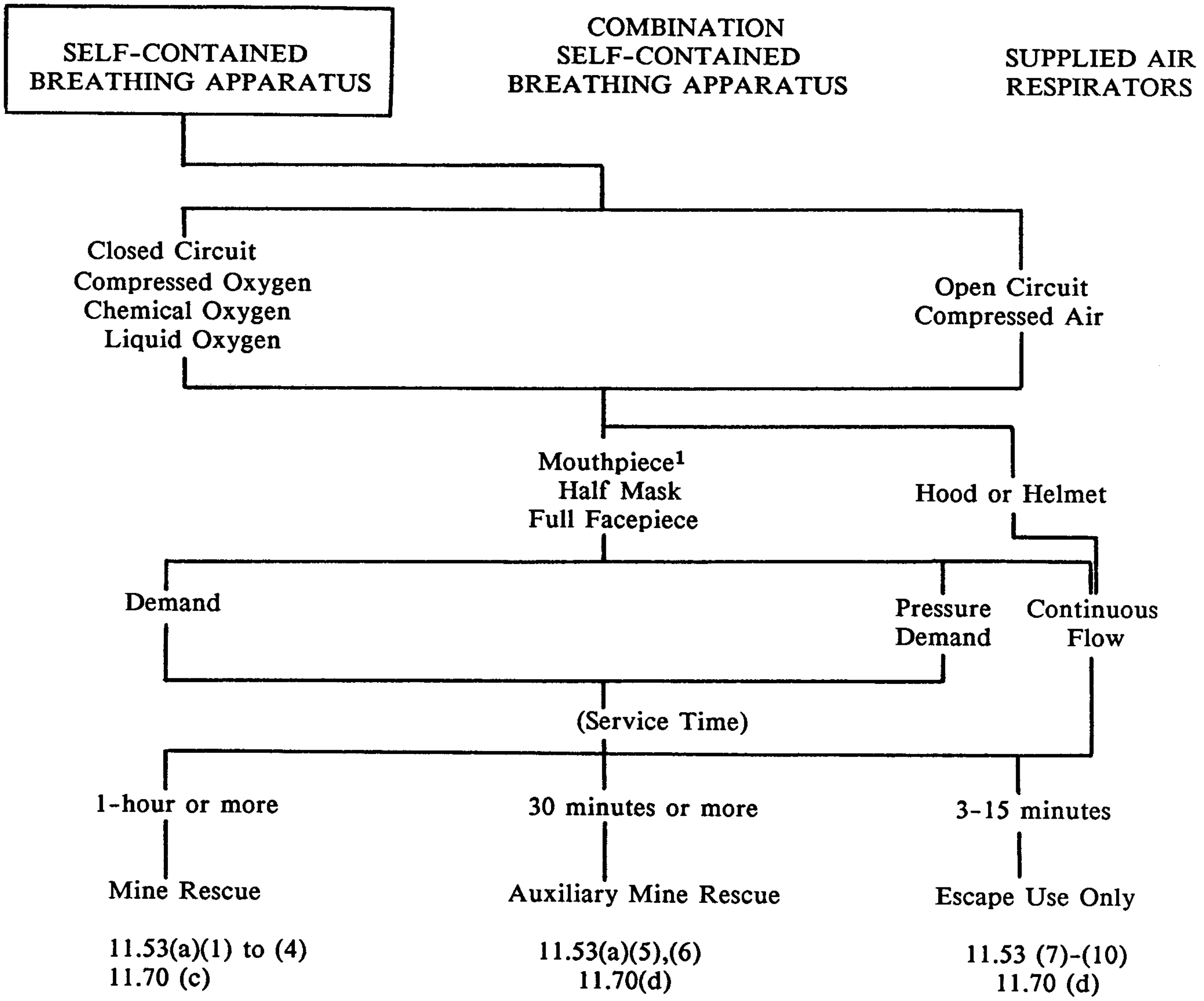

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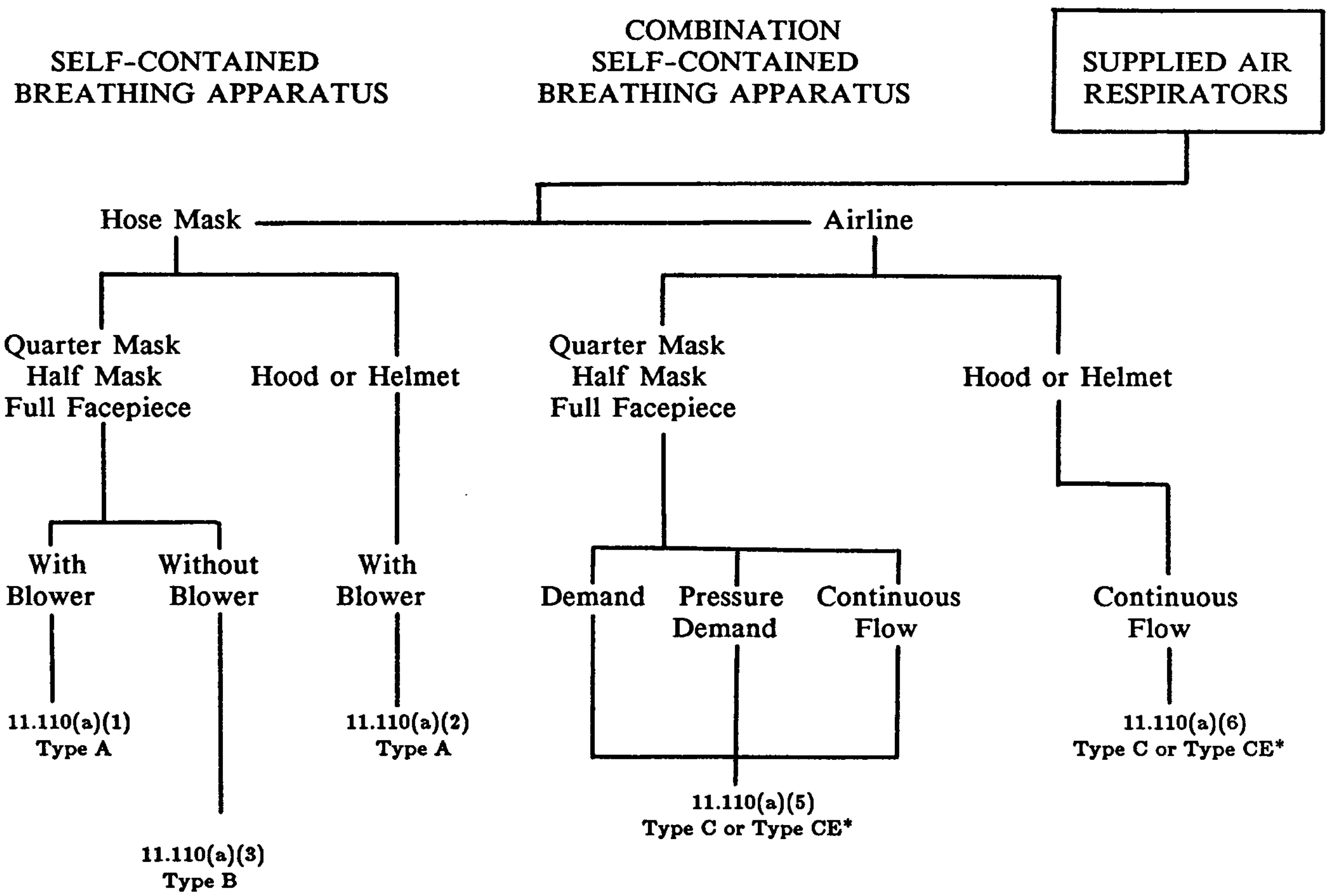
Figure 2-4. **Self-contained breathing apparatus**

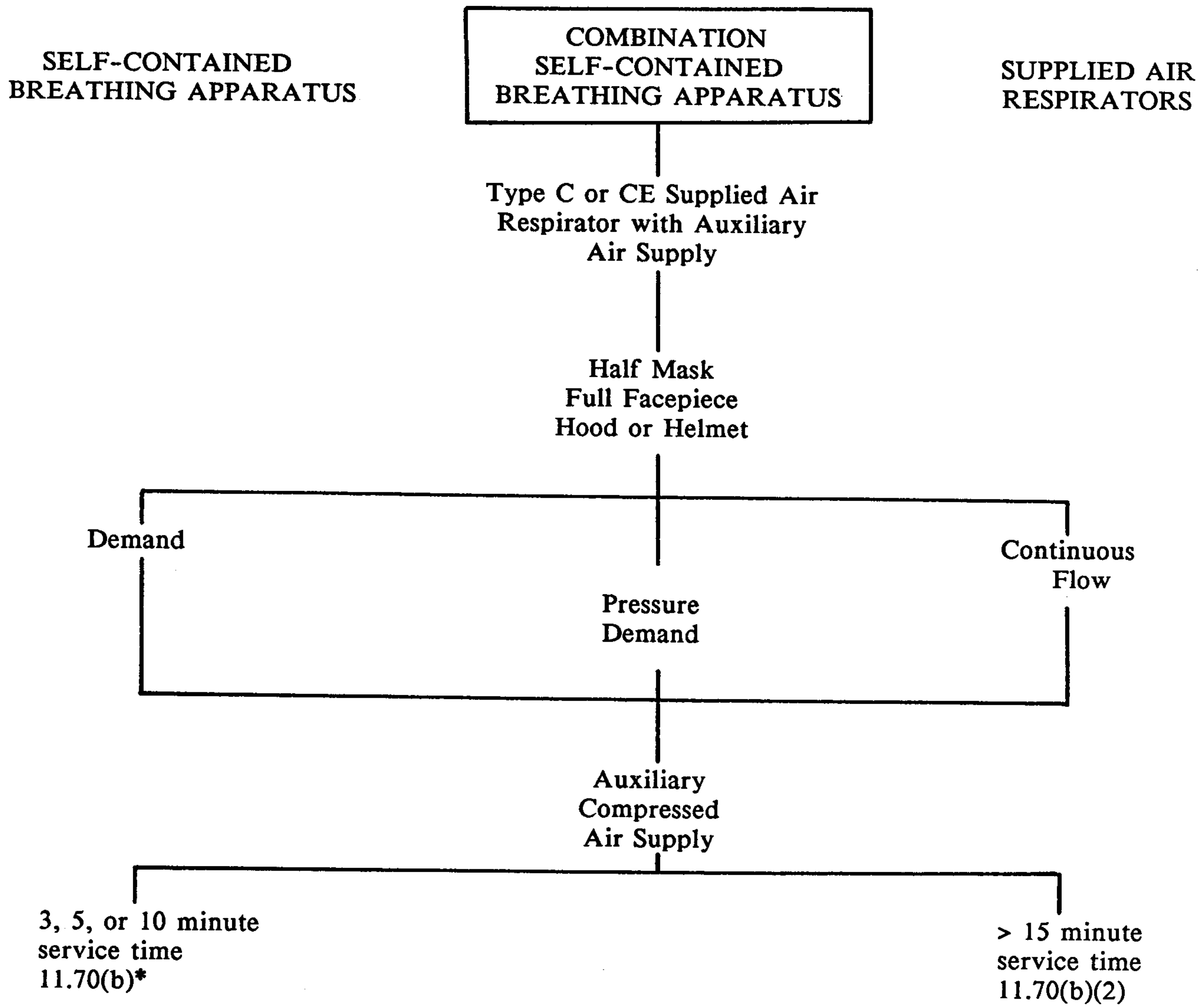
ATMOSPHERE-SUPPLYING RESPIRATORS



* Type CE respirators must have a means of protecting the wearer's head and neck against impact and abrasions from rebounding abrasive material and with shielding material such as plastic, glass, woven metal wire, etc.

Figure 2-5. **Supplied-air respirators**

ATMOSPHERE-SUPPLYING RESPIRATORS



* SCBA can be used for egress only.

