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Energy Research and Development Administration Division of Safety, Standards, and Compliance Respirator Manual

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ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION DIVISION OF SAFETY, STANDARDS, AND COMPLIANCE RESPIRATOR MANUAL

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1. INTRODUCTION

1.1 Purpose

This manual has been prepared to provide technical information for contractors of the Energy Research and Development Administration (ERDA) on the application of respiratory protective devices for protection against airborne contaminants, both radioactive and nonradioactive. The various elements of a respirator program including selection and maintenance of equipment and training of personnel are described to assist in establishing adequate programs.

1.2. Scope

Broad guidance is provided for the planned use of respirators as protection from hazardous airborne materials. The guidance is intended for use by management in establishing programs and by operating personnel in implementing programs.

Guidance is primarily directed to the use of respirators to prevent the inhalation of airborne contaminants. Protection against other modes of intake (e.g., absorption, swallowing, wound injection, etc.) is, in general, not covered; nor is the use of protective equipment for head, eye, or skin protection. When such additional modes of intake or concurrent hazards are present they must also be considered; and respiratory protective equipment must be compatible with the protection chosen against the combination of hazards encountered.

2. BASIC POLICY REGARDING USE OF RESPIRATORS

2.1. Use Conditions

The primary objective of respirator programs considered in this guide is to limit the inhalation of airborne contaminants. This objective is to be accomplished first by the application of engineering controls, such as process change, containment and ventilation; then administrative control, and finally, when such controls are not feasible or cannot be applied, the use of respiratory protective devices. In general, the use of respirators as a substitute for other methods of control entails both greater likelihood of accidental exposures and greater likelihood that such exposures may go undetected. It might also subject the wearer to additional stress and increase his risk of injury by interfering with his vision, freedom of motion, and ability to communicate. The provision and the use of respiratory protective devices are subject to the following considerations.

2.1.1. Routine Operations. Routine operations are planned activities that are generally repetitive and occur with various frequencies. For such operations, potential sources of airborne contaminants should be identified so that respiratory protection may be accomplished by the use of process change, containment and ventilation measures and by pre-planning of work. The use of respirators as a substitute for practicable engineering controls in routine operations is inappropriate. Respirators may be considered for use, however, while engineering controls are being instituted or evaluated.

2.1.2. Non-Routine Operations. Non-routine operations are activities that are either nonrepetitive or else occur so infrequently that adequate limitation of exposures by engineering controls is impractical.

2.1.3. Emergencies. Emergencies are unplanned events characterized by risks sufficient to require immediate action to avoid or mitigate an abrupt or rapidly deteriorating situation Plans for coping with potential emergencies shall include a program for providing necessary respiratory protection from the hazards. The advance preparations appropriate to a particular potential emergency will depend upon both its possible consequences and the probability of its occurrence.

2.1.4. Other Considerations. Most operations can be readily recognized as "routine," "nonroutine," or "emergency;" however, there are some activities that are difficult to assign to any one category. Those individuals responsible for establishing and maintaining respiratory protection programs must exercise sound judgement and utilize engineering controls in as many situations as possible to avoid possible temptation to make unwarranted use of respirators.

2.2. Work Periods

The periods of time for which respirators may be worn continuously, and the over-all time of use should be kept to a minimum. It is necessary to allow respirator users adequate relief from wearing respirators at reasonable intervals and to limit total time of use, however, it is difficult to assign specific time limits on respirator use as a general guide because of wide variations in job requirements and in the physical capacities and psychological attitudes of individuals. Such factors must be taken into account in establishing a respirator program. The supervisor shall be responsible to see that it is possible for the respirator user to be relieved in case of equipment malfunction, undue physical or psychological distress, procedural or communication failure, significant deterioration of operational conditions, or other significant conditions.

3. ELEMENTS OF AN ACCEPTABLE PROGRAM

Federal regulations currently in effect are listed in this chapter. Subsequent chapters will frequently list Federal requirements and they are generally differentiated from recommendations by the use of the words, "shall" and "must" instead of "should."

3.1. Regulations Pertaining to Respirator Use

3.1.1. General Respirator Program Regulations and Recommendations.

3.1.1.1. ERDA Manual Chapter 0550. This chapter contains references to certain consensus standards. The referenced recommendations included in these standards are considered to be part of the requirements.

3.1.1.2. American National Standards Institute (ANSI) Z88.2-1969, "Practices for Respiratory Protection." ANSI Z88.2 covers all major aspects of a minimum respirator program. Complete familiarity with the standard is essential to anyone supervising a respirator program.

3.1.2. Breathing Air Specifications.

3.1.2.1. ANSI Z48.1-1954, "Method of Marking Portable Compressed Gas Containers to Identify the Material Contained" is referenced in 29 CFR Part 1910, & 1910.134(d) which is concerned with air quality. It is required that compressed air cylinders for breathing be marked in accordance with Z48.1, or:

3.1.2.2. Federal Specification BB-A-1034a, June 21, 1968, "Air, Compressed for Breathing Purposes," or:

3.1.2.3. Interim Federal Specification GG-B-00675b, April 27, 1965, "Breathing Apparatus, Self-Contained." The applicable standard or specification shall be specified on any purchase orders or service contracts.

3.1.2.4. Compressed Gas Association Commodity Specification, G-7.1-1966, "Commodity Specification for Air" (also designated ANSI Z86.1-1973.), Breathing air in gas cylinders shall meet the requirement, as a minimum, of Grade E as given in G-7.1. (See Sec. 5.2.4.1.)

3.1.2.5. Department of Transporation, 49 CFR 178, "Shipping Container Specification Regulations." These regulations specify the testing and maintenance requirements for compressed breathing air cylinders.

3.2. Respirator Certification

3.2.1. Mine Enforcement Safety Administration, National Institute for Occupational Safety and Health (MESA)/NIOSH) Joint Respirator Approval. Title 30 CFR 11, "Respiratory Protective Devices; Tests for Permissibility; Fees", Volume 37, No. 59, March 23, 1972, replaced Parts 11, 12, 13, 14, and 14a, Sub-Chapter B, Chapter 1, Title 30, CFR (Bureau of Mines Schedules 13E, 14F, 19B, 21B, and 23B). The new 30 CFR 11, prescribes the approval procedures, establishes the fees, and consolidates and extends the requirements for obtaining joint approval of respirators by MESA/NIOSH.

Respirators purchased now must be approved by MESA/NIOSH according to the test procedures in the new 30 CFR 11. Bureau of Mines approved respirators purchased prior to 6/30/70 and approved under Schedule 13-13E, 19B, 21B, and 23B are approved for use

until 3/31/79, 3/31/80, 3/31/76, and 3/31/76, respectively. Note that respirators under Schedules 21B and 23B are no longer approved for use. Schedule 14F (gas masks) has no expiration date at this time. It is likely that major revisions will be made in 30 CFR 11 in the near future. Therefore, it is important that the contractor be continually aware of changes as they occur. This can be done by maintaining close communication with other contractors and MESA/NIOSH and by monitoring publications in the Federal Register.

While 30 CFR 11 is not directly applicable to a contractor's respirator program, it is necessary for him to conduct his program in such a way that the respirator approvals are not voided. A listing of current and newly approved respirators can be found in the the publication entitled "NIOSH Certified Protective Equipment." This listing is periodically updated through publication of Supplements. The approval of a respirator is automatically voided if:

1. The respirator is not the same in all respects as those respirators which have been approved by meeting the minimum requirements for performance and respiratory protection prescribed in 30 CFR 11.
2. The respirator is not maintained in an approved condition.

3.2.2. ERDA Acceptance of Non-Approved Devices. By special provision, equipment which is not eligible for certification by MESA/NIOSH (which is not eligible for approval) may be used by ERDA contractors. A contractor may apply to the Division of Safety Standards and Compliance (SSC) for authorization to use such equipment if it can be demonstrated, by testing or on the basis of reliable test information, that the equipment is capable of providing an acceptable degree of protection under proposed conditions of use.

After submission of an application, the device will be tested by LASL under an agreement with SSC. The LASL test data will be submitted to the LASL Respirator Advisory Committee for review. Upon consideration of this data, a recommendation is made and report issued to SSC who may in turn accept the device for use.

3.3. Minimum Acceptable Program Requirements Summary

The following are minimum general requirements for any respirator program. Details are given in subsequent chapters of this Manual and in the regulations previously cited.

1. Written standard operating procedures and a policy statement. (See Chapters 12. and 3.4.)
2. Proper selection of equipment, based on the hazard. (See Chapter 6.)
3. Proper training and instruction of users. (See Chapter 7.)
4. Proper fitting, use, cleaning, storage, inspection, quality assurance, and maintenance of equipment. (See Chapter 8.)
5. Appropriate surveillance of work area conditions and degree of employee exposure to stress. (See Chapter 2.2 and 4.2.)
6. Regular inspection and evaluation to determine the continued program effectiveness. (See Chapter 12.3.)
7. Program responsibility shall be vested in one qualified individual. (See Chapter 1.1.1.)
8. An adequate medical surveillance program for respirator users. (See Chapter 6.2.3.)
9. Use of only MESA/NIOSH certified or ERDA authorized equipment. (See Chapter 3.2.1. and 3.2.2.)
10. Maintenance of a bioassay program, conducted by an accredited laboratory. (See Chapter 10.)

3.4. Policy Statement

No respiratory protection program is considered adequate without a written policy statement on respirator usage, issued from a high management level so that its provisions may be adequately enforced. Items in Sec. 2 shall be covered in the statement. Strong management backing is essential for an adequate respiratory protection program.

4. EVALUATION OF HAZARDS

In general, the degree of protection against specific respiratory hazards will vary with the design of the respirator. Some respirators will provide a higher degree of protection than others. Some designs will protect only against a single hazard or a limited number of hazards; others will provide protection against a broad class of hazards. Thus, proper selection of respirators requires adequate identification of all respiratory hazards present.

4.1. Classification of Hazards

Respiratory hazards may be classified as follows:
a. Oxygen deficiency.
b. Air contaminants.
1. Gaseous Contaminants (gases and vapors).
2. Particulate Contaminants (dusts, fogs, fumes, mists, smoke, and sprays).
(Combinations of these hazards are, of course, possible.)

4.1.1. Oxygen Deficiency. Normal air contains about 21% oxygen (O_2) by volume. An atmosphere with oxygen content less than about 16% by volume (at sea level) is insufficient for human needs. At decreased atmospheric pressures or increased altitudes, greater percentages of O_2 are required for human needs. For example, at an altitude of 7000 feet, a minimum of 18% O_2 content is required.