Figure 2-6. **Combination SCBA and supplied-air respirators**

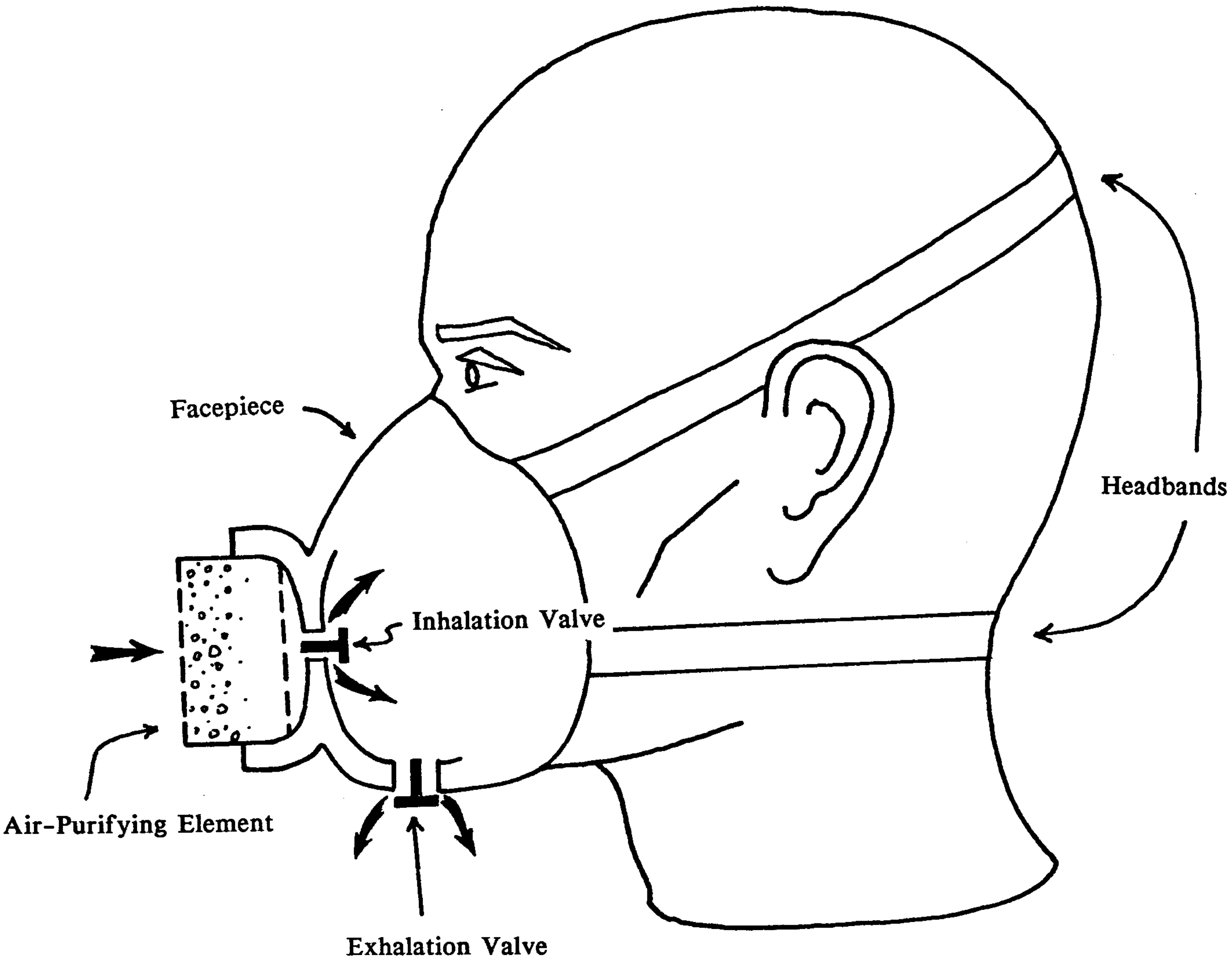


FIGURE 2-7. **Typical quarter-mask respirator**

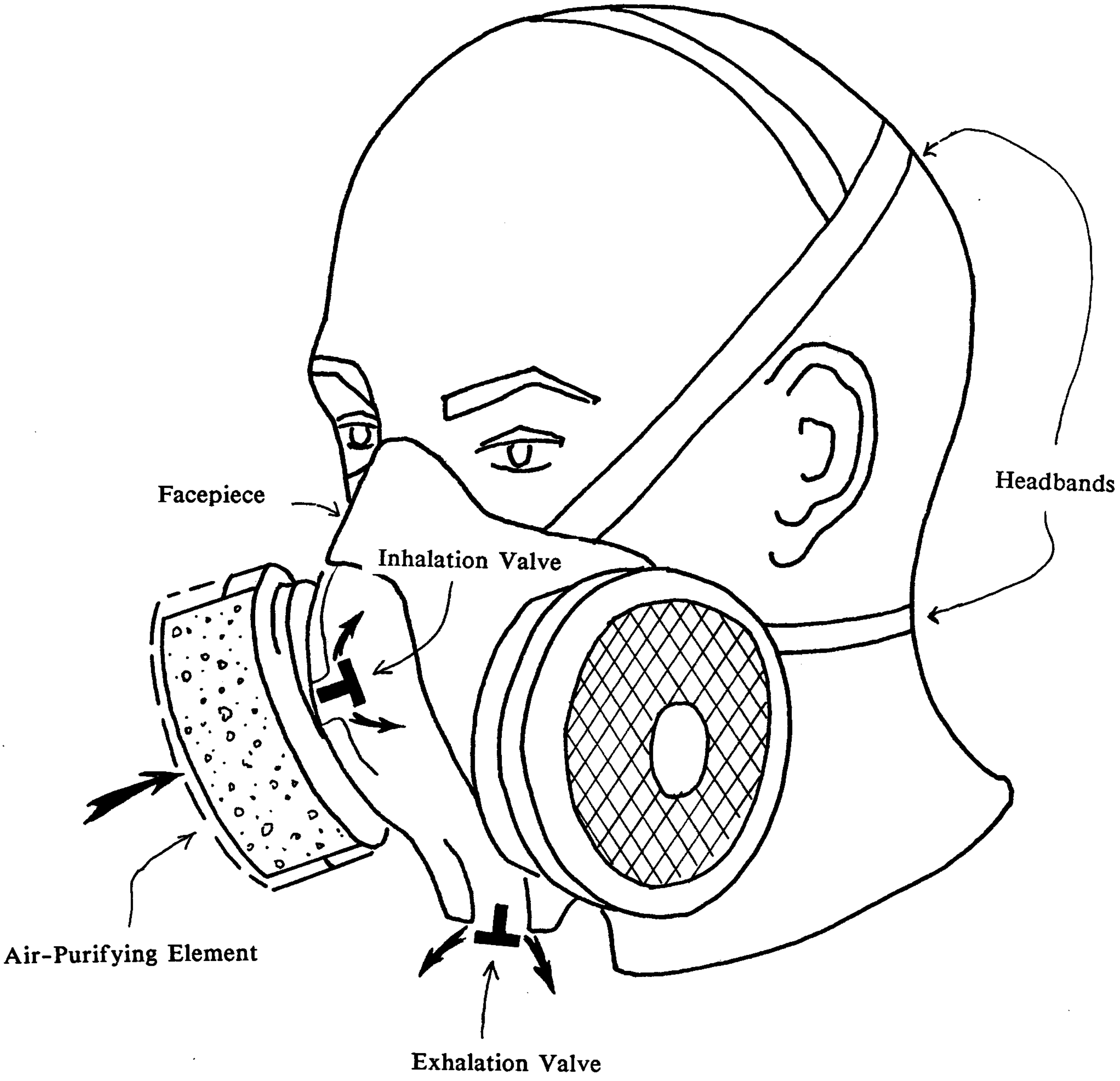


FIGURE 2-8. **Typical half-mask respirator**

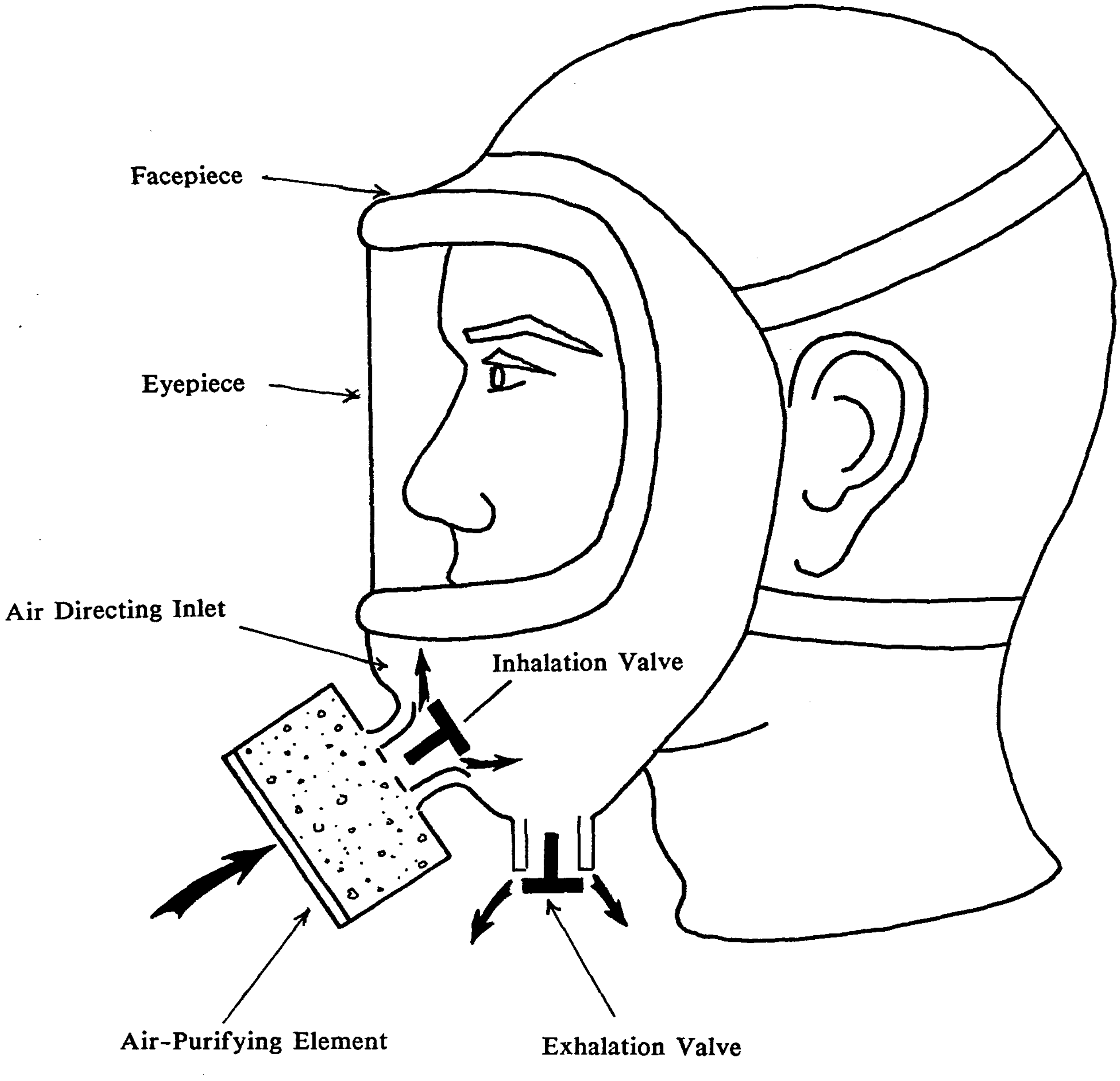


FIGURE 2-9. **Typical full-facepiece respirator**

as well. Full-facepiece respirators, both air-purifying and atmosphere-supplying, are designed for use in higher concentrations of toxic materials than are quarter- or half-mask respirators.

The mouthpiece consists of a mouthpiece held in the teeth (the lips seal around it) and a clamp that closes the nostrils (Fig. 2-10). Mouthpiece respirators should provide a good seal, but they eliminate communication, may cause fatigue, and provide no eye protection. Therefore, mouthpiece respirators are certified for use as escape-only respirators.

B. Loose-fitting coverings

Loose-fitting coverings include hoods, helmets, suits, and blouses. The wide variety of designs precludes any simple description, but Fig. 2-11 shows a blouse which typifies the basic principles of construction and operation of all such devices.

Generally, loose-fitting respirators enclose at least the head. A light flexible device covering only the head and neck, or 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. The enclosure includes a system through which clean compressed air is distributed around the breathing zone.

A special type of loose-fitting covering in common use is the abrasive-blasting hood (Fig. 2-12). The hood material is designed to withstand rebounding particles of abrasive material. Also, there is usually an impact-resistant glass or plastic viewing lens with additional plastic, glass, or woven wire shielding that deflects the rebounding particles.

II. Air-Purifying Respirators

A. Particulate Filtering Respirators

Particulate filtering respirators are used for protection against dusts, fumes, and/or mists. A dust is a solid, mechanically produced particle. A fume is a solid condensation particulate, usually of a vaporized metal. A mist is a liquid condensation particle.

Presently, all particulate filtering respirators use fibrous material (a filter) to remove the contaminant. As a particle is drawn onto or 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, shape, and electrical charge of both particle and fiber. With current filter media, any filter designed to be 100% efficient in removing particles would be unacceptably difficult to breathe through.