Sufficient oxygen or breathing quality air must be supplied to avoid the adverse physiological effects of oxygen deficiency. Oxygen deficiency may result from depletion of oxygen by combustion, chemical reaction or absorption, from displacement of air by other gases or vapors, or from use of inert atmospheres. It may also result from the failure of breathing air or oxygen supplies, or from rebreathing air in a confined space. Particular care must be taken to avoid using air-purifying respirators (e.g. filter types) in oxygen deficient atmospheres.

Table 4-1 gives the symptoms of O_2 deficiency as a function of oxygen content and altitude.

4.1.2. Air Contaminants. Air contaminants may consist of radioactive contaminants, nonradioactive contaminants, or both. Criteria for protection against radioactive hazards and those for nonradioactive hazards differ in several ways.

1. They are based on different dose-effect relationships.
2. They involve different types or degrees of risk.
3. They are expressed in different and unrelated units.

Criteria for protection against nonradioactive hazards in industrial atmospheres are generally based on a threshold concept which postulates that, while all substances may be toxic or irritant at sufficiently high concentrations, there is some limiting "threshold"

TABLE 4-1

SYMPTOMS OF OXYGEN DEFICIENCY vs OXYGEN CONTENT AND ALTITUDE

Ambient Atmospheric Pressure (mm H_2O)[a]	760 [b] Sea Level oxygen (Vol. %)	635 [c] 5000 ft oxygen (Vol. %)	585 [c,d] 7300 ft oxygen (Vol. %)	202 O_2 Partial pressure (mm H_2O)
Breathing and Pulse Rate Increased	12-16	15-19.5	16-21	94-123
Abnormal Fatigue upon exertion, disturbed respiration, consciousness continues	10-14	12.5-17.5	13.5-18.5	79-108
Nausea and vomiting inability to move freely, loss of consciousness may occur	6-10	7.5-12.5	8-13.5	47-78
Convulsive movements, gasping respiration, respiration stops, death	Below 6	Below 7.5	Below 8	Below 47

[a] Based on ICAO Standard Atmosphere

$$P = Poe \cdot \left(\frac{z-zo}{h}\right) ,$$

P = barometric pressure (mm H_2O) at altitude z (km) .

z = altitude (km) ,

z_0 = sea level = o ,

P_o = sea level barometric pressure = 760 mm H_2O ,

h = standard ICAO column = 8.434 km .

[b] From "Industrial Hygiene and Toxicology", F. A. Patty.

[c] Calculated. Based on data from "Physiology of Man in Space," Edited by J. H. U. Brown.

[d] Does not take into account acclimatization which takes 4 to 6 weeks.

concentration (the "threshold limit value" or "TLV") below which an individual may be exposed repeatedly without any resultant injury.[1] In contrast to criteria for protection against hazards where the emphasis is on a threshold limit, criteria for radiation protection take into consideration a "no-threshold" concept, i.e., it is assumed that every increment of radiation dose, however small, will contribute to risk. Concentration limits for airborne radioactive materials are designed to keep accumulative radiation doses sufficiently low so as to prevent immediate effects and to make the risk of delayed effects so small as to be acceptable to the exposed individual and to competent medical authorities.[2,3,4] "Acceptable" is used in the sense that the risks involved will be no greater than those commonly accepted in ordinary activities. This concept has been more fully examined by the National Council on Radiation Protection and Measurements and others.[5]

Generally, the manner in which concentration limits for radioactive and nonradioactive contaminants in air are determined results in levels of risk which differ greatly when individuals are exposed to concentrations substantially in excess of the limits. Concentration limits for nonradioactive materials may not be more than an order of magnitude below those levels of exposure that produce adverse effects (ranging widely from discomfort to death). On the other hand, concentration limits for radioactive hazards relate to

levels of exposure that are far below those at which any observable effect would be expected. Thus, exposure for an hour to airborne radioactive materials at levels two or three orders of magnitude above the maximum permissible concentration would not be expected to result in any acute effects; whereas, similar exposure in excess of the threshold limit value, for many nonradioactive contaminants, may result in severe injury. These examples are used to compare the differences in risk represented by the different types of limits; they do not imply that exposure to either hazard is acceptable. Even though acute effects would not be expected from exposures to the radioactive concentrations discussed, the actual exposures must be kept as low as practicable.[6]

4.1.2.1. Limits of Airborne Concentrations and Their Related Units.

4.1.2.1.1. Threshold Limit Values (TLVs) are limits on the concentration of a number of airborne contaminants and physical agents. TLVs are developed by the Threshold Limits Committee of the American Conference of Governmental Industrial Hygienists (ACGIH), and are published[7] with yearly revisions by the ACGIH, listing limits for gases, vapors, and aerosols. Concentrations may be expressed in parts per million (ppm) by volume of the substance in air (ppm at 25°C and 760 mm Hg); as milligrams per cubic meter of air (mg/m^3); or as particles per cubic centimeter or cubic foot depending on the form of the airborne contaminant. The TLVs are published along with precautionary notes and explanations which are essential to their proper use.

Before 1963, all TLVs were defined as time-weighted average concentration limits; i.e., the concentrations might vary above and below the TLV over a working day so long as the average value did not exceed the TLV. It was implied but not defined that extreme exposure above the TLV was to be avoided. In 1963, the ACGIH changed certain of the TLVs to upper "ceiling" limits, i.e., an absolute limit below which concentrations might fluctuate so long as the "ceiling" itself was not exceeded and provided guidance to control extreme exposures. Guidance is also given concerning the extreme upper limit of exposure that can be tolerated for materials without ceiling values. This guidance is useful for short-term exposure to high concentrations which when compared with the 8-h work day produce acceptable time-weighted average (TWA) exposures, but unacceptable short-term peak exposures. Now some TLVs are given in terms of time-weighted average value and others (listed with a "C" before them in the ACGIH tables) are ceiling limits. As shown in Table 4-2, TLVs are given "C" rating if exposure in excess of the TLV for 15 min would result in certain immediate adverse effects such as intolerable irritation, chronic or irreversible tissue change, narcosis sufficient to impair self rescue, or increase accident-proneness, or materially reduced work efficiency. If the "test factor" times the TLV would produce these effects in 15 min, the TLV is given a ceiling rating. This same table is also used to determine acceptable upper excursion limits when determining time-weighted average values for substances not assigned "C" ratings.

TABLE 4-2[a]

CEILING LIMIT TEST CRITERIA

TLV Range (ppm, or mg/m^3)	TLV Test Factor
0 - 1	3
>1 - 10	2
>10 - 100	1.5
>100 - 1000	1.25

[a]From Stokinger, Amer. Ind. Hyg. Assoc. J., Ref. 1.

4.1.2.1.2. Maximum Acceptable Concentrations (MACs). MACs are ceiling limits on airborne concentrations of a number of chemical and physical agents. They are developed by the American National Standard Institute (ANSI).

The chief distinction between the TLV and the MAC is that the MAC is always a ceiling limit* below which concentrations may fluctuate while the TLV may be either a ceiling value or an averaged value. MACs and TLVs are expressed in the same units; and the types of risk to which they relate are almost always toxic or irritant effects. Even for TLVs which are not "C" listings, exposure to concentrations somewhat in excess of the TLV for a working day might result in immediately observed effects. Since the TLVs and the MACs relate to such a wide range of effects (from discomfort to death) they do not represent uniform degrees of risk. For example, if the TLV for hydrogen cyanide, 10 ppm, is exceeded by a factor of 10 for a short time, death may occur, however, a carbon monoxide exposure of 500 ppm, ten times the TLV may cause only mild physiological change for the same short time period.

4.1.2.1.3. Maximum Permissible Concentrations (MPCs). MPCs for occupational exposure are recommended upper limits on concentrations of radionuclides to which workers may be exposed. They are issued by groups such as the International Commission on Radiological Protection [2] and the National Council on Radiation Protection and Measurements.[8] Such recommendations may be used as the basis for limits in the regulations of agencies such as the Energy Research and Development Administration and the Nuclear Regulatory Commission. MPCs are established for air and water, respectively designated as MPC_a or MPC_w. In this guide the term "MPC" is used to designate MPC_a for simplicity. MPCs are generally expressed in microcuries per milliliter or μCi/ml). They are generally used as averaged values, although they may sometimes be used as "ceiling," "peak," or "instantaneous" values.

It is intended that control to the level of the MPC will limit annual radiation doses to maximum permissible levels, even after exposure to airborne radioactive materials throughout a working lifetime. Such exposures would not be expected to result in any appreciable risk to the exposed individual. Further discussion of TLVs and MPCs may be found in Ref. 1.

One note of caution to be observed in using MPCs and TLVs is that they are intended for use by people experienced in the field who are fully aware of the range of use, developmental background, technical implications and limitations inherent in the concepts.

4.1.2.2. Relation of MPC to Mode of Exposure. In most cases the airborne MPCs are based on internal dose from the amount of a radionuclide retained in the body (or critical organ) following inhalation, however, airborne concentration limits for large clouds of noble gases or other relatively inert gases are based on the external dose that an individual would receive if he were surrounded by a semi-spherical infinite cloud of radioactive gas. Under these circumstances, the dose to the whole body or to the skin from the radioactive cloud would be higher than that from gas within the lungs or other body organs. The radioactive gases of major significance that have MPCs based on submersion dose to the whole body are argon-41, the kryptons and the xenons. Lower energy particle emitters such as argon-37 and hydrogen-3 (as tritium gas) have MPCs based on submersion dose to the skin.

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*ANSI has been considering other limits which are not ceiling values. These include concepts such as "acceptable maximum for 'peaks' above acceptable base line for continuous exposure," "acceptable concentration to avoid discomfort" and "minimum level for sensory response."

Tritium in the oxide form as HTO vapor (less commonly as DTO vapor) in air presents an additional problem since approximately as much tritium enters the body by absorption through the skin as enters by inhalation. The airborne concentration limits for tritium oxide vapor are therefore based on this dual mode of entry into the body.

4.2. Air Sampling Program

A comprehensive air sampling program is essential to evaluate the hazards associated with work situations involving potentially toxic materials. In many instances, air sampling data can also provide the basis for development and evaluation of control procedures and can indicate whether or not operational changes are necessary to provide adequate protection for the worker. In conjunction with a respiratory protection program, air sampling data are necessary to define the air contaminant concentration levels so that the proper respiratory protective equipment can be selected. Since respirator protection factors vary over several orders of magnitude, it is imperative that an initial estimate be made of the air contaminant concentration levels relative to appropriate limits. Thus, adequate protection can be provided while minimizing necessary inconvenience to the worker wearing a respirator. Air sampling programs may also be designed to estimate the release of contaminants to the general work area, and to the outside environment.