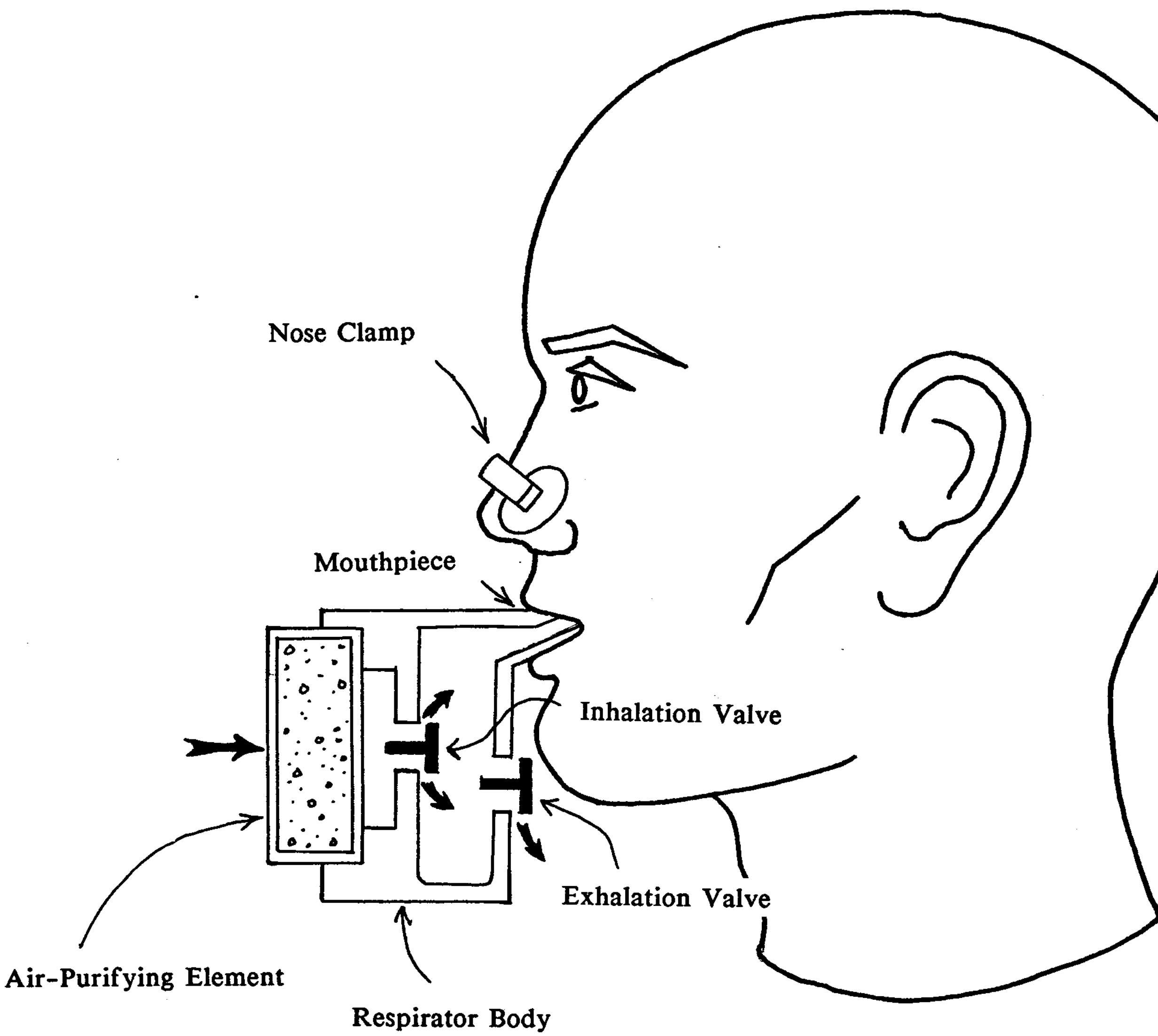


FIGURE 2-10. **Typical "mouthpiece" respirator**

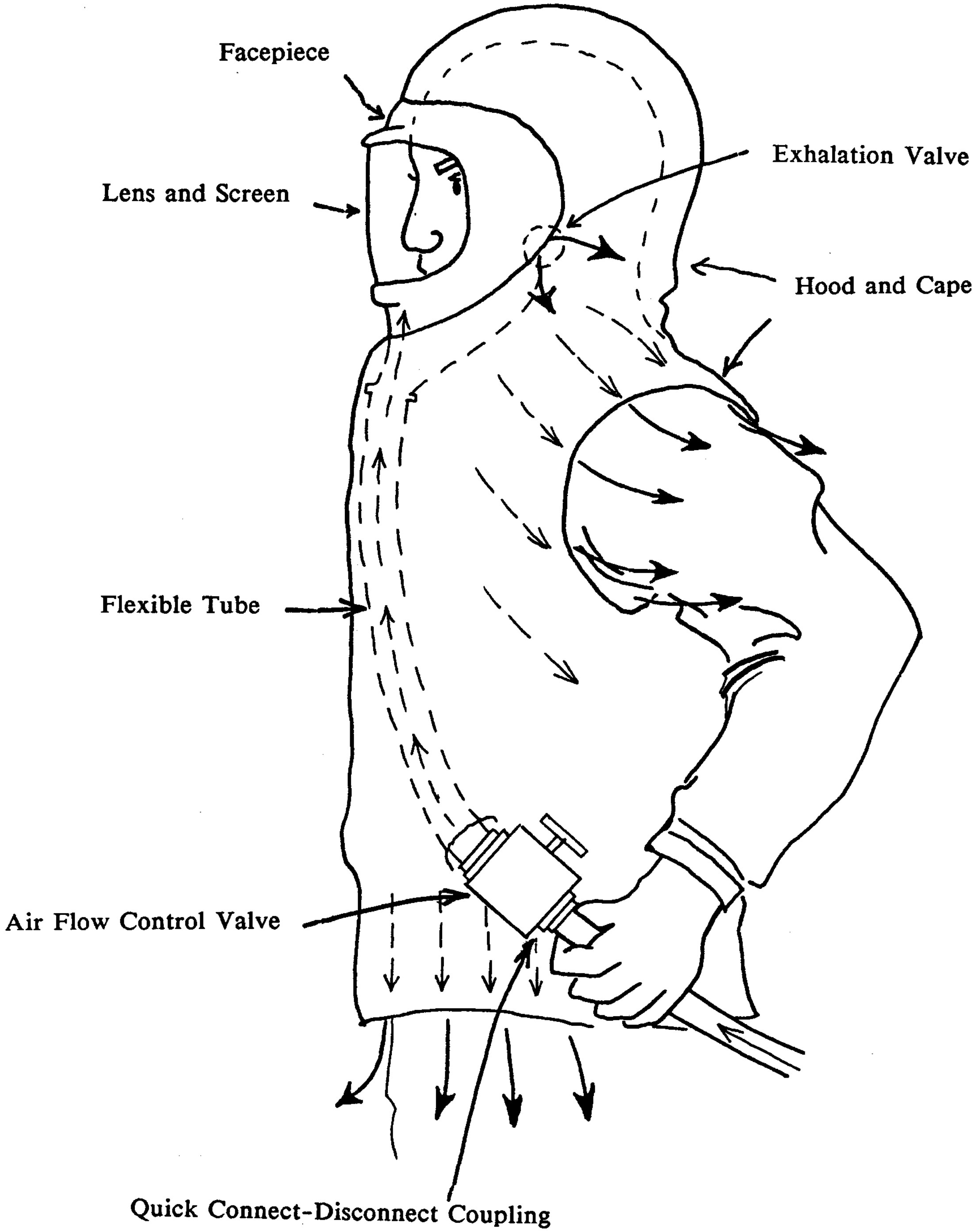


FIGURE 2-11. **Loose-fitting blouse**

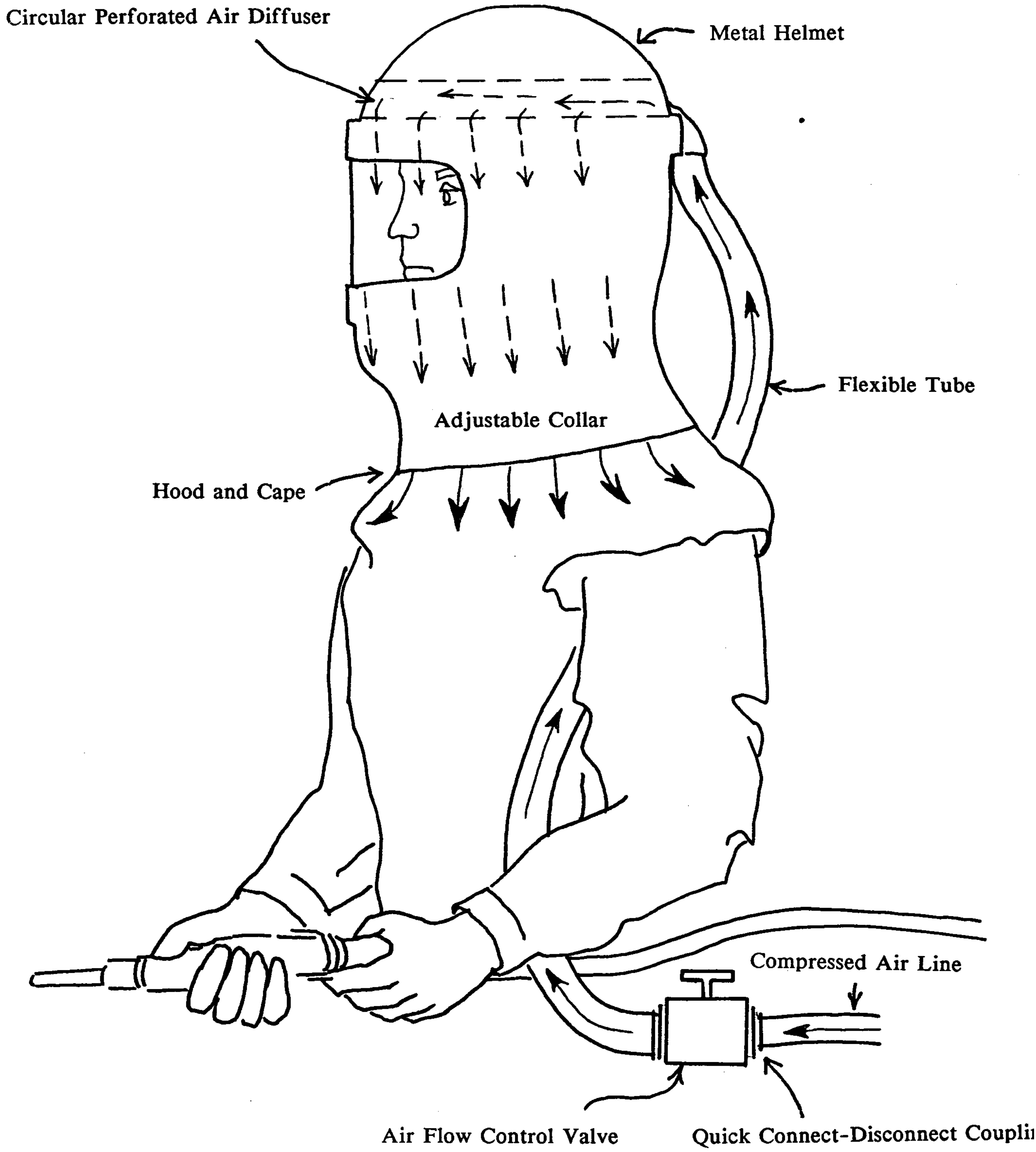


FIGURE 2-12. **Typical abrasive blasting hood**

Manufacturers try to produce the most efficient filter with the lowest breathing resistance. As the particulate respirator is used particulate material collects on the filter and the openings between fibers become smaller. This results in an increase in the breathing resistance. The filter may also become more efficient.

There are several designs of respirator filters. Each can be described by its filtration mechanism(s), production methods or type, the aerosol against which it is designed to provide protection, and the filtering efficiency.

1. *Filtration Mechanisms*

Particulate filters are of two types: absolute and non-absolute. Absolute filters use screening to remove particles from the air; that is, they exclude the particles which are larger than the pores. However, most respirator filters are non-absolute filters, which means they contain pores which are larger than the particles to be removed. They use combinations of interception capture, sedimentation capture, inertial impaction capture, diffusion capture, and electrostatic capture to remove the particles. The exact combination of filtration mechanisms which come into play depends upon the flowrate through the filter and the size of particle. Brief descriptions of these filtration mechanisms follow.

a. Interception Capture

As the air streams approach a fiber lying perpendicular to their path, they split and compress in order to flow around the fiber and rejoin on the other side (Figure 2-13). If the center of a particle in these airstreams comes within one particle radius of the fiber, it encounters the fiber surface and it is captured. As particle size increases, the probability of interception capture increases. The particles do not deviate from their original streamline in this mechanism.

b. Sedimentation Capture

Only large particles (2μ and larger) are captured by sedimentation. Since this type of capture relies on gravity to pull particles from the airstream, flowrate through the filter must be low (Figure 2-14).

c. Inertial Impaction Capture

As the airstreams split and change direction suddenly to go around the fiber, particles with sufficient inertia cannot change direction sufficiently to avoid the fiber. Thus they impact on the surface of the fiber (Figure 2-15). A particle's size, density, speed and shape determine its inertia.

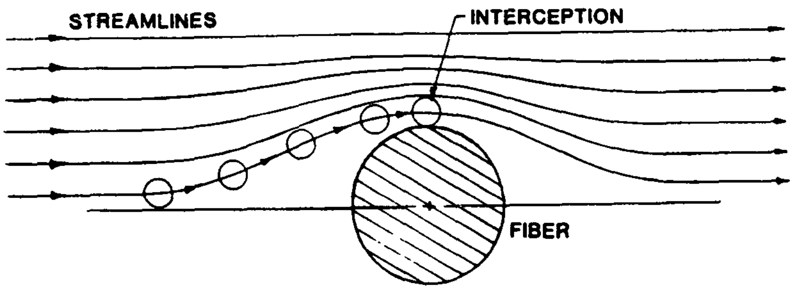


FIGURE 2-13. **Interception capture mechanism**[1]

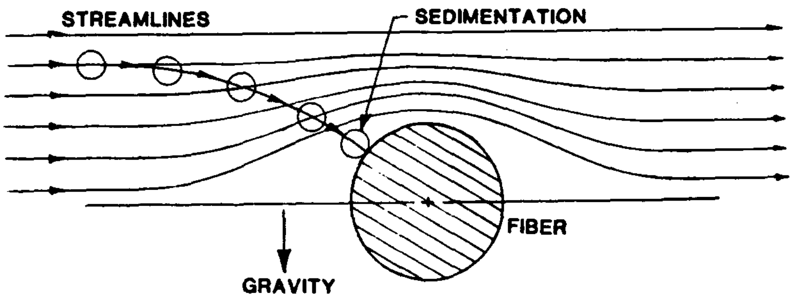


FIGURE 2-14. **Sedimentation capture mechanism**[1]

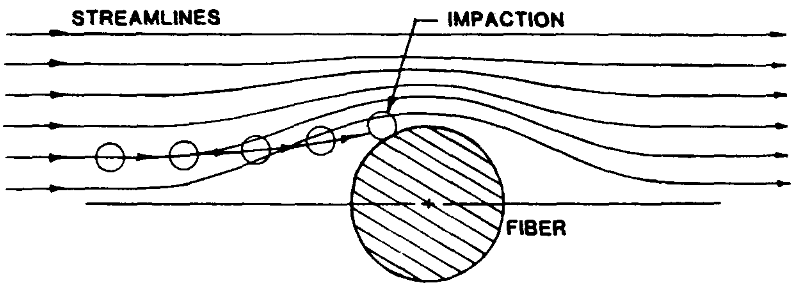


FIGURE 2-15. **Impaction capture mechanism**[1]

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[1] Japuntich, Daniel A. Respiratory Particulate Filtration. J. Ind. Soc. Respir. Prot. 1984; 2(1):137-169.

d. Diffusion Capture

The motion of smaller particles is affected by air molecules colliding with them. The particles then can randomly cross the airstream and encounter the fiber as they pass (Figure 2-16). This random motion is dependent on particle size and the air temperature. As the particle size decreases and air temperature increases the diffusive activity of the particle increases. This increases the probability of capture. Lower flowrate through the filter also increases the probability of capture because the particle spends more time in the area of the fiber.

e. Electrostatic Capture

In electrostatic capture, the particle is charged and the filter fibers have the opposite charge. Therefore, the particles are attracted to the fibers (Figure 2-17). The electrostatic capture mechanism aids the other capture mechanisms, especially interception and diffusion.

As was mentioned previously, the exact combination of capture mechanisms taking place depends upon several factors. However, some generalizations can be made. Large heavy particles are usually removed by inertial impaction and interception. Large light particles are removed by diffusion and interception. Diffusion removes very small particles.

2. Types of Filters

Three types of particulate filter predominate. The most common type presently available is a machine made flat disk of random laid non-woven fiber material which is carefully controlled to produce maximum filter efficiency and minimum resistance.

Another type (Figure 2-18) 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 protect adequately against most industrial dusts, but one precaution should be observed in their use. Certain agents, such as oil mists, and storage in very humid air remove the electrostatic charge. Therefore this type of filter should be stored in its original package, kept out of oil mists and high (>80%) humidity, and used as soon as possible after purchase.

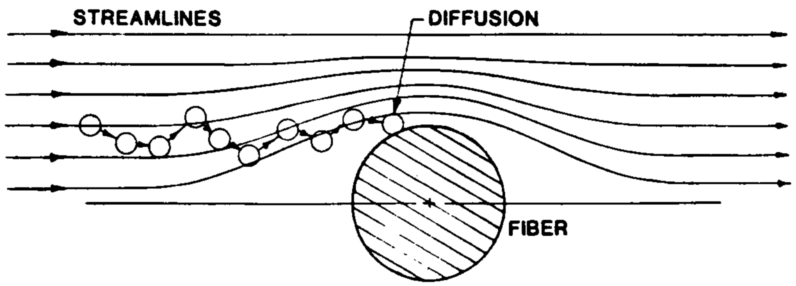

FIGURE 2-16. **Diffusion capture mechanism[1]**

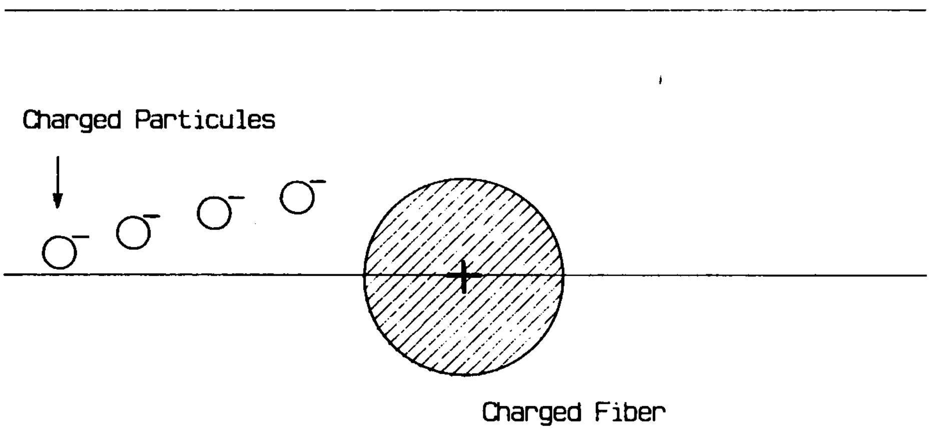

FIGURE 2-17. **Electrostatic capture**

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1 Japuntich, Daniel A. Respiratory Particulate Filtration. J. Ind. Soc. Respir. Prot. 1984; 2(1):137-169.

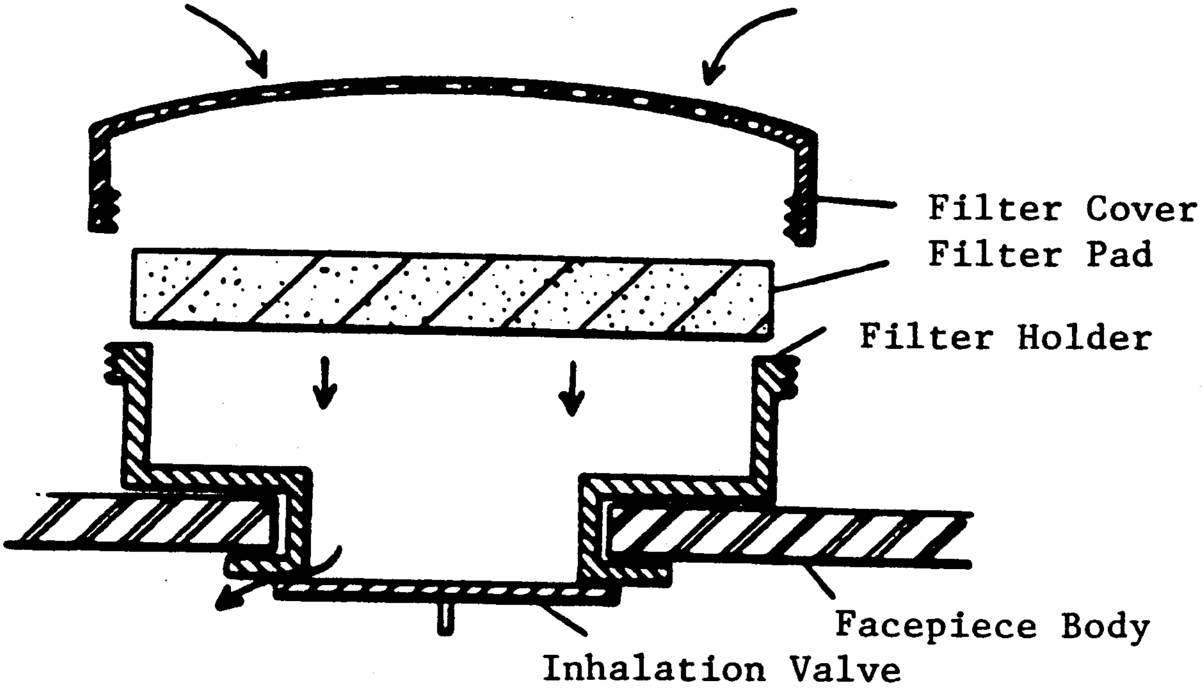


FIGURE 2-18. **Typical resin-impregnated felt dust filter**

The resin impregnated felt filter is readily identified by rubbing it between the fingers and then rubbing the fingers together. The fingers will feel slightly sticky.

Another type of dust filter is shown in Figure 2-19. The filtering medium is only loosely packed in the filter container so it is much thicker than the compressed type. Such filters are generally made of fibrous glass, although nonfelted, resin impregnated natural wool fibers have been used. They are not as common as the felted type. Typical dust respirators are shown in Figure 2-20.

Figure 2-21 shows a typical high efficiency dust, fume, and mist filter and Figure 2-22 shows high efficiency respirators. The filter is a flat sheet of material that is pleated and placed in the filter container. 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 or rows of pleats. This configuration is common, but other methods of construction are also used.

3. Particulate Respirator Classifications

For the 30 CFR 11 Subpart K certification tests particulate respirators are classified as designed for protection against a variety of dusts, fumes, mists. The following types are presently certified by MSHA/NIOSH:

a. Replaceable or Reusable Dust and Mist

Respirators, either with replaceable or reusable filters, designed as respiratory protection against (1) dusts and mists having an exposure limit not less than 0.05 milligram per cubic meter of air, or (2) dusts and mists having an exposure limit not less than 2 million particles per cubic foot of air.

b. Replaceable Fume

Respirators, with replaceable filters, designed as respiratory protection against fumes of various metals having an exposure limit not less than 0.05 milligram per cubic meter.

c. Replaceable Dust, Fume, and Mist

Respirators, with replaceable filters, designed as respiratory protection against dusts, fumes, and mists of materials having an exposure limit less than 0.05 milligram per cubic meter or 2 million particles per cubic foot of air.

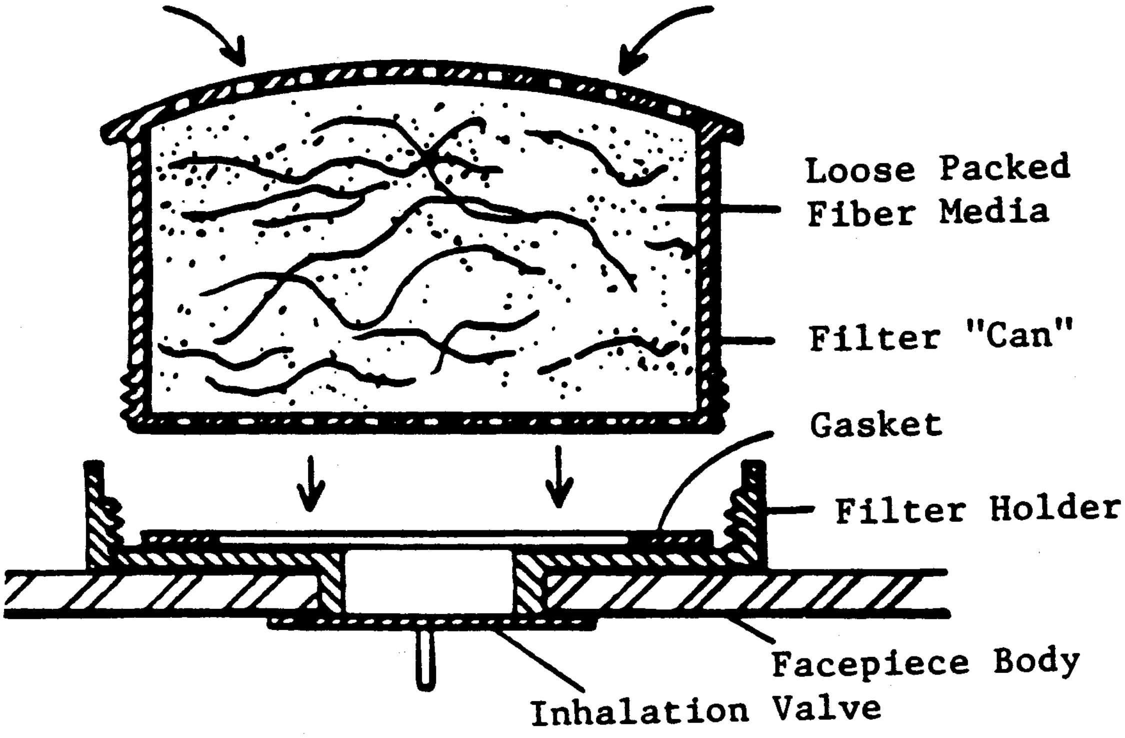
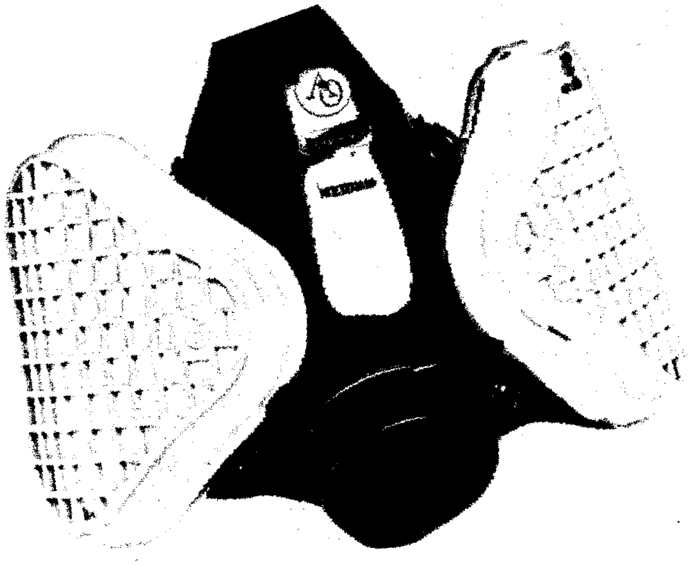
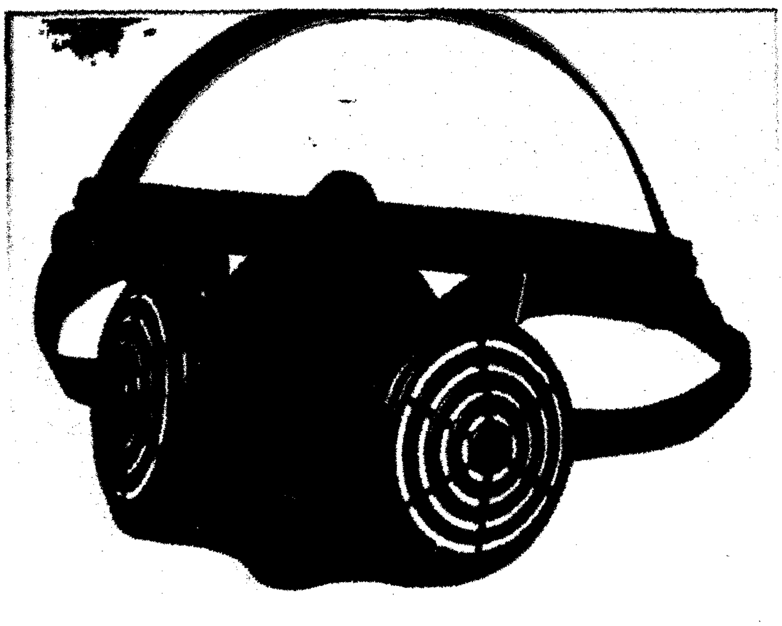