Specific goals of an air sampling program directly related to respiratory protection include:

1. Providing an estimate of the potential intake of airborne contaminants and resulting exposure of the individual worker.
2. Providing criteria for the selection of respiratory protective equipment which will provide adequate protection under exposure conditions.
3. Preventing excessive long-term exposure to the worker.
4. Providing documentation of personnel exposures for legal or regulatory purposes.

A general air sampling program would also include the following goals.

1. Identify and characterize the contaminants and their sources.
2. Determine the requirements for engineering or administrative controls.
3. Indicate the continuing effectiveness of existing controls, and warn of the deterioration of control equipment or operating procedures.
4. Follow long-term trends showing variations in contaminant levels.
5. Continuously measure the level of airborne contaminants in and about work areas and warn of the release of airborne contaminants to the outside environment.

4.2.1. Consideration in Air Sampling. A variety of factors must be considered in designing an air sampling program so that the data obtained are directly related to the problem of concern. As part of a respiratory protection program, air sampling procedures should take into account (a) the physical and chemical state of the contaminant, (b) aerodynamic size characteristics of airborne particulates; (c) range of contaminant concentration; (d) environmental conditions such as temperature; (e) sampler location relative to the worker and the source of contamination; (f) instrument operating and response characteristics; (g) instrument portability; (h) sensitivity of the associated analytical procedures relative to the specified concentration limits and quantity of material sampled; (i) implications of short term exposures, and (j) chemical reactiveness of the contaminants with sampling system materials.

For airborne particulates, it is important to consider particle solubility, chemical composition, and aerodynamic size since these determine final deposition sites within the body. These factors have been emphasized by the 1959 report of Committee II of the

International Commission on Radiation Protection[2] (ICRP) and are re-emphasized by the 1966 report of ICRP Task Group on Lung Dynamics.[32] Concentration limits for radioactive particulates in the 1959 ICRP report are based on assumptions about lung deposition which are set out in Table 4-3. For aerosols whose deposition characteristics upon inhalation, are known to be different from those in the Table, particularly if the deposited fraction retained in the lung is greater than that assumed by ICRP, account must be taken of the increased retention under these circumstances in limiting individuals' intake of airborne contaminants. Please refer to report of Task Force on Lung Dynamics[32] for further information on this subject.

4.2.2. Sampler Location. During the past few years, several investigators have called attention to the need for obtaining air samples in the breathing zone of the worker to provide an adequate estimate of potential exposures. Under some work situations, properly located fixed air samplers may be used to approximate exposure to the individual worker, however, in light of the variation in air concentration as a function of time and sampler location, this procedure can only be considered an estimate of actual exposure. Breathing zone samples can be obtained by providing the worker with a small battery-operated sampler using a pump and battery mounted on the workers belt. with the sampler attached close to the worker's breathing zone. This technique provides the best estimate of individual worker exposure but does introduce an additional problem since the low sampling flow rate may cause some problems relative to analytical sensitivity. Several investigators have shown that these personal samplers detect contaminant concentrations considerably better than those measured by well-located fixed area samplers. Potential errors of 2 to 30 fold have been measured between personal and fixed air samplers, with the fixed samplers tending to read lower. These errors may be even greater when the contaminant is released from a point source. Fixed air samplers will indicate general area contamination levels, or changes in these levels, provided that careful attention is directed at their location relative to the contaminant sources in the working area.

4.2.3. Sampling Procedures. Considerable information is available regarding air sampling procedures, theory, equipment characteristics and limitations, measurement techniques, and data interpretation. In general, high efficiency filter media such as glass

TABLE 4-3

PARTICULATES IN RESPIRATORY TRACT OF THE STANDARD MAN

Retention of particulate matter in the lungs depends on many factors, such as the size, shape and density of the particles, the chemical form and whether or not the person is a mouth breather; however, when specific data are lacking it is assumed the distribution is as shown below.

Distribution	Readily soluble compounds (%)	Other compounds (%)
Exhaled	25	25
Deposited in upper respiratory passages and subsequently swallowed	50	50
Deposited in the lungs (lower respiratory passages)	25 (this is taken up into the body)	25[a]

[a] Of this, half is eliminated from the lungs and swallowed in the first 24 hours, making a total of 62½ percent swallowed. The remaining 12½ percent is retained in the lungs with a half-life of 120 days, it being assumed that this portion is taken up into body fluids.

and cellulose membrane are used to provide an estimate of gross particulate concentrations. Attention should be directed to the limitations inherent in this type of sample relative to the previously described concept of lung deposition as a function of particle size. Samples to estimate respirable fractions can be obtained using pre-samplers which have been calibrated to separate respirable and nonrespirable particles. Detailed particle size information can be provided by using impactor samplers. Particle size information can then be used to relate to the more recent lung deposition model proposed by a task group of the ICRP in 1966.

Samples for gases can be obtained using charcoal or other solid sorbents, followed by radiometric counting or desorption with the appropriate analytical chemistry techniques for analysis. Any sorbent used must be carefully evaluated since the sorption-resorption efficiencies may vary depending on the sorbent batch and the gas to be absorbed. Direct read-out instruments have been developed for some contaminants of concern (carbon monoxide, ozone, nitrogen oxides, etc.) but frequently the instrument is nonspecific, and will respond to other materials present.

For some work situations, measurement of the oxygen concentration is of major importance. Portable direct-reading instruments are available to indicate an abnormal oxygen concentration. Monitoring of this situation is critical since air-purifying respirators will provide no protection against oxygen deficiency and the adverse effects of a lack of oxygen are very rapid and, of course, extremely dangerous.

When possible, use of rapid response instruments is desirable in work situations which may result in a highly variable level of contamination, and where short duration exposures constitute a significant risk. In all cases, the efficiency of the air sampling and associated analytical procedures must be evaluated. High efficiency filter media are extremely reliable for the measurement of airborne particulate concentrations. As mentioned, the efficiency of sorbents, such as activated charcoal, may vary depending on the charcoal, the chemical state of the contaminant, and environmental conditions.

Air sampling data should be related to actual exposures by other techniques, including bioassay programs, and correlation of general air and breathing zone samplers. When interpreting sampling results, it is imperative that consideration be given to the variations inherent in air sampling data due to changes in airborne contaminant concentration as a function of sampler location.

Instrumentation techniques and other specifics related to air sampling and data interpretation constitutes a separate discussion and are not detailed in this guide.

5. CLASSIFICATION, DESCRIPTION, AND LIMITATIONS OF RESPIRATORS

The degree of protection afforded by a properly-fitted and worn respirator against airborne contaminants depends chiefly on its design and mode of operation.

It should be kept in mind that there are limitations as well as advantages in the use of each of the various types of equipment. The advantages and limitations are summarized in ANSI Z88.2-1969.[9]

5.1. Facepieces, Hoods, and Suits

Most respirators have an enclosure such as a facepiece, hood or suit to ensure that the atmosphere furnished by the respirator is conducted to the nostrils and mouth of the user and that the irrespirable atmosphere is excluded. These enclosures are sometimes referred to as "respiratory inlet coverings." There are some respirators which utilize a clip to close off the nostrils along with a mouthpiece or bit, through which the wearer

breathes, connected to a cartridge, canister, or bottled air supply. These devices are intended to be worn only in emergency-escape situations. All other respirators considered here are designed to be used with one or more of the enclosures described below.

5.1.1. Facepiece. A facepiece is a tight-fitting enclosure over all or a portion of the face. Three types of facepieces with replaceable filters or cartridges are commonly used: the quarter-mask, half-mask, and the full face mask. These facepieces can be obtained equipped as air-purifying devices (see Sec. 5.2.1) and as atmosphere-supplying respirators (see Sec. 5.2.4). Half and quarter-mask facepieces are available with non replaceable filters and are designated single-use respirators, which makes up a fourth class of facepiece.

The *quarter-mask* is similar in appearance to the half-mask, but the lower portion of the mask fits between the chin and the lower lip instead of under the chin as with the half-mask. It is not acceptable for protection against radioactive particulates due to its generally inferior sealing qualities, however, it is acceptable for protection against less hazardous particulates. While some quarter-masks can be equipped with high efficiency filters, their use is not recommended where the toxicity of the contaminant demands this degree of protection, e.g. radioactive particulates and other contaminants with a TLV ≤ 0.05 mg/m^3.

The *half-mask* fitting *under* the chin and enclosing the wearer's nose and mouth (Fig. 5-1) is the only nonfull-face respirator type acceptable for protection against radioactive particulates. This facepiece is supported by two headbands with an adjustable four-point suspension. (Note: Two-point suspension is not acceptable because it does not provide a stable and reliable method of maintaining an adequate seal against the face.) Woven elastic headbands are generally more desirable for half-masks than rubber because of ease in adjustment.

The *full-face mask* completely encloses the wearer's eyes, nose, mouth, and chin (Fig. 5-2). This facepiece is supported by a head harness.

Full facepieces are constructed of rubber or flexible plastic, and have one or two transparent lenses for viewing. They have a head harness which is attached to the facepiece at five or six points, or have an adjustable semi-rigid "welder's type" suspension attached at the temples at two points.

The *single-use* respirators are exclusively of the air-purifying type, consisting of a facepiece fitting either on or under the chin and equipped with a nonreplaceable particulate filter or chemical sorbent. These respirators are designed for protection against the less toxic dusts such as silica or very low gas and vapor concentration, and are meant to be discarded after use. They shall not be used against highly toxic or radioactive particulates, gases and vapors.

In the air-purifying facepieces, again excepting the single-use types, the airflow is inward through the cartridge or canister and through an inhalation valve which prevents a back flow of air through the cartridge during exhalation. An exhalation valve allows release of the exhaled breath to the atmosphere and prevents a flow of contaminated ambient air into the facepiece during inhalation. Additionally, there is usually an exhalation valve cover which traps a small amount of clean exhaled air. This serves as a reservoir of clean air which is drawn into the facepiece as the exhalation valve closes at the very beginning of the inhalation cycle. Atmosphere supplying devices generally have only an exhalation valve.

5.1.2. Hoods and Helmets. A hood is a loose-fitting enclosure over the head, neck, and all of the shoulders, gathered around the neck or below the shoulders to insure a snug fit (Fig. 5-3). The hood is generally constructed of light nonrigid plastic or coated or impregnated fabric with a large transparent viewing window.