FIGURE 2-19. **Typical dust filter with loose packed medium**



Photograph courtesy of American Optical Corporation



Photograph courtesy of U.S. Safety S

FIGURE 2-20

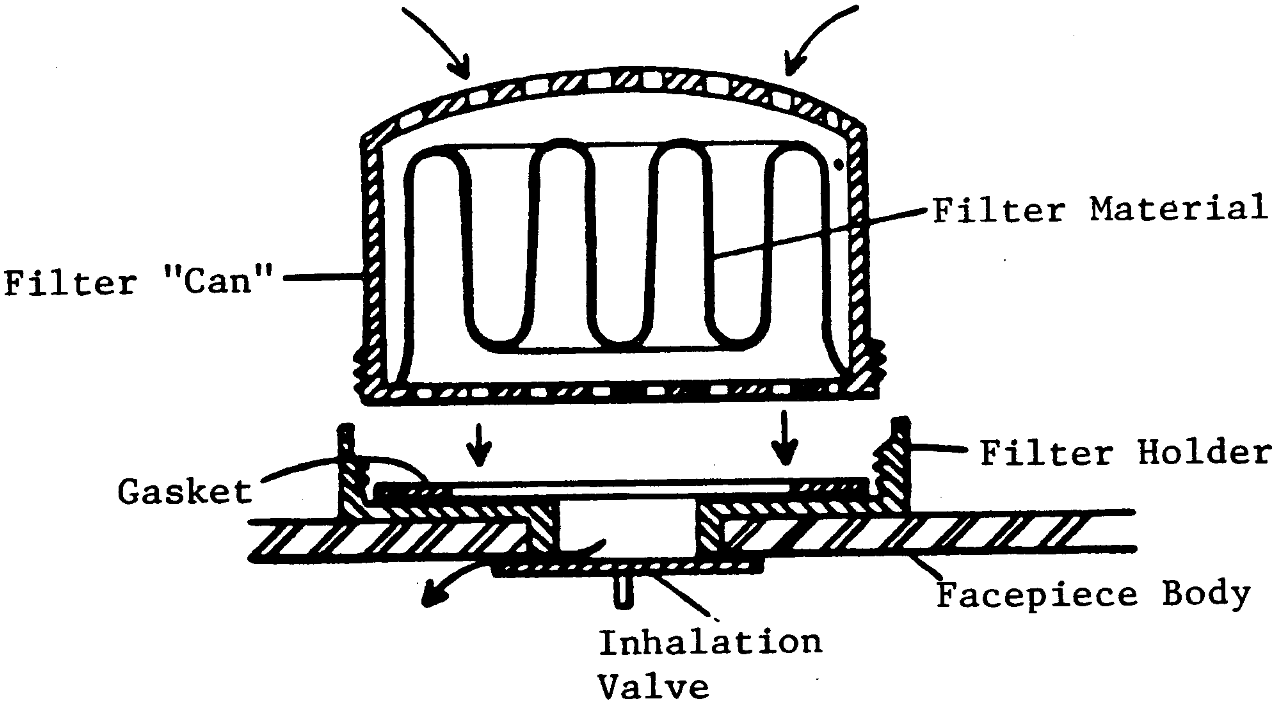


FIGURE 2-21. **Typical high efficiency filter**

Photograph Courtesy of U.S. Safety Service

Photograph Courtesy of Willson Safety Products

FIGURE 2-22. **Typical half- and full-facepiece high efficiency respirators**

d. Single-use

Respirators designed as respiratory protection against pneumoconiosis- and fibrosis-producing dusts, or dusts and mist. In the single-use respirator, the filter is either an integral part of the facepiece or it is the entire facepiece itself (see Figure 2-23).

4. Filter Efficiency

Filter efficiency may be classified as follows:

a. High Efficiency

The highest efficiency filters (99.97 percent against 0.3µ dioctyl phthlate particle) are used on high efficiency respirators certified for protection against dusts, fumes, and mists having an exposure limit less than 0.05 milligram per cubic meter or 2 million particles per cubic foot of air.

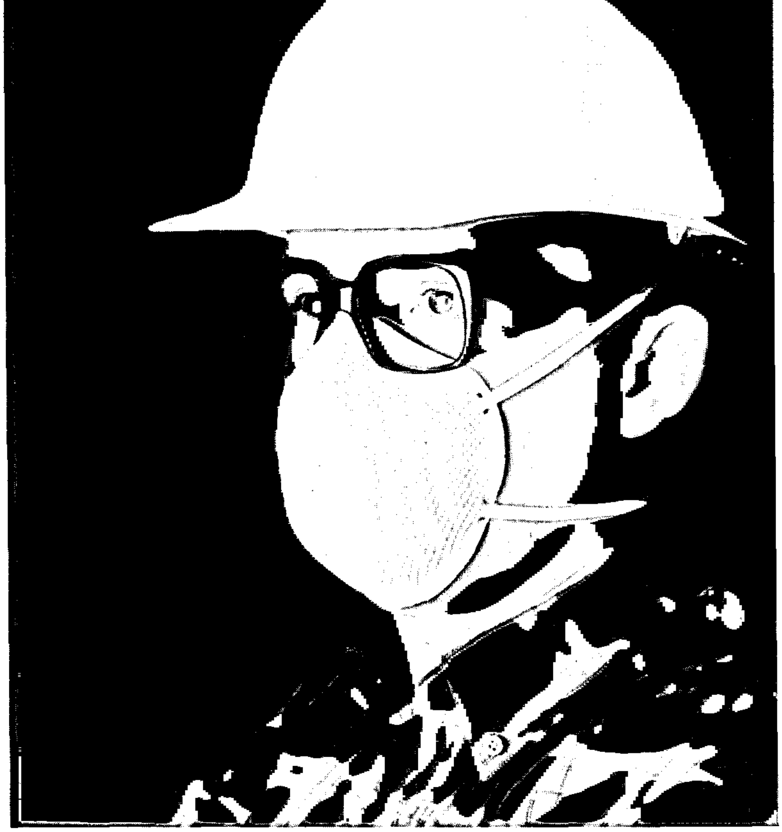
b. Lower Efficiency

Respirators for dusts, fumes, and mists having an exposure limit not less than 0.05 milligram per cubic meter, have lower efficiency filters as classified in 30 CFR 11 (approximately 99 percent against a lead fume aerosol).

Dust, mist, single-use dust and mist respirators also have lower efficiency filters as classified in 30 CFR 11 (approximately 99 percent against a silica dust particle with a geometric mean diameter of 0.4 to 0.6µ and a standard geometric mean deviation not greater than 2).

B. Vapor and Gas Removing Respirators

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 gas and mercury vapor, and classes of gases and vapors, such as acid gases and organic vapors. 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 for protection against specific contaminants.



Photograph Courtesy of Moldex-Metric Inc.

Photograph Courtesy of Louis M. Gerson Co., Inc.

FIGURE 2-23. **Typical single use respirators**

1. Removal Mechanisms

Vapor and gas removing respirators normally 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. In addition to sorption, some respirators use catalysts which react with the contaminant to produce a less toxic gas or vapor.

Three removal mechanisms are used in vapor and gas removing respirators.

a. Adsorption

Adsorption retains the contaminant molecule on the surface of the sorbent granule by physical attraction. The intensity of the attraction varies with the type of sorbent and contaminant. Adsorption by physical attraction holds the adsorbed molecules weakly. If chemical forces are involved, however, in the process called chemisorption, 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 m^2/g of sorbent. Activated charcoal is 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 sorbents which could be used in vapor and gas removing respirators include molecular sieves, activated alumina, and silica gel.

b. Absorption

Absorbents may also be used to remove gases and vapors. 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 usually 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.

c. Catalysis

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 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 and into the facepiece. This is in contrast to mechanical 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. For example, increasing moisture content of a sorbent designed to sorb acid gases may increase sorbent efficiency since most acid gases normally dissolve in water. Vapor and gas removing cartridges should be protected from the atmosphere while in storage.

2. ***Cartridges vs. Canisters.***

a. Sorbent Volume

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 on full-facepieces. The sorbent volume of a cartridge is small, about 50-200 cm^3, 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. The user should refer to NIOSH recommendations, certification labels, or specific standards set forth by regulatory agencies for specific maximum use concentrations.

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 (up to the immediately dangerous to life or health level) than those with cartridges. Chin-style canisters have a volume of about 250-500 cm^3 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 cm^3. Front- or back-mounted and chin-style canisters are used with full-facepieces as part of "gas masks." The "gas mask" is certified for single or specific classes of gases and vapors. 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.

b. 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 has the proper device? The printed certification label clearly lists these contaminants. An American National Standard, ANSI K13.1-1973, established a color code for the various types of sorbent cartridges and canisters which identifies the contaminants they are designed to protect against. Users should not rely on memorizing the color code, but should always **READ THE LABEL!** This is the only foolproof way of ensuring use of the correct cartridge or canister. The color code of the ANSI K13.1 standard has been included verbatim in the OSHA regulations, 29 CFR 1910.134(g).

c. Construction

The type of sorbent found in vapor and gas removing cartridges and canisters for use against a particular substance may vary from manufacturer to manufacturer. However, cartridge and canister construction varies little. The basic construction problems are the same: to provide enough sorbent bed depth and volume to ensure that 1) the contaminant is totally removed in the times specified in 30 CFR 11 bench tests, and 2) the sorbent remains mechanically stable in the container.

Figure 2-24 shows a typical chemical cartridge certified for use with a half-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 (Figure 2-25). The pads only keep the fine granules 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 Chapter 5, **Respirator Use Under Special Conditions.**

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 a tendency toward channeling where the irregular sorbent granules touch the smooth canister wall. Sometimes channeling is prevented by forming ridges in the canister shell like those in Figure 2-26. The retaining screens and pads hold the granular sorbent bed in place. The spring ensures that the sorbent remains tightly packed.

Photograph Courtesy of Glendale Protective Technology

FIGURE 2-24. **Typical half-mask chemical cartridge**

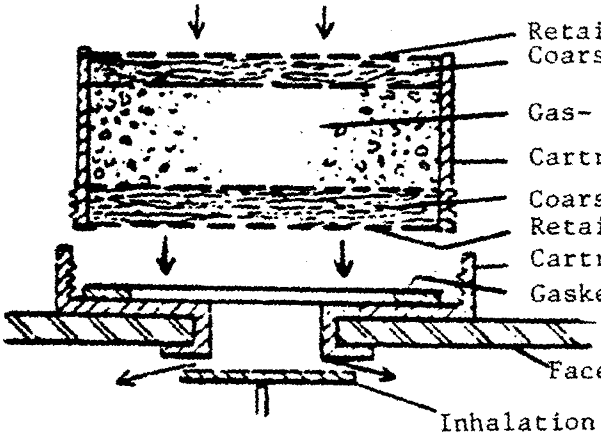


FIGURE 2-25. **Typical chemical cartridge**

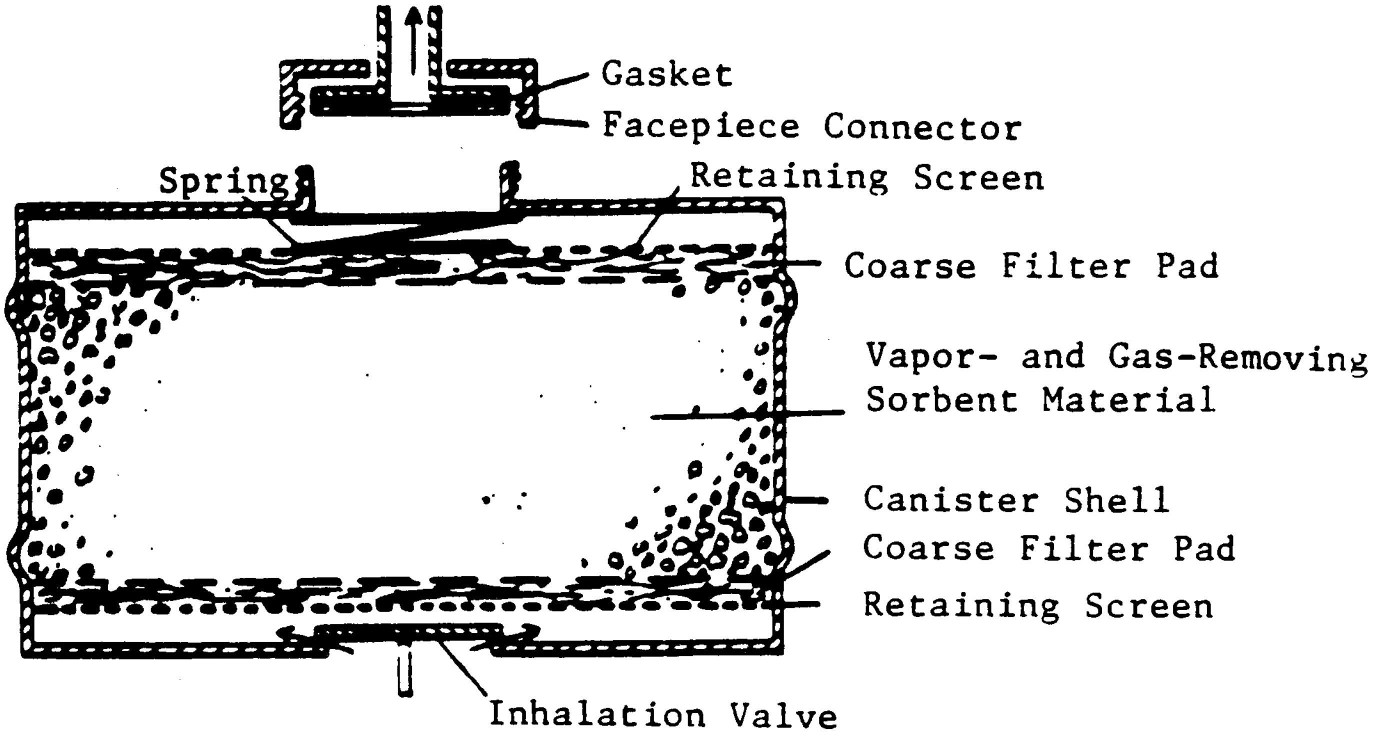


FIGURE 2-26. **Typical chin style canister**

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 with care.

3. *Vapor and Gas Respirator Classifications*

a. Chemical Cartridge Respirators

Figure 2-27 shows a typical chemical cartridge air-purifying respirator with an array of various cartridges that can be used with it. Chemical cartridge respirators can be either powered or non-powered, and either disposable or with replaceable cartridges or canisters. A listing of the vapors and gases and maximum concentrations for which chemical cartridge respirators are certified is included in 30 CFR 11.150. Note the accompanying restrictions on maximum use. These concentrations pertain to the cartridge and thus are the limiting concentration for the respirator regardless of whether a full or half facepiece is used.

In addition to the gases and vapors listed, 30 CFR 11.150 also allows MSHA/NIOSH to certify chemical cartridge respirators for gases and vapors other than those listed. Fox example, MSHA/NIOSH have certified respirators for use against:

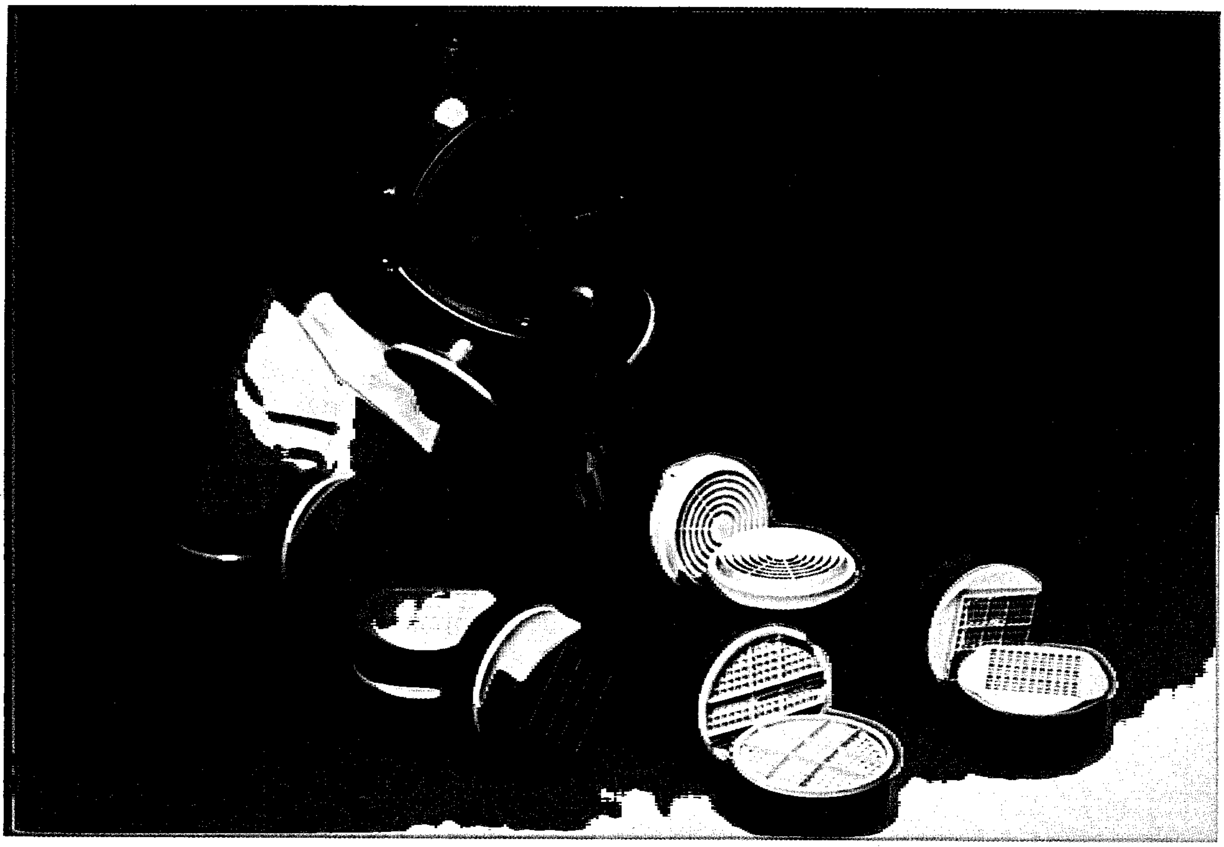
Gas/Vapor	*Maximum Use Concentration*
Mercury*	0.5 mg/m^3
Hydrogen sulfide*	100 parts per million
Chlorine dioxide	1 part per million
Formaldehyde	30 parts per million

*Respirators may be certified for gases and vapors with poor warning properties if there is a regulatory agency standard which permits their use and an effective end-of-service-life indicator is provided (Reference: FR 49 No. 140 pages 29270-29272, July 19, 1984).

b. Gas Masks

The following types of gas masks have been certified by MSHA/NIOSH:

Front- or back-mounted canisters
Chin-style canisters
Escape



Photograph Courtesy of SurvivAir

FIGURE 2-27. **Full-facepiece chemical cartridge respirator with alternate cartridges**

Front- or back-mounted. Front- or back-mounted canisters are usually certified for use with a full-facepiece. However, some half-mask or mouthpiece gas masks are certified. 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 Figure 2-28. Note that the construction does not differ markedly from that of the chemical cartridge shown in Figure 2-24. Other than the volume of sorbent contained (1000-2000 cm^3), the greatest difference is that the canister, rather than the facepiece, usually contains the inhalation valve. Figures 2-29 and 2-30 show typical front- and back-mounted canister gas masks.

Canisters can be designed for one or more type(s) of gas(es) or vapor(s). Several specific gases and vapors for which MSHA/NIOSH can issue certifications are listed in 30 CFR 11.90. In addition, MSHA/NIOSH have certified gas masks for gases and vapors not listed but which have adequate warning properties (e.g., hydrogen fluoride, formaldehyde and phosphine). MSHA/NIOSH have also certified gas masks for ethylene oxide. However, since ethylene oxide has poor warning properties, these canisters are required to have an end-of-service-life indicator.

Canisters designed for protection against more than one vapor or gas have their sorbents either arranged in layers or intermixed. Figure 2-31 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.

Chin-style. Chin-style gas masks typically have a medium-sized (250-500 cm^3) canister rigidly attached to a full-facepiece (Figure 2-32). 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. Gas masks can either be powered or non-powered. The maximum use concentration for both the front- or back-mounted and chin style gas masks is the immediately dangerous to life or health (IDLH) level of the substance.

Escape masks. Gas masks for use during escape from (not entry or reentry into) atmospheres immediately hazardous to life and health are certified under 30 CFR 11, Subpart I. They consist of a facepiece or mouthpiece, a canister, and associated connections. Where eye irritation is a consideration, a full-facepiece gas mask is necessary. An example of an escape gas mask is the "filter" self-rescuer for carbon monoxide used in escaping from mines (Figure 2-33).