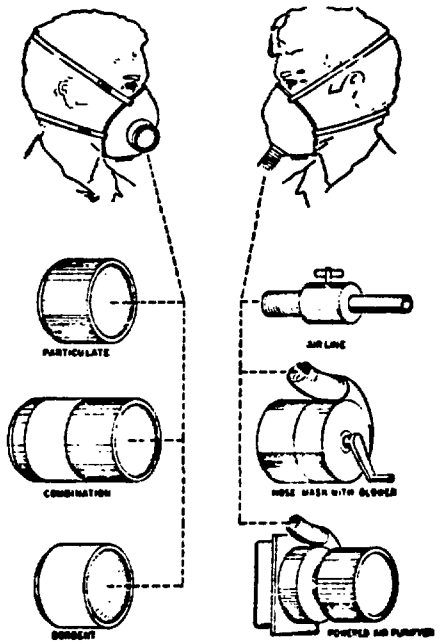

Fig. 5-1.
Half mask.

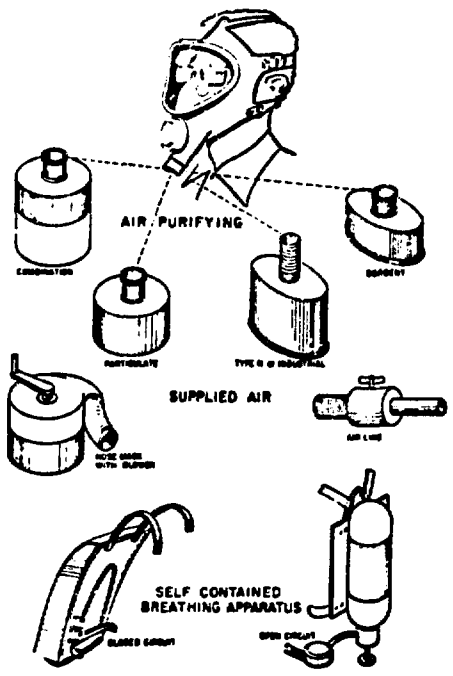

Fig. 5-2.
Full facepiece.

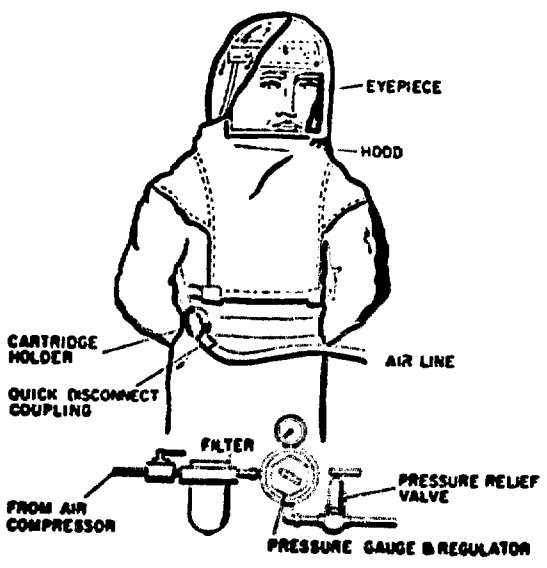

Fig. 5-3.
Supplied air hood.

A helmet is a similar device of more rigid construction providing some impact protection to the eyes, face, and other parts of the head. Not all helmets are approved as hard hats.

Air to the hood or helmet is introduced into the head enclosure. The air flows past the breathing zone and escapes around the hood or helmet. The continuous flow of air alleviates the need for an exhalation valve.

The hood or helmet acts as a positive pressure chamber which is continuously purged with respirable air at low velocity. There must be enough airflow to prevent a "bellows effect" from the wearer's movements, aspirating contaminants into the hood. With some hoods or helmets, this effect may be lessened by placing the cape attached to the hood or helmet below the shoulders under an outer garment.[10]

NIOSH regulations for approved hoods and helmets in 30 CFR require that the maximum airflow not exceed 15 CFM. Flow rates of 8-10 CFM may be necessary to provide thermal comfort depending on ambient temperatures, circulation of air inside the hood or helmet, and work rate. It should be noted that there frequently is discomfort from air impact on the face at these higher flow rates.

Noise from the airflow within a hood or helmet may be a hazard. Hoods must be designed to reduce the noise to less than 80 dBA while maintaining the airflow rates required for adequate protection.[11, 12]

An air-control valve, if provided, is generally located on the wearer's belt in a position where the user may partially regulate his own supply above the minimum flow rate specified for approval. For MESA/NIOSH approval, each air-control valve must be tested to assure that a minimum flow rate of 6 CFM is provided regardless of the wearer's control of the valve.

5.1.3. Suits. An air line suit consists of a suit of plastic, coated, or impregnated fabric which is maintained under positive pressure by an air line supply (Fig. 5-4). In general, the air supply is distributed within the suit by a system of ducts to the head, trunk and extremities and exits either through the suit closures or through special exhaust valves. Sufficient air must be provided both for breathing and for cooling to avoid heat exhaustion.

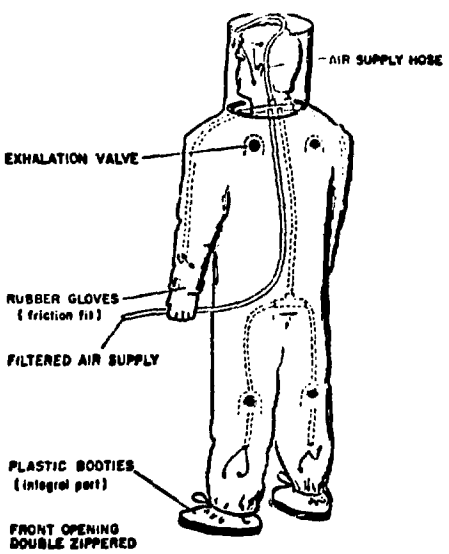

Fig. 5-4.
One piece supplied air suit.

The need for an adequate continuous supply of respirable air to suits is more important than with other air line respirators. Such a need stems from the lack of adequate warning to the wearer in case of interruption of the air supply and the difficulties encountered by the wearer in extricating himself from the suit as carbon dioxide, moisture and heat build up, and oxygen becomes deficient. A loss of a continuous air supply and a consequent deficiency of oxygen caused by re-breathing can cause rapid onset of unconsciousness and death[13].

For this reason, a second individual equipped with self-contained breathing apparatus shall be stationed in respirable air outside the contaminated area. This individual shall be prepared and trained to render emergency assistance to the individual in the suit in case of failure of the air supply. He shall be in visual, voice, or signal line communication at all times.

It should also be recognized that suit materials may have some permeability to chemicals with associated retention of toxic materials. Such permeability may ultimately result in the exposure of the wearer to the contaminant, even though the suit is continuously maintained at positive pressure.[19-22] Cooling equipment, such as a vortex tube or a refrigerated air supply may also be required at high ambient temperatures and high humidity conditions.

5.2. Respirator Types, Descriptions, and Limitations

5.2.1. Air-Purifying Respirators. An air-purifying respirator is one that removes contaminants from the ambient air. The purification of the air is accomplished by mechanically filtering out particulate contaminants or by removing contaminating gases and vapors. Cartridges and canisters are available which are capable of removing both types of contaminants. Throughout this guide "cartridges" will refer to the smaller types of air-purifying sorbents or filters used generally on half-mask and quarter-mask respirators, while "canisters" will refer to the larger capacity devices used on full-facepiece respirators, either attached to the respirator facepiece (chin style) or carried on the chest or back and attached to the facepiece with a flexible hose (Type N or industrial size). The word "filter" generally refers to a mechanical device used to remove particulate contaminants.

Air-purifying respirators generally operate in the negative pressure (NP) mode, that is a negative pressure is created in the facepiece during inhalation. A special type of powered air-purifying respirator using an air-purifying filter and/or sorbent cartridge and a motor driven blower operates continuously in the positive pressure (PP) mode (Fig. 5-1).

5.2.1.1. Air-Purifying Respirator - Negative Pressure Mode. This common type of air-purifying respirator is used with a tight-fitting facepiece. The motive force for passage of contaminated air through the air-purifying media is provided by the wearer's breathing. During inhalation, the facepiece is under a negative pressure created by the resistance to flow of the air purifying media. This negative pressure results in varying degrees of penetration of contaminants by inward leakage through the seal area between the facepiece and the wearer's face (assuming no other potential sources of leakages). Full facepieces generally have lower penetration through the seal area than half-mask or quarter-mask facepieces and single-use respirators. During exhalation, the mask interior is at positive pressure due to the resistance of the exhalation valve. Since the leakage through the filters is generally much less than the potential leakage around the facial seal, the limitations placed upon the several types of air-purifying respirators are based primarily upon the ability to obtain an initial fit of the facepiece to the wearer's face and to maintain the quality of the fit during wearing.

5.2.1.2. Air-Purifying Respirator - Positive Pressure Mode. This special type of air-purifying respirator may be used either with a tight-fitting facepiece or with a loose-fitting hood or helmet. The motive force for passage of the contaminated air through air-purifying media is provided by a blower. The blower may be driven by a battery or by a line-powered motor. The interior of the facepiece, hood or helmet is maintained at pressures positive with respect to the ambient atmosphere at all times during blower operation. Thus, inward leakage around the facial seal area is minimized. Respirators of this type, furnished with a tight-fitting facepiece, may be designed for use without the blower (in the negative pressure mode) in the event of a power failure.

5.2.1.3. Filters and Sorbents (Air-Purifying Media). Air-purifying media consist of fiber filters or sorbents used individually or in combination and contained in a suitable protective casing which is designed for attachment to the respirator facepiece or breathing tube. (In the case of single-use respirators the filter or sorbent is built into the facepiece.)

5.2.1.4. Filters. A filter is a fibrous medium used for the removal of airborne solid or liquid particulates from the air stream entering the respirator enclosure. It may be designed for a single-type of particulate, such as dusts only, or for various combinations of particulates, such as dusts, fumes and mists. Filter media used for protection against radioactive particulate contaminants shall be of the high efficiency type, 99.97% effective against thermally-generated 0.3 micrometer dioctyl phthalate (DOP). They are not effective against gases and vapors.

5.2.1.5. Sorbents. Sorbents are used for removing toxic gases and vapors from the air stream entering the respirator facepiece.

Sorbents may be used singly or in mixtures and multiple layers to give protection against a single gaseous contaminant, a class of contaminants (e.g., organic vapors or acid gases), or combinations of gases and vapors. They are not, of themselves, effective against particulates. If the efficiency of a sorbent is not well established for a particular gas or vapor, then sorbent canisters or cartridges shall not be used for protection against that gas or vapor.

5.2.1.6. Combination Filter - Sorbent Canisters. Canisters used for protection against particulates as well as gases and vapors consist of various combinations of filters and sorbents appropriate to the hazards for which protection is desired. For radioactive particulate contaminants, the filter media shall be of the high efficiency type.

5.2.1.7. Limitations on Air-Purifying Respirators. The application of air-purifying respirators for protection against airborne particulate hazards is subject to the following additional limitations:

5.2.1.8. Oxygen Deficiency. Air-purifying respirators remove a specified contaminant from the inhaled air. These devices do not supply oxygen; therefore, they shall not be used in atmospheres deficient in oxygen.

5.2.1.9. Nature of Contaminant. Air-purifying respirators offer protection to the wearer by removing a specific contaminant from the inhaled air by means of a particulate filter, sorbent, or combination of both. The sorbent media are designed for removal of

specified vapor(s) or gas(es), and the components of the canister or cartridge are chosen to fulfill this purpose. The canister or cartridge is, therefore, not a universal sorbent and it is vital to assure that it is selected appropriate to the hazard.

Unless a particulate filter element is added, as in the case of the combination filter-sorbent canister, protection against particulates is not provided by a canister or cartridge designed for gases and vapors. Only the high efficiency type of filter shall be used for protection against airborne radioactive particulates, and other highly toxic particulates with a TLV <0.05 mg/m^3.

Other types of particulate filters are available for protection against less toxic airborne contaminants such as dusts and metal fumes. High efficiency filters can be used against these contaminants, however these filters generally have poor particulate loading characteristics.

Air-purifying respirators must be used with adequate skin protection when worn in atmospheres containing substances such as hydrocyanic acid or organophosphate which may be absorbed through the skin.

5.2.1.10. Physical State of Contaminant. The physical state of the contaminant must be considered in the selection of an air-purifying respirator canister or cartridge. (See Sec. 6.0 for details on selection.) For example, the radionuclide chlorine-36 may be present as airborne radioactivity in any of the following forms: gaseous (as chlorine gas), vapor (as a chlorinated hydrocarbon vapor), or particulate (as a hydrochloric acid mist or fume, or as a dust of a chlorine salt).

A canister containing only a particulate filter is inappropriate for use with contaminants which decay from a particulate to a gaseous state, or from a gaseous to a particulate state.

5.2.1.11. Concentration of Contaminant. Experience has shown that there are maximum concentrations above which a person may not be safely exposed while wearing an air-purifying respirator. Air-purifying respirators shall not be used in atmospheres immediately hazardous to life or health (See ANSI Z88.2 for definition).

For many particulates the limiting concentration would be the one which causes rapid plugging of filter media with resultant increase in breathing resistance, however, rapid plugging is not generally a problem in dealing with airborne radioactivity unless other hazards (chemical, dust, etc.) are also present.

The dust and fume filters have better loading characteristics than high efficiency filters and still provide the protection necessary against the less toxic particulates.

5.2.1.12. Service Life. Service lives of the filter media of air-purifying respirators are directly related to the capacity of the filter for the contaminant, the air concentration of the contaminant, and the respiratory minute volume (amount of air breathed in per minute) of the wearer as determined by his work rate.

The service life of a particulate filter is limited by the amount of material that can be retained before the resistance to inhalation increases significantly. A second limitation results from the radiation and potential contamination hazard due to the material deposited on the filter.

Sorbent cartridges and canisters may be used only for nonradioactive gases and vapors and should always be kept sealed until installed on the respirator because exposure to high humidities may shorten their useful lifetimes. Unsealed, unused cartridges and canisters may be kept for use for one year if attached to a respirator and sealed in a plastic bag. Unsealed cartridges or canisters not so stored shall be discarded even though unused. The date of removal of the seal should be clearly marked on the cartridge or canister.

Particulate filters used for protection against radioactive and nonradioactive particulates may be reused only if a quality assurance program (see Chap. 10) is in effect to ensure that the filters meet the requirements for efficiency and resistance to breathing specified for unused filters, and if a means is available to determine the extent of radioactive contamination of the filters. If these criteria are not met, particulate filters shall not be reused.

Sorbent cartridges and canisters shall never be reused, as there is no way of determining the useful service life remaining after use.

5.2.1.13. Knitted Cloth Covers (Facelets). Knitted cloth covers (facelets) have been used on half-mask and quarter-mask respirators for sanitary purposes. They shall not be used as they interfere with the facepiece fit.

5.2.2. Atmosphere-Supplying Respirators, Descriptions, and Limitations. An atmosphere-supplying respirator is one that furnishes respirable air or oxygen to the wearer from an uncontaminated supply, such as compressed or liquid breathing air or compressed or liquid oxygen cylinders, oxygen-generating canisters, or a breathing air compressor which draws its supply from an uncontaminated ambient atmosphere. This type includes air line respirators, self-contained breathing apparatus, and hose masks.

5.2.2.1. Air Line Respirators - Demand, Pressure Demand, Continuous Flow. An air line respirator provides protection against contaminants by providing an adequate supply of respirable air by any of three modes of operation. They are: (1) continuous flow, (2) demand, and (3) pressure demand. Air is supplied through a hose to a facepiece, hood, helmet, or suit. The source of respirable air may be either a cylinder of liquid or compressed pure breathing air, or a breathing air compressor located so that the air is uncontaminated and respirable. If the air supply system pressure for demand type air line respirators at the hose connection to the user exceeds 125 psig, a pressure reduction stage must be used, with a pressure relief device in case of valve failure.

For continuous flow units, it is possible that the wearer may partly control the flow with an air-regulating valve worn at some conveniently reached position. Under current MESA/NIOSH approvals, such an air-regulating valve, at any setting, must not reduce the flow of air to less than 4 cu. ft. per minute for tight-fitting facepieces or 6 cu. ft. per minute for loose fitting helmets or hoods with the maximum specified length of hose and the minimum specified air supply pressure.

Detailed requirements on air supply lines, length of hose, airflows and other components may be found in Table 8 of 30 CFR 11, Subpart J., §11.124-7.

While ANSI Z-88 *Standard Practices for Respiratory Protection*[9] recommends that breathing air meet at least the requirements for Grade D air as described in Compressed Gas Association (CGA) Commidity Specification for Air, G-7.1-1966,[22] it is recommended that breathing quality air shall be supplied meeting at least the requirements for Grade E air in the CGA specification. The important characteristics for Grade E air are:

Constituent	Maximum Concentration
Oxygen	19-22%
Hydrocarbons (Condensed)	5 mg/m^3
Carbon monoxide	10 ppm
Carbon dioxide	500 ppm

The CGA specifies that for breathing air there must be no pronounced odor. NIOSH approvals require a minimum of 19.5% oxygen by volume.

Oxygen shall never be used with air line respirators.

5.2.2.1.1. Continuous Flow Type. The continuous flow air line respirator may be used with either a half-mask facepiece, full facepiece, hood, helmet, or suit. The minimum airflow required is 115 liters per minute (4 cu. ft.) for tight-fitting facepieces, such as the half-masks and full face masks, and 170 liters per minute (6 cu. ft.) for hoods and helmets as specified in the NIOSH approvals. Airline suits require a flow of 170 liters per minute or more, depending on the suit design.

5.2.2.1.2. Demand Types. The demand regulator is usually located between the breathing tube leading to the facepiece and the small diameter pressure line from a high-pressure air source, such as a compressor (~100 psi) or breathing air cylinder (~2400 psi). Sometimes this regulator is mounted directly on the mask. The regulator has a diaphragm-actuated valve which opens on inhalation and permits air to flow into the facepiece only as long as the negative pressure exists. The negative pressure can cause leakage of contaminants into the facepiece where it seals to the face. This creates the added hazard of possible inward leakage during inhalation which is not present in the pressure demand types; therefore, the demand type devices provide no higher degree of protection against contaminants than an air-purifying respirator with the same facepiece.

5.2.2.1.3. Pressure-Demand Types. In the pressure-demand air line respirator, a spring loaded regulator and exhalation valve combination provides a flow of air into the facepiece which maintains a slight positive pressure at all times. Any outward leakage around the facepiece seal will result in an increase in air consumption as compared to the demand types, however, if the facepiece is fitting properly, there will be little increase in air consumption.

Some pressure-demand regulators are supplied with a control so that the respirator may be operated in either the pressure demand or demand mode. Where such a control is provided, care must be exercised to ensure that the regulator is operating in the appropriate mode.

The pressure-demand device requires a special exhalation valve. A facepiece fitted with a demand type exhalation valve cannot be used with a pressure-demand regulator, unless the exhalation valve system is changed, as there will be a continuous flow of air.

5.2.2.1.4. Limitations on Air Line Respirators. While most atmosphere-supplying respirators are capable of providing protection against high concentrations of many toxicants, no device is 100% efficient. Some leakage into the facepiece may occur, particularly with apparatus operated in the demand mode where there is negative pressure in the mask during part of the breathing cycle. Since the same facepieces are used for many air line devices as well as air-purifying respirators, there are limitations on their use with beards, eyeglasses, and other facial problems common to the air-purifying respirators.

There is no protection if the air supply fails, unless an auxiliary supply is available. There is no protection, other than to the face, against contaminants irritating to the skin; and there is no protection against materials such as tritium oxide vapor or hydrocyanic acid gas that can be absorbed through the unbroken skin. Even supplied-air suits, which may afford more protection against the latter hazards, are permeable to varying degrees depending on factors such as concentration of contaminant, time of exposure and the properties of the suit material.

Air line respirators that rely on an external air source connected by a length of hose or similar device to the facepiece, hood, or suit, shall not be used for emergency rescue, or escape, or in atmospheres immediately hazardous to life or health. The restriction to movement imposed by the hose and the possibility of physical damage to the hose if used in an area where there might be sharp objects, as after an explosion or fire, make this a dangerous procedure. A positive-pressure self-contained breathing apparatus shall be used under these conditions.

The wearer's travel is limited by the length of air-supply hose; and he must retrace his route in the contaminated atmosphere to return to fresh air while wearing the respirator unless an auxiliary air tank is provided for escape. These respirators must be used within the limits set by the manufacturer and approved in 30 CFR 11 for air-supply hose length, type and range of pressure applied.