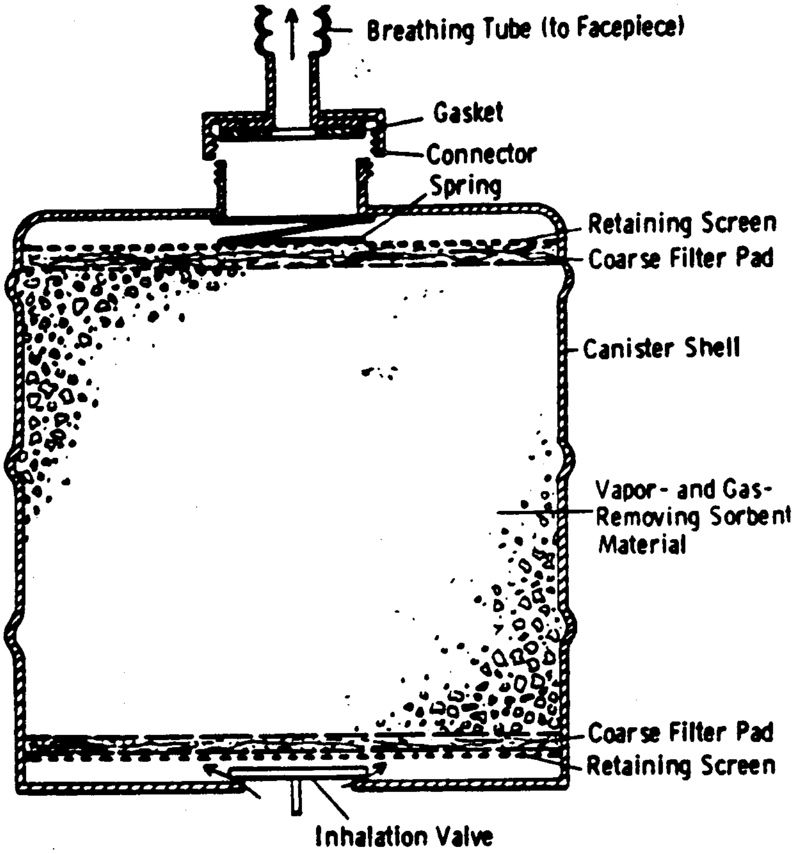


FIGURE 2-28. **Typical front- or back-mounted canister**

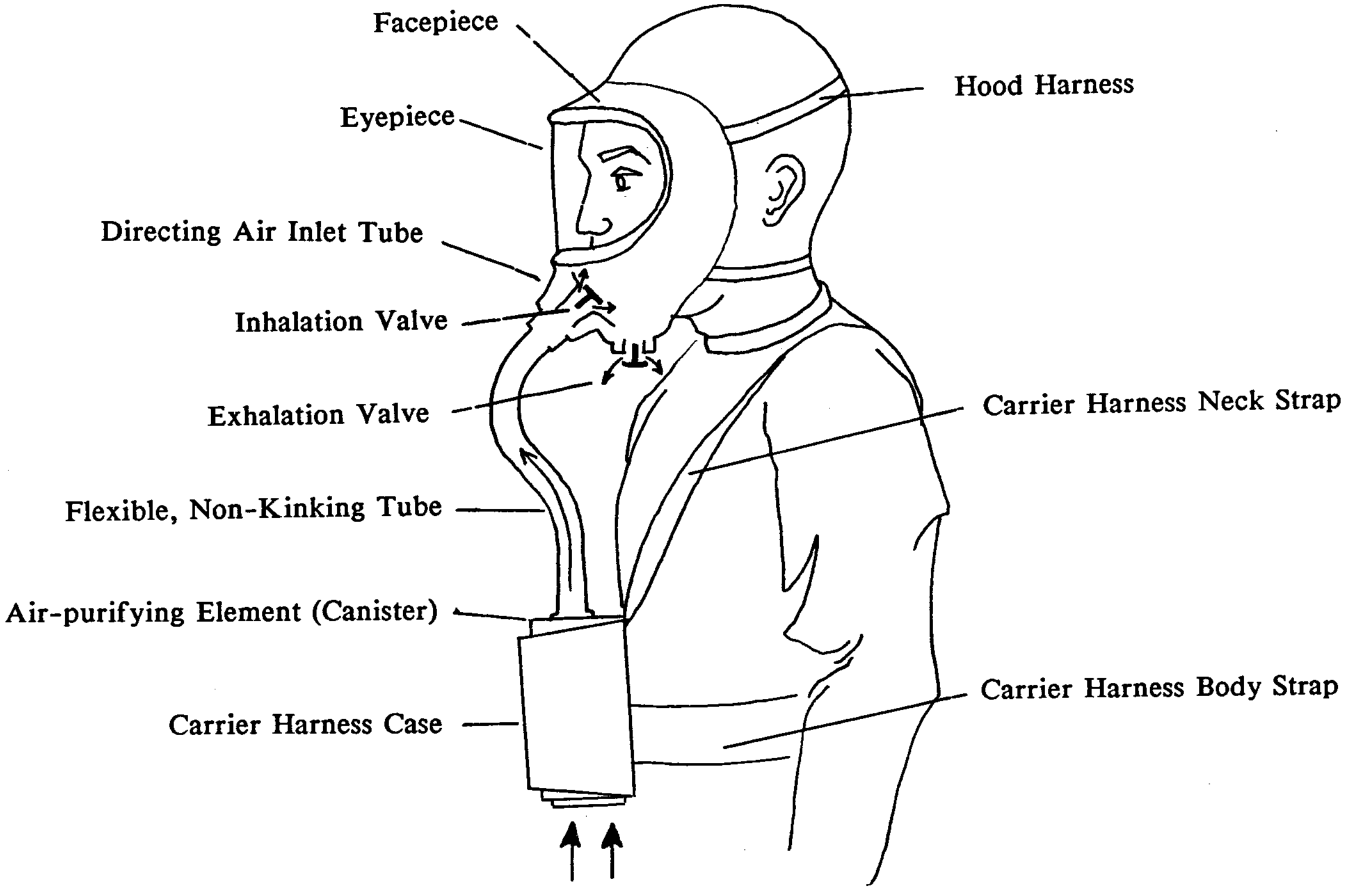


FIGURE 2-29. **Typical front- and back-mounted canister gas mask**

Photograph Courtesy of Mine Safety Appliances

FIGURE 2-30. **Typical back-mounted canister gas mask**

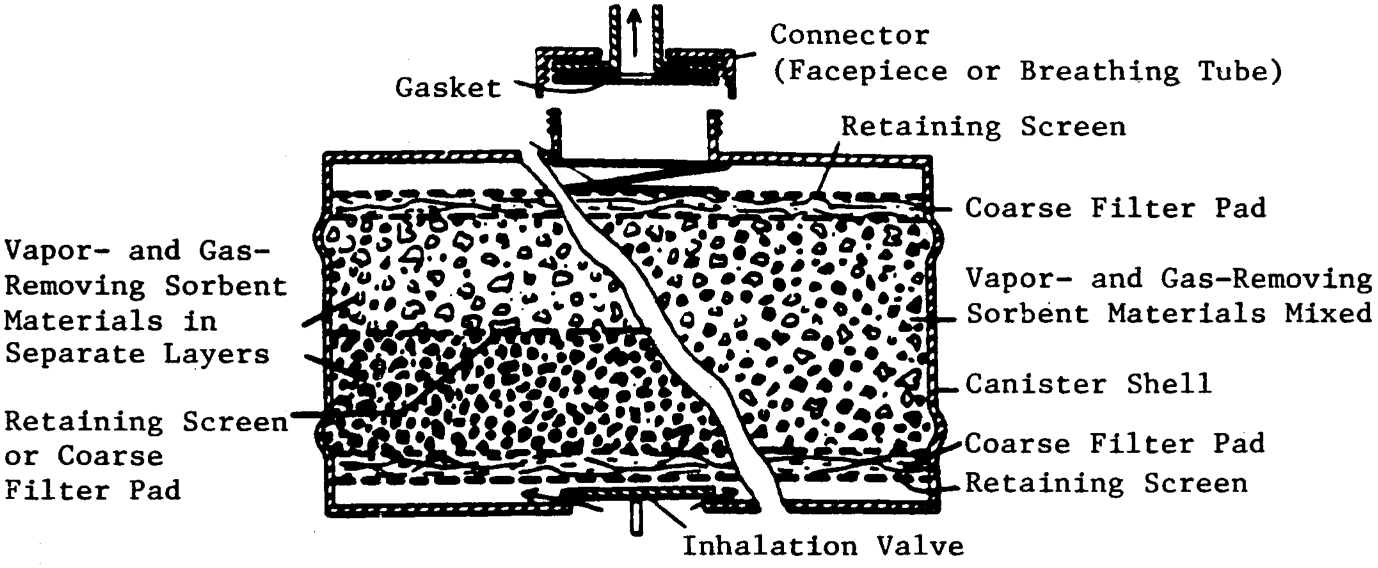


FIGURE 2-31. **Typical chin-style canister for more than one vapor**

Photograph Courtesy of Scott Aviation

Photograph Courtesy of Draeger

FIGURE 2-32. **Chin-style canister gas masks**

Photograph Courtesy of Draeger

FIGURE 2-33. **Filter self-rescuer**

c. Particulate Vapor and Gas Removing Air-Purifying Respirators

Cartridges and canisters are available to protect against both particulates and vapors and gases. These devices look much like the sorbent cartridge or sorbent canister alone. Figure 2-34 shows the two methods of attaching a particulate filter to a typical cartridge. In A, the particulate filter is inside the cartridge container, 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. Where filters are used in combination with cartridges, the filter must always be located on the inlet side of the cartridge. Pesticide and paint spray respirators use combination respirator cartridges, although paint spray respirators are certified under Subpart L of 30 CFR 11 (Chemical Cartridge Respirators), and pesticide respirators under Subpart M. Typical combination particulate, vapor, and gas removing respirators are shown, in Figure 2-35, being used in paint spraying.

High efficiency particulate filters are included on some types of combination canisters like the front-mounted canisters shown in Figure 2-30.

A very specialized type of combination particulate and vapor and gas removing canister is the so called "Type N," or "Universal" canister (Figure 2-36). 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 Type N canister may contain several different sorbents for ammonia, acid gases, and organic vapors; a catalyst, hopcalite, to convert carbon monoxide to carbon dioxide; layers of drying agent to protect the catalyst from water vapor; and a high efficiency filter for particulates.

All of these layers are packed into a space equivalent in size to the conventional canister; therefore, the sorptive capacity of any single layer of sorbent in the Type N canister is 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 relatively short.

All canisters approved for entry into carbon monoxide atmospheres must have an indicator, usually behind a small window, that shows when the canister will no longer remove the carbon monoxide. Actually, it indicates the condition of the drying agent upstream of the catalyst. The CO catalyst, hopcalite, is rendered useless by moisture, and this indicator tells only the condition of the hopcalite, not that of the acid gas, ammonia gas, or organic vapor sorbent. Therefore, it cannot be used as an indication of the overall canister condition.

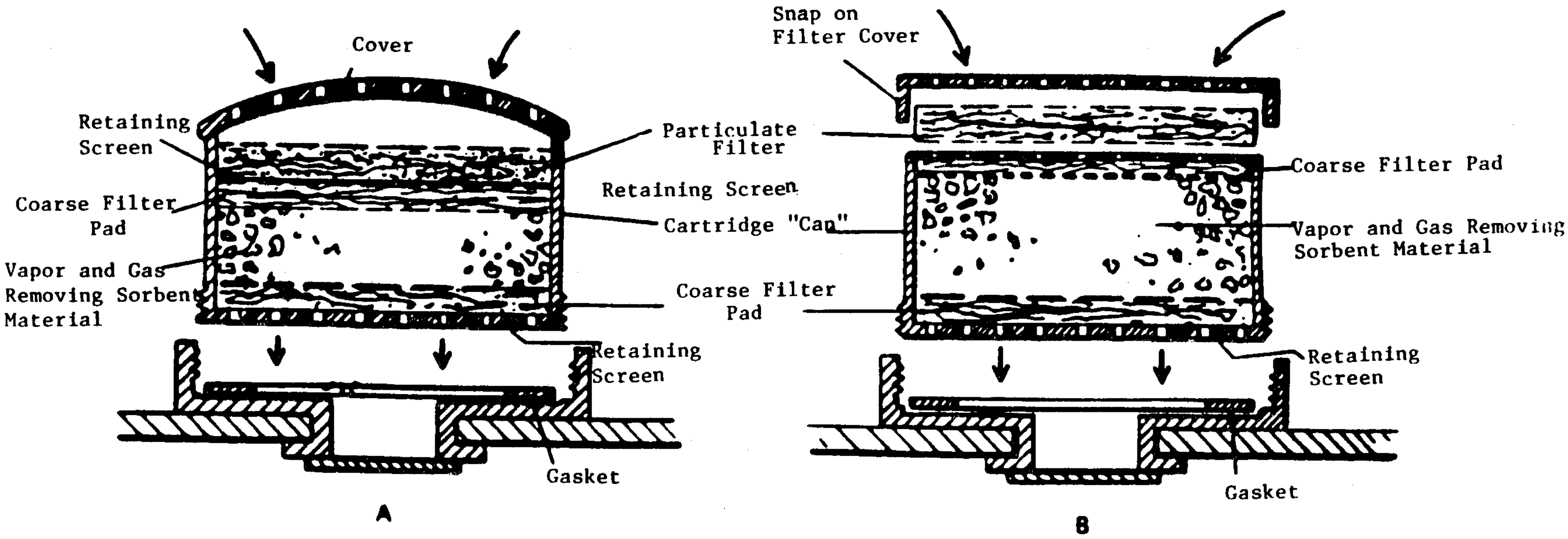
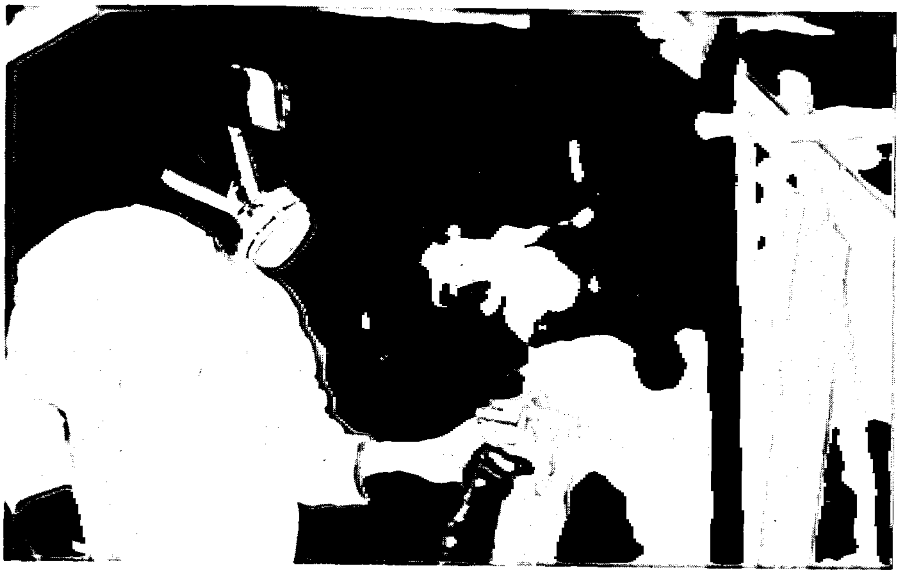


FIGURE 2-34. **Typical combination particulate- and gas- and vapor-removing cartridges**

Photograph Courtesy of SurvivAir



Photograph Courtesy of North

FIGURE 2-35. **Combination particulate-, gas- and vapor-removing respirator**

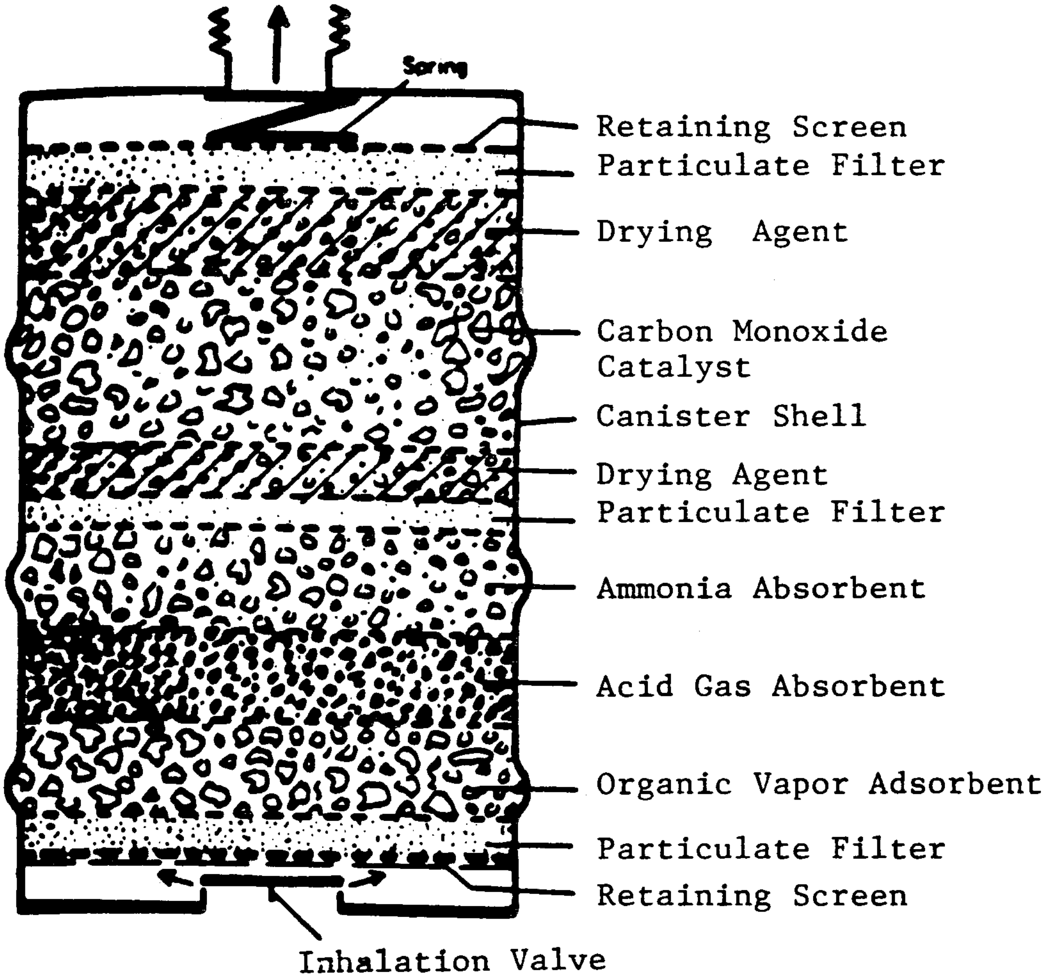


FIGURE 2-36. **Typical Type N canister**

Figure 2-37 shows a typical front-mounted Type N canister attached to a full-facepiece.