5.2.2.2. Self-Contained Breathing Apparatus (SCBA), Description and Limitations. A self-contained breathing apparatus is a respirator in which the supply of air, oxygen, or oxygen-generating material is carried by the wearer. These devices can be either open circuit, wherein the exhaled breath passes to the ambient atmosphere through the facepiece exhaust valve, or closed circuit (rebreathing), wherein the carbon dioxide and water vapor are removed from the exhaled air, oxygen is added and the recycled air is rebreathed. An open-circuit SCBA operates on either compressed air, compressed oxygen, liquid air, or liquid oxygen. A closed-circuit SCBA utilizes compressed, liquid, or chemically generated oxygen.

Compressed air and oxygen may not be used interchangeably in the same apparatus. Compressed air contains slight amounts of oil which, if deposited in the system, create an explosion hazard.

5.2.2.2.1. Demand Type, Open Circuit. The demand type, open circuit, self-contained breathing apparatus is similar to the demand type of air line respirator except that the source of respirable air is a cylinder of compressed air or oxygen carried by the wearer. This apparatus usually consists of a full facepiece equipped with a demand valve and a pressure-reducing valve connected to a cylinder of compressed air, compressed oxygen, or liquid oxygen. A pressure gauge is located near the demand valve to indicate the pressure in the gas cylinder. An alarm device indicates when the reservoir pressure drops below a predetermined point, allowing enough reserve time for the wearer to exit from a contaminated area.

A demand type SCBA does not provide any higher degree of protection against airborne contaminants than an air-purifying respirator with the same facepiece, but it does provide protection against oxygen deficiency. A demand-type SCBA must never be used as a standby emergency rescue device because the possibility of facepiece leakage does not warrant its use in unknown, but potentially high, contaminant concentrations.

5.2.2.2.2. Pressure-Demand Type, Open Circuit. Pressure-demand self-contained breathing apparatus is an open-circuit apparatus similar to the pressure-demand air line respirator except that the supply of respirable air is a cylinder of compressed air carried by the wearer.

A spring loaded regulator and exhalation valve combination maintains a positive pressure in the facepiece slightly above atmospheric at all times. Therefore, any leakage will be outward.

Because of the high degree of protection provided by the pressure-demand SCBA, this type of unit is recommended for emergency use, escape and rescue.

5.2.2.2.3. Recirculating, Closed-Circuit. In the recirculating or closed-circuit self-contained breathing apparatus, conservation of oxygen or air supply is obtained by recirculation between the facepiece and a breathing bag or reservoir. Carbon dioxide and water vapor in the exhaled breath are removed by an absorber. Oxygen is added to the closed-circuit as needed from a cylinder of compressed or liquid oxygen. Units of this type can be obtained which have useful lifetimes up to four hours.

5.2.2.2.4. Limitations on Self-Contained Breathing Apparatus. The lengths of time that these devices may be used are limited by the air or oxygen supply that the wearer can carry. Units are given nominal ratings for the length of time they would protect an average person doing moderately heavy work. These ratings are only a guide, and oxygen or air may be used more rapidly than the rating indicates.

The duration of the unit will depend on factors such as:

(a) the degree of physical activity of the user;

(b) the physical condition of the user;

(c) the degree to which the user's breathing is increased by excitement, fear, or other emotional factors;

(d) the degree of training or experience which the user has had with this or similar equipment;

(e) whether or not the cylinder is fully charged at the start of the work period;

(f) carbon dioxide concentrations in the compressed air of greater than that normally found in atmospheric air;

(g) the atmospheric pressure; if used in a pressurized tunnel or caisson at 2 atmospheres (15 psi gage) the duration will be one-half as long as when used at 1. atmosphere; and at 3 atmospheres will be one-third as long;

(h) the condition of the apparatus. The demand types of self-contained breathing apparatus rely on a negative pressure being created in the facepiece to actuate the air or oxygen supply. Although they do supply respirable air to the facepiece, thereby protecting against oxygen deficiency, they are no more efficient than an air-purifying respirator employing the same facepiece. They are not recommended for entry into atmospheres immediately hazardous to life.

Further limitations on use of these devices may result from their size and weight where the work is to be done in a very confined space.

5.3. Combination Respirators

A combination respirator is any respirator which affords the wearer the option of changing from one basic type of respirator operation to another, either by operation of a selector valve or by disconnecting the source of respirable air supply. The degree of protection afforded by the combination respirator is determined by its operating characteristics for the mode being used and the type facepiece being used. Combination respirators may be categorized in one of the following three classes:

5.3.1. Air Line Respirator - Air-Purifying Respirator. This type of combination respirator is designed to be operated either (1) as a continuous flow or as a demand air line respirator, or (2) as an air-purifying respirator. The selector switch may be manually operated or may operate automatically contingent upon failure of the air line supply.

5.3.2. Self-Contained Breathing Apparatus - Air-Purifying Respirator. This type of combination respirator utilizes a full facepiece and consists of a self-contained

breathing apparatus of the demand or pressure-demand type with appropriate valving so that the respirator may be operated in the air-purifying mode. The operation of the selector switch may also be manual or automatic.

5.3.3. Self-Contained Breathing Apparatus - Air Line Respirator. This type of combination respirator utilizes a full or half-mask facepiece and generally consists of a demand, pressure demand or constant flow air line respirator with additional valving so that a small cylinder of compressed air, attached to the unit, may be used to supply respirable air if the air line supply is interrupted. The small cylinder (5-7 ft^3) is suitable for escape purposes.

5.4. Hose Masks With Blower and Hose Masks Without Blower

These masks consist of a full facepiece connected by one or more flexible breathing tubes to a large diameter hose. In the hose mask with blower, the large diameter hose is connected to a blower operated in respirable air; in the hose mask without blower, the inlet end of the large diameter hose is anchored in respirable air. The use of hose masks is generally limited owing to the difficulty of keeping the short hoses in uncontaminated air.

5.5. Emergency Use, Escape and Rescue Devices

Because an emergency is an unplanned event (see Sec. 2.1.3.), it must be assumed that contaminant air concentrations may be "immediately dangerous to life" (ANSI Z88.2, Sec. 4, Table I). Therefore, devices for use during escape, firefighting, rescue and emergency re-entry should provide a high level of protection. (Fig. 5-5.)

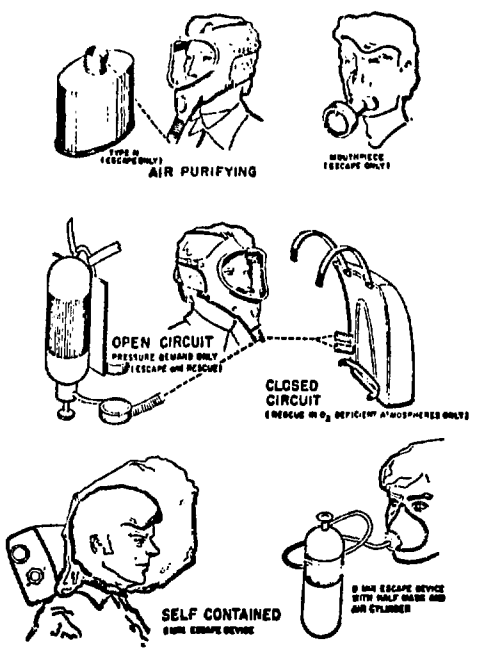

Fig. 5-5.
Emergency escape and rescue.

5.5.1. Self-Contained Breathing Apparatus. Generally, only the pressure-demand type SCBA should be selected for emergency use, rescue and re-entry into a contaminated area to perform emergency shutdown or maintenance of equipment. The pressure-demand type with a positive pressure in the facepiece provides a much higher level of protection than the demand-type with a negative pressure in the facepiece.

MESA/NIOSH approves a 5 to 10 min SCBA for emergency escape only. These devices are lighter and may be donned rapidly with proper training.

5.5.2. Air-Purifying Respirator. As a general rule, the use of air-purifying respirators during emergencies is to be strongly discouraged. Under certain conditions, particularly where donning time may be a factor, use of an air-purifying respirator *for escape purposes only* may be preferable to an atmosphere-supplying device which takes longer to put on. Under no circumstances should an air-purifying respirator be used for re-entry into a contaminated atmosphere which potentially could be immediately hazardous to life or health. The choice of an air-purifying respirator for escape during an emergency should be made only after careful consideration of all factors involved, not only the donning time, but also the potential airborne contaminant concentrations, and the time required for egress from the work area.

5.5.3. Mouthpiece Respirators. A mouthpiece respirator is a compact device designed for quick use in sudden contamination releases. They normally consist of a housing with a mouthpiece and a single canister or cartridge, a nose clamp, exhalation and inhalation valves, and a neckband. These devices can be carried on the belt, in a laboratory coat pocket, or around the neck. When properly used, there is little inward leakage when breathing through the mouthpiece with the nose clamp in place. These devices are available with high efficiency filters and various types of sorbent cartridges.

Mouthpiece respirators shall never be used as a routine means of protection against radioactive contamination or for re-entry into a contaminated area during an emergency.

5.5.4. Combination Respirators. There are combination air line respirators with auxiliary self-contained air supply that are recommended for atmospheres immediately dangerous to life. The degree of protection provided depends on the mode of operation.

A combination pressure-demand, or continuous flow type, air line respirator with an auxiliary self-contained air supply provides a high degree of protection. The combination demand-type air line respirator with an auxiliary self-contained air supply provides a much lower level of protection due to the negative pressure in the facepiece.

5.6. Selection of Approved or Accepted Equipment

5.6.1. 30 CFR Part 11, and Bureau of Mines Schedules. Respirators that are specifically approved or certified for radioactive particulates are listed in NIOSH publications.

5.6.1.1. The Approved Respirator - 30 CFR Part 11. The OSHA requirements, in Sec. 1910(b)(11), state that "Approved or accepted respirators shall be used when they are available." Legally, the Occupational Safety and Health Administration (OSHA) may recognize a respirator evaluated by any competent authority as being an "approved" device. At this time, OSHA has chosen only to recognize respirators jointly approved by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Enforcement and Safety Administration (MESA).

The requirements for respirator performance which lead to the granting of approvals for respirators by NIOSH and MESA are found in Title 30, Code of Federal Regulations, Part 11 (30 CFR 11).

The manufacturer has the option of submitting a prototype device to NIOSH and MESA for testing under the provisions of Part 11; however, an approval cannot be granted on the basis of this prototype. For final approval, the manufacturer must submit a production model manufactured with production tooling and have a quality control plan approved, then the Part 11 tests are performed, the results reviewed both by NIOSH and MESA, and the joint approval granted. This approved device is then eligible for use to meet the requirements of 1910.134.

5.6.1.2. Historical Changes. Historically, 30 CFR 11 came into existence in 1972. The Bureau of Mines had started approving self-contained breathing apparatus and gas masks for mine rescue in 1919 and added approval schedules for other types of respirators through the years. NIOSH became a partner with MESA (a new organization which assumed the responsibilities of mine health and safety formerly controlled by the Bureau of Mines) in carrying out a respirator approval program in 1971.

The question can be legitimately asked, what happened to all of the Bureau of Mines approvals and does a Bureau of Mines approved respirator meet the requirements of 1910.134? The answer is somewhat involved.

Respirators carrying a Bureau of Mines approval could continue to be sold by respirator manufacturers as approved respirators only until June 30, 1975. After that data only respirators approved under 30 CFR Part 11, with the exception of gas masks, can be sold by respirator manufacturers as appproved respirators. Gas masks approved under the provisions of Bureau of Mines Schedule 14F can continue to be sold by respirator manufacturers after June 30, 1975, as approved respirators. Bureau of Mines approved respirators purchased by the user on or before June 30, 1975, can continue to be used until the following dates unless, and this applies to certain selfcontained breathing apparatus only, they are upgraded to meet the requirements of 30 CFR 11. and are relabeled.

1. Self-contained breathing apparatus, March 31, 1979.
2. Supplied-air respirators, March 31, 1980.
3. Dust, fume, and mist respirators, March 31, 1976.
4. Chemical-cartridge respirators, March 31, 1976. This means that if the user has Bureau of Mines approved respirators on hand, he may continue to use them until the above mentioned dates and will be in compliance with 1910.134. After the above dates, only those devices approved by NIOSH and MESA under the provisions of 30 CFR 11 may be used in order to be in compliance with 1910.134. Note that dust, fume, and mist respirators and chemical cartridge respirators can no longer be used unless they are NIOSH/MESA approved.

5.6.1.3. Identification of Approved Respirators. How does the user identify an approved respirator? The Bureau of Mines approvals required that the entire respirator be approved as a unit and that the device be permanently marked with the approval number. Therefore, the user will find markings such as these: BM-2301, BM-21B-86.

The first example identifies the respirator as being Bureau of Mines approved under the provisions of the schedule for chemical cartridge respirators (23) with an approval number (01). In the second example, the respirator was approved under the schedule for dust, fume, and mist respirators (Schedule 21B), and was the 86th respirator approval under that schedule. The approval designation also appears on the approval label of the carton or on the device itself.

Respiratory protective devices approved by NIOSH and MESA under 30 CFR 11 may be identified by the "TC" preceding the approval schedule designation and approval number. This identification will appear on the carton as respirators are now approved as an entire assembly of parts. Each respirator component must be marked with a part

number and the part numbers are listed on approval labels. Therefore, if the carton is not available, a respirator approved under 30 CFR 11 will be recognized by the absence of the "BM" designation on the facepiece and the appearance of a part number instead. A particular approval does, however, consist of a series of part numbers, and no part with a different number may be exchanged without negating the approval. This system does allow the same part, for example a facepiece, to be used on several types of respirators.

5.6.2. ERDA Testing Programs. An extensive amount of field testing of respirators has been performed by various ERDA contractors and other laboratories. Most of these testing programs, including the tests in the field, have been reported in the public literature and may be used for guidance in the selection of respirators.[13-20,23,24,25,26 28]

5.6.3. Selection Guidance from Other Sources. The recommendations of the American Industrial Hygiene Association, the American Conference of Governmental Industrial Hygienists, the National Safety Council, the American National Standards Institute and others who have applied the use of respirators towards protecting against toxic agents should be considered in respirator selection.[21]

5.6.4. "Accepted" Devices. The ERDA permits use of other than approved or certified devices when such devices are not eligible for certification by NIOSH/MESA.

ERDA has established, through the LASL Respirator Research and Development Section, a Respirator Advisory Committee. Contractors may, through ERDA, request LASL to evaluate special respiratory protective equipment. If the equipment meets the above criteria, LASL will evaluate it and submit the result to the Advisory Committee. The Committee will transmit its recommendation on the acceptability of the equipment through LASL to ERDA SSC.

6. SELECTION GUIDES (PROTECTION FACTORS)

The overall protection afforded by a given respirator design is 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 facepiece under conditions of use. Respirators must be selected so that the contaminant concentration inhaled by the wearer will not exceed the appropriate limit.

Table 6-1 lists protection factors for the various classifications of respirators. The PFs are based on laboratory leakage studies in the use of the devices and have been extensively investigated by Hyatt.

In using the table, scrupulous attention must be paid to the limiting and qualifying notes. The indiscriminate and uncritical use of this table where it does not apply might result in undue hazards.

The respirators are classified in two basic groups (air-purifying and atmosphere-supplying), based on mode of operation. Facepiece or enclosure air pressure is tabulated for each type of device. The facepiece pressures listed for two types of devices may be questioned by some and are therefore explained.

The hose mask with blower is obviously designed to operate with a positive pressure in the facepiece. For approval, the blower is only required to deliver 50 liters of air per minute to the facepiece. This will provide a positive pressure for low work rates. However, at a medium to heavy work rate, the wearer will create a negative pressure in the facepiece during inhalation. Therefore, Table 6-1 lists a negative facepiece pressure for this device.

The closed circuit SCBA has recommended PFs for operation with a negative pressure in the full facepiece. For guidance in selection, LASL studied the facepiece pressure for two types of closed-circuit SCBA during several exercises, ranging from normal breathing to walking rapidly at four mph on a treadmill. The results indicate the average peak pressure in the facepiece was negative for all exercises.

The closed-circuit oxygen-generating type SCBA is not listed on Table 6-1 because of insufficient performance test data. Preliminary tests have been made by LASL to measure the percentage of time this type unit is under negative pressure during various exercises. During walking on level ground for 10 minutes, the facepiece pressure was negative only 1.0% of the time. However, when walking rapidly on a treadmill at four mph for four minutes, the facepiece was under negative pressure 95% of the time. Further testing should be done on this type of device.

Because of the concern that Table 6-1 may be reproduced separately from this document, detailed footnotes have been added.

TABLE 6-1
RESPIRATOR PROTECTION FACTORS[a]

Type Respirator	Facepiece[b] Pressure	Protection Factor
I. Air-Purifying		
A. Particulate[c] removing		
Single-use,[d] dust[e]	-	5
Quarter-mask, dust[f]	-	5
Half-mask, dust[f]	-	10
Half- or Quarter-mask, fume[g]	-	10
Half- or Quarter-mask, High-Efficiency[h]	-	10
Full-Facepiece, High-Efficiency	-	50
Powered, High-Efficiency, all enclosures	+	1000
Powered, dust or fume, all enclosures	+	X[i]
B. Gas-and Vapor-Removing[j]		
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[k]	+	1000
Pressure-Demand, Full-Facepiece[l]	+	2000
Hose Mask With Blower, Full-Facepiece	-	50
Continuous-Flow, Half-Mask[k]	+	1000
Continuous-Flow, Full-Facepiece[l]	+	2000
Continuous-Flow, Hood, Helmet, or Suit[m]	+	2000
B. Self-Contained Breathing Apparatus (SCBA)		
Open-Circuit, Demand, Full-Facepiece	-	50
Open-Circuit, Pressure-demand Full-Facepiece	+	10 000[n]
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 6-1 is not to be reproduced without the accompanying footnotes.

Footnotes for Respirator Protection Factor Table 6-1

[a]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 PFs 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.

[b]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.

[c]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.

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

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

[f]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.

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

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

[i]To be assigned, based on dust or fume filter efficiency for specific contaminant.

[j]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.

[k]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.

[l]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 2000.

[m]The design of the supplied-air hood, suit, or helmet (with a minimum of 170 liters/min 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.

[n]The SCBA operated in the positive pressure mode has been tested on a selected 31-man panel and the facepiece leakage recorded as <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

TABLE 6-1A
MAXIMUM RESPIRATOR PROTECTION FACTORS FOR INDIVIDUAL WEARERS BASED ON OVERALL PERFORMANCE CRITERIA MEASURED BY QUANTITATIVE MAN TESTS

Type of Respirator	Criteria Allowable max av penetration %	Maximum Permissible PF
I. Air-Purifying		
A. Particulates		
Type, Filter Facepiece		
Single-Use, Dust, and Mist	10	10
Dust, Mist, or Fume, Half- or Quarter-Mask	5	20
Hi-Eff., Half- or Quarter-Mask	2	50
Hi-Eff., Full-Facepiece	0.2	500
B. Gases and Vapors		
Half-Mask Facepiece	2	50
Full-Facepiece	0.2	500
II. Atmosphere-Supplying		
A. Supplied-Air, Mode, Facepiece		
Demand, Half-Mask	2	50
Demand, Full Face	0.2	500
Hose Mask Without Blower, FF	0.2	500
Atmosphere-Supplying		
B. SCBA, Mode, Facepiece		
Open-Circuit, Demand, FF	0.2	500
Closed-Circuit, FF	0.2	500

When an employer conducts *quantitative* respirator man tests on individual wearers in addition to establishing and enforcing a minimal acceptable respirator program, maximum permissible PFs are recommended in Table 6-1A. This table lists only devices that operate with a negative air pressure in the facepiece during inhalation.

The PF listed for each type of device listed in Table 6-1A applies *only* to the individual wearer tested when the man-test data are equal to or greater than the allowable maximum average penetration criteria listed for that PF. If the maximum average penetration is greater than the criteria listed for that device in Table 6-1A, then a lower PF may be used.

6.1. Activities of Wearer

An important element to be considered, in the selection of respirators, is the degree to which the device selected will meet the physical and physiological requirements of the work to be done without causing undue stress to the wearer or imposing restraints which lead to unsafe practices.[14,29]

It should be recognized that the wearing of respirators usually results in some additional stress, and therefore, added risk to the wearer. Thus respirators must be selected so that any specific job can be performed with a minimum of stress.

The work rate of the wearer determines his respiratory minute volume, peak respiratory airflow rate, and the inhalation and exhalation breathing resistance associated with the respirator. The minute volume is significant when self-contained and air line respirators are operated from cylinders because it determines the useful duration of the air supply. The useful life of the air supply at moderate work rates may be only one-third that at sedentary use.