C. Powered Air-Purifying Respirators

The powered air-purifying respirator (PAPR) uses a blower to pass contaminated air through an element that removes the contaminants and supplies 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, canister or canister and filter. The covering may be a facepiece, helmet, or hood. These respirators are certified under 30 CFR 11, Subparts I, K, L, and M.

Powered air-purifying respirators come in several different configurations. One configuration consists of the air-purifying element(s) attached to a small blower which is worn on the belt and is connected to the respiratory inlet covering by a flexible tube as shown in Figure 2-38. This type of device is usually powered by a small battery (either mounted on the belt separately or as part of the blower), although some units are powered by an external DC or AC source.

Another type consists of the air-purifying element attached to a stationary blower, usually mounted on a vehicle, powered by a battery or an external power source and connected by a long flexible tube to the respiratory inlet covering.

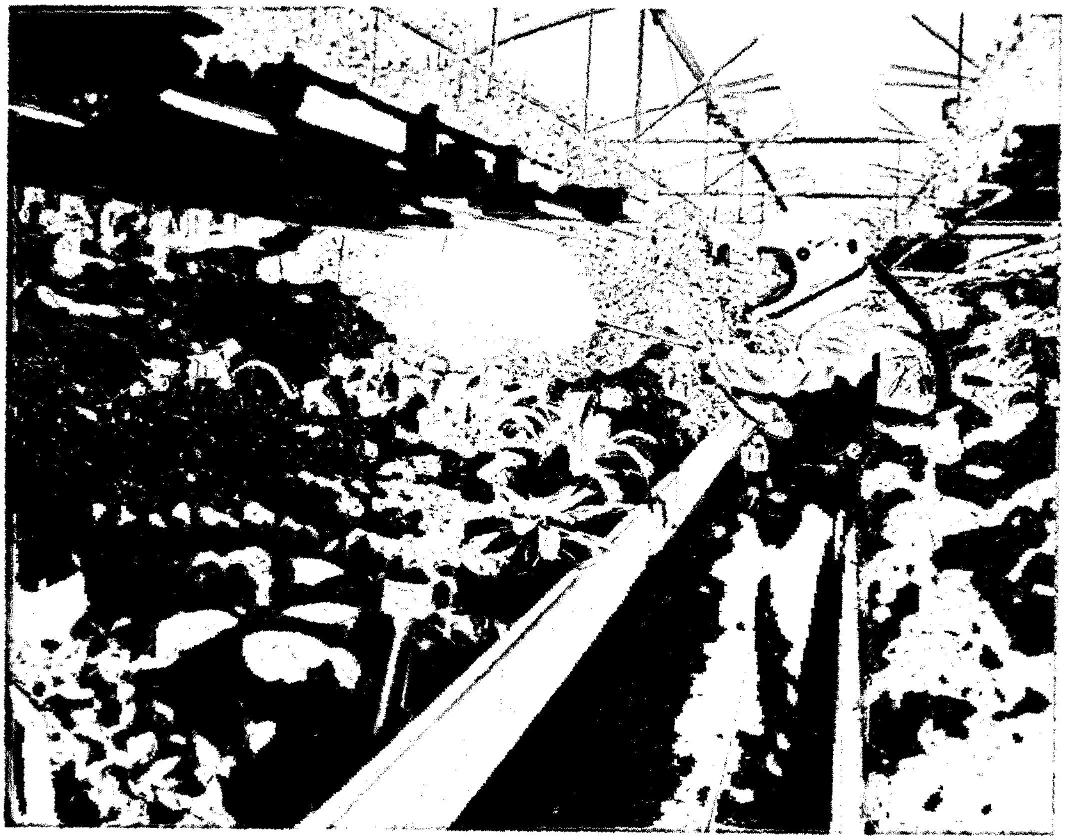
The third type of powered air-purifying respirator consists of a helmet or facepiece to which the air-purifying element and blower are attached. Only the battery is carried on the belt.

The respiratory inlet covering for a powered air-purifying respirator may be a tight fitting half-mask (Figure 2-39) or full-facepiece, or a loose fitting hood or helmet (Figure 2-40). A powered air-purifying respirator with a tight fitting facepiece must deliver at least four cubic feet of air per minute (115 liters per minute). A powered air-purifying respirator with a loose fitting hood or helmet must deliver at least six cubic feet of air (170 liters per minute) at all times.

One potential disadvantage of powered air-purifying respirators is that since there is a constant flow through the air-purifying element instead of flow only during inhalation; the useful service lifetimes of the air-purifying elements on powered air-purifying respirators could be shorter than the service lifetimes of comparable elements attached to a negative pressure respirator. In order to overcome this problem, some powered air-purifying respirators have a spring loaded exhalation valve assembly. This causes the blower assembly to slow down when the wearer exhales. This helps to extend the service lifetime of the air-purifying elements.

Photograph Couresy of Mine Safety Appliances

FIGURE 2-37. **Typical front-mount Type N canister gas mask**

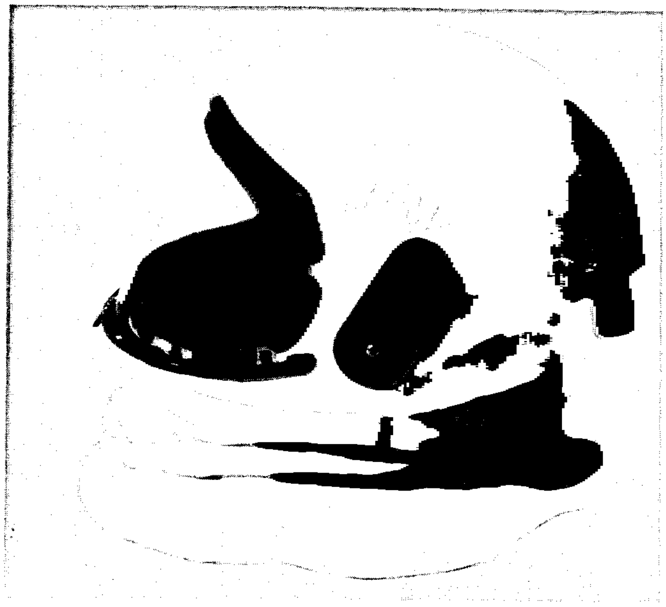


Photograph Courtesy of Kasco Inc.

FIGURE 2-38. **Powered air-purifying respirator with chemical cartridges and breathing tube**

Photograph Courtesy of Neoterik

FIGURE 2-39. **Tight fitting half-mask powered air-purifying respirator**



Photograph courtesy of 3M Company

Photograph Courtesy of Racal Airstream

FIGURE 2-40. **Helmeted powered air-purifying respirator**

Powered air-purifying respirators using chemical cartridges and canisters have the same limitations, insofar as the air-purifying elements are concerned, as the negative pressure respirators approved for the same gases or vapors.

In the past, powered air-purifying respirators were considered positive pressure respirators, since they normally supplied air at positive pressure. It was assumed that any leakage was outward from the facepiece. They were given correspondingly high protection factors. However, recent field studies by NIOSH and others have indicated that the level of protection provided by these respirators may not be as high as previously reported. Because of the potential for overbreathing at the minimum airflow rates, NIOSH now recommends much lower protection factors.

D. Advantages and Disadvantages of Air-Purifying Respirators

Air-purifying respirators are generally small and are easily maintained. (The exceptions to this are the combination Type C supplied-air and air-purifying respirator and powered air-purifying respirator.) They restrict the wearer's movements the least. The many combinations of facepieces, mouthpieces, filters, cartridges and canisters allow the user to match the respirator to the particular situation.

Air-purifying respirators should not be used in atmospheres containing less than 19.5 percent oxygen nor in atmospheres immediately dangerous to life or health (except escape gas masks). They should not be used for protection against gases or vapors with poor warning properties except for escape only or where permitted by a regulatory agency and the respirator is equipped with an end of service life indicator for that particular substance. The cost of replacement elements for air-purifying respirators can be high. Chemical cartridge respirators have fairly low maximum use concentrations, even when used with a full-facepiece.

1. Particulate Respirators

The advantages of particulate filter respirators include their light weight, small size and ease of maintenance. In general, these respirators will not affect the mobility of the worker and may present little physiological strain to the wearer. 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 has to be replaced frequently. Elements should be replaced at least daily or more often if breathing resistance becomes excessive or if the filter suffers physical damage (tears, holes, etc.). Filter elements designed to be cleaned and reused also should be cleaned at least daily in accordance with the manufacturer's instructions. Between uses, reusable respirators should be packaged to reduce exposure to conditions which cause filter degradation, such as high humidity.

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 or oil mists 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 and hence may exacerbate respirator faceseal leakage, significant plugging increases the materials' efficiency in removing particles from air.

2. *Vapor and Gas Removing Cartridges and Canisters*

Gas and vapor removing cartridges and canisters have the same advantages as particulate filter respirators. Certain cartridges and canisters have higher breathing resistance than particulate filter respirators and thus will present a slightly higher physiological burden to the wearer. If a vapor or gas lacks adequate warning properties (odor, taste, irritation) in a concentration above the established breathing time-weighted average concentration (TWA), a vapor and gas removing air-purifying respirator should not be used unless the respirator incorporates an adequate end of service life indicator .

Another disadvantage is the 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 facepiece. If the wearer detects an odor or taste of gas in the inspired air, or feels eye or throat irritation, he/she should leave the hazardous area immediately and go to a safe area that contains respirable air. Then the wearer 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. Discarding the cartridge/canister is recommended at the end of the day, even if the wearer does not detect odor, taste or irritation. This is due to the possibility of desorption of the gas or vapor occurring during overnight storage.

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.

In addition to odor thresholds, users can institute change-out schedules based on reliable service-life data. Users should be warned to replace cartridges whenever they detect the odor of the substance and at the end of the service time indicated by the change-out schedule.

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, unsealed cartridges and canisters should not be used. Also, remember that if the hazardous atmosphere is very moist or dry, the useful service time may be markedly reduced.

3. *Nonpowered Air-Purifying Respirators*

In addition to those limitations imposed by respiratory inlet coverings (see Chapter 2), 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 properly. This can best be accomplished by individual fittings and fit tests.

Other disadvantages of nonpowered air-purifying respirators include resistance to breathing and need for frequent replacement of air-purifying elements (except for disposable respirators).

4. Powered Air-Purifying Respirators

One advantage of powered air-purifying respirators is that they provide an airstream to the wearer. This airstream has the advantage of providing a cooling effect in warm temperatures, but can present a problem in cold temperatures. The decreased inhalation resistance makes the respirator possibly more comfortable to wear. Powered air-purifying respirators with loose fitting hoods or helmets have the advantage that since there are no large sealing surfaces on the face, some people who cannot wear a tight-fitting facepiece for such a reason as facial scars or facial hair can wear them.

Powered air-purifying respirators normally do not restrict mobility. In addition, these respirators offer minimal breathing resistance since the blower supplies the filtered air to the breathing zone of the wearer. Powered air-purifying respirators have limitations in addition to those imposed by respiratory inlet coverings, particulate filter elements and cartridges containing sorbents. A powered respirator's battery should 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 which will eventually wear out. Therefore, the blower will have to be replaced periodically. If the blower fails, the wearer of a powered respirator should go to the nearest safe area.

Other disadvantages include weight, bulk, complex design, the need for continual maintenance, at least daily replacement of air-purifying elements, and periodic replacement of batteries and blowers. Out-of-doors use presents special problems if hot or very cold air is supplied to the respiratory inlet covering.

Until recently, powered air-purifying respirators were considered positive pressure devices. Field studies by NIOSH as well as others, have indicated that these devices are not positive pressure, and that their assigned protection factors are inappropriately high.

III. Atmosphere-Supplying Respirators

Examples of respirators that provide breathing gas from a source independent of the surrounding atmosphere instead of purifying the atmosphere are shown in Figures 2-4 thru 2-6. The different types are classified according to the method by which the breathing gas is supplied and used and the method used to regulate the gas supply.