Peak respiratory airflow rate is of importance because the supply to continuous flow air line respirators or to positive pressure air-purifying respirators must be greater than the peak respiratory airflow rate to maintain the respirator under positive pressure at all times. The 4 cu. ft. per min. supply (minimum) recommended for tight-fitting facepieces is 115 liters per minute or approximately the peak airflow rate for a normal person working at a moderate work rate of 622 kg-m/min. Similar considerations apply to the 6 cu. ft. per min. supply (minimum) recommended for hoods.

The resistance to breathing associated with air-purifying and demand-type SCBA and air line respirators of the negative pressure (NP) type used by a person working at a moderate work rate or at higher elevations can result in worker fatigue and discomfort. This is especially true of gas masks.

Visual and communications limitations of respirators and other special problems must not be neglected. Appropriate equipment with proper visual and communications capabilities must be provided where the work demands it. Otherwise, hazardous situations may arise; for example the wearer might remove the respirator in a hazardous area in order to see (lens fogging) or to be heard.

6.2. Individual Wearer Requirements

6.2.1. Fit. The most significant individual requirement of the wearer is proper respirator fit. Most commercial quarter-masks, half-masks, and full-face respirators manufactured in the U.S. to date have been available in one size only. Since a given respirator in a single size will not fit all the population, it is necessary that devices from several manufacturers be available in order that each person may be fitted with more than one device to determine the one that provides the best fit. (A few individuals of unusual facial size or contour may be encountered who cannot be fitted adequately, and should therefore not be permitted to use negative pressure respirators.) An adequate fit is important with any facepiece operating in the negative pressure mode (NP type).

6.2.2. Anthropometric Criterion. Although there is a wide variety of facial sizes and shapes in the general population, most commercial respirators are available in only one size. In addition, masks are usually manufactured in larger sizes which fit more men than women. Most women have faces that are both narrower and shorter than men, hence it is to be expected that women will be more difficult to fit.

Many factors affect the fit of a mask. There are a few key facial dimensions of importance in respirator fitting as shown in Figs. 6-1 through 6-4. Different masks of the same length and width may accommodate different faces if there are differences in the design of the seal, shape, and materials of manufacture. Because each of the different brands of commercial masks differs considerably in design, the availability of different brands and the use of a fitting test is the most effective way at the present time to provide adequate protection for much of the population.

Fig. 6-1.
Menton-Nasal root depression length. With subject's face in profile, measure the distance from the menton to the point of maximum nasal root depression (midpoint of nasal root).

Fig. 6-2.
Bizygomatic breadth. Measure the maximum horizontal diameter of the face across the zygomatic arches (the most laterally projecting bones of the cheeks). Before measuring, find the widest points and mark them. If the bones are flat and there are no obvious points, use the most anterior places on the zygomatic arches.

Fig. 6-3.
Lip length. Measure the maximum distance between the fleshy corners of the lower lip (at the point where the colored flesh turns inward).

6.2.2.1. Anthropometric Facial Measurements and Characteristics Relating to Facepiece Fit. Standard anthropometric techniques consist of measuring between selected points on the face with anthropometric calipers. These points, called landmarks, refer to either visible features on the face such as the corners of the mouth, or to points on the underlying skull. The latter must be located by palpating the skin and marking the correct location with some sort of mark - colored pencil. The actual measurements can then be taken using the indicated landmarks. An example of a landmark located by palpation is the menton, which is the point of the chin in the center of the jaw (see Fig. 6-1).

Face length is perhaps the most important single dimension in respirator design and fitting. Face length is measured from the menton (the center of the chin) to the nasal root depression (the area of greatest indentation where the bridge of the nose meets the forehead). This distance is shown in Fig. 6-1. It might be noted that while a full face mask covers the distance from under the chin to above the eyebrows, this distance is closely related to the face length.

An appropriate breadth measurement for a full face mask is face width. It is defined as the maximum horizontal breadth of the face across the zygomatic arches, which are the bony arches extending horizontally along the side of the head from the cheekbone to the ear. Fig. 6-2 indicates face width.

Other factors of possible importance in fitting a full face mask include the shape of the jaw, and the width across the eyebrows.

The correlation between face length and width is low, as it is for most facial dimensions. Therefore, subjects with a long face do not necessarily have a wide face.

For half-mask fitting, face length is also important and is used. A different width measurement, however, is more appropriate. Lip width, shown in Fig. 6-3, is measured from one corner of the mouth to the other. This width is related to the ability of a half- or quarter-mask to seal around the mouth, although the mouth width can change while the subject is talking or moving his jaw. Other measurements may be important in evaluating the fit of a half mask, such as the width of the nasal bridge, and studies are being carried out to find what their significance may be.

6.2.2.2. Facial Abnormalities. Many characteristics of the face can adversely affect the seal of a respirator facepiece. Some of the obvious facial features that should be carefully checked by the individual doing the respirator fitting, are:

1. The effect of facial hair.
2. The shape and size of the nose (for half- and quarter-masks). A nose that is skewed to one side, broken, or exceedingly broad or thin may prevent a good seal.
3. A jaw without a clearly defined menton.
4. Hollow temples or cheeks, scars, or excessive wrinkles that may provide a channel for contaminated air to enter the breathing zone.
5. Missing dentures.

6.2.3. Medical Limitations. Workers must be evaluated by competent medical personnel to assure that they are physically and mentally able to wear the respirators under simulated and actual working conditions. These evaluations should be an important part of the employee's periodic physical examinations routinely given in most industrial medical facilities.

Adequate medical supervision of respirator users is indispensible in determining the extent of individual stress tolerance, and preventing potential physiological difficulties.

6.2.3.1. Physiological Factors. The Respiratory Protective Devices Manual[11] devotes an entire chapter to the physiology of respiration and the effects of respiratory protection on respiration. Much additional research is needed to correlate the effects of stress caused

by breathing against some resistance while performing various types of work, including studies of energy expenditure, pulmonary ventilation - perfusion, cardiovascular physiology, and potential for precipitating pulmonary dysfunctions.

Because of the additional stress placed on the cardiopulmonary system, some pathological conditions, especially those associated with hypoxemia, should preclude the use of respiratory protective devices. Other cardiovascular or systemic diseases may be aggravated or these diseases may limit the use of respiratory devices.

The following clinical conditions are among those which are most likely to be investigated by the examining physician:

1. Chronic obstructive and restrictive lung disease: chronic bronchitis, emphysema, pneumoconioses, fibrothorax, asthma, etc.
2. Ischemic heart disease: coronary insufficiency and myocardial infarction.
3. Benign and accelerated hypertension.
4. Hemorrhagic disorders: vascular hemophilia, hypersplenism, thrombocytopenia, purpura, etc.
5. Thyroid disorders or cystic fibrosis.
6. Epilepsy: grand mal, focal, etc.
7. Diabetes mellitus.
8. Cerebrovascular accidents.
9. Facial abnormalities.
10. Kidney diseases.
11. Conductive and sensorineural hearing loss.
12. Serious defects in visual acuity.
13. Ruptured ear drum.
14. Other disabilities.

6.2.3.2. Psychological Factors. It is generally very difficult to evaluate a wearer's psychological limitations through a routine medical examination. The examining medical doctor should investigate any mental illness thoroughly to ascertain that the wearing of respiratory protective equipment will not aggravate the existing condition. Under the best conditions, a degree of anxiety is often encountered when wearing a respirator which may become exaggerated in emergency situations. Experienced personnel who fit and train respirator users should note unusual behavior patterns.

6.2.3.2.1. Wearer Acceptance. Wearer acceptance of a respirator can best be accomplished through proper training. Knowing the reason for using a device, the possible consequences of not wearing it, its capabilities, explaining why engineering controls are not used, relieving "fears of the unknown" or "only sissies use them" concepts, and any other preconceived notions, will greatly improve wearer acceptance.

6.2.3.2.2. Claustrophobia. Some people experience claustrophobia when wearing respirators. Claustrophobic reactions may not be detected when a device is first tried on or during the fitting phase. It usually does not appear until the wearer goes into an atmoshere that is either hazardous or irritating. Use of a room, chamber, or "smoke house" filled with an irritating smoke, such as from burning wet straw, assists greatly in identifying those individuals who tend to develop claustrophobia.

6.2.3.2.3. Stress. Stress conditions generated in an emergency may completely incapacitate an individual, not only endangering himself, but others around him. Emergency personnel such as standby men who are observing workers in a tank, or rescue teams, should be trained, using simulated conditions. Because there is no way to predict how an individual might react under actual stress conditions, every effort should be made to condition him physically, mentally and psychologically. This can only be accomplished by repeated and sufficient training.

6.2.3.3 Periodic Medical Examinations. Physical examinations are required for each user before he wears any device and at least annually thereafter. A physician shall determine if health and physical conditions are pertinent and will make necessary recommendations for each situation.

6.2.3.4 Medical Approval Forms. It is recommended that each contractor utilize medical approval forms for every individual who might use respirators. These forms are to be completed by the examining physician for the person in charge of the respirator program. The assessment of medical restrictions will facilitiate the planning of training activities and the type of job assignments.

6.3. Wearer Comfort

Comfort relates to the degree of physical stress to the respirator wearer. Everyone who wears a respirator may be expected to experience some discomfort. Distress associated with the work environment tends to be accentuated by wearing a respirator: vision is restricted; breathing is difficult; ventilation across the face is limited; equipment is cumbersome and restricts movement; and wearing the respirator adds to the adverse effects of temperature extremes. Other factors also mitigate against wearer acceptance. An improperly fitted mask may create intolerable pain spots. Improperly designed or malfunctioning valves may cause uncomfortable restrictions to breathing or an irritating flicking and popping. Limitations on communications may be unpleasant and add to the hazards. All these factors contribute to the physical discomfort which affects willingness to wear and to make proper use of respirators. If proper attention is paid to these factors in selecting equipment, most people may be provided with respirators that do not cause undue distress and that will effectively protect the wearer.

7. TRAINING

7.1. Qualifications of Training Personnel

Training in the use of respiratory protective devices shall be given by a qualified and experienced instructor, such as a health physicist, industrial hygienist, or safety engineer. The instructor shall have a thorough knowledge of the application and use of respiratory protective equipment and of the hazards associated with airborne contaminants both radioactive and nonradioactive. He also shall have had experience in the practical selection and use of a respirator.

7.2. Extent of Training

The instructor shall develop an adequate training program based on the hazards to be encountered and the types of respirators to be worn. Training must be given not only to the persons who will perform the work using the respirators but also to those individuals who will direct the work. It is important, especially where respirators are used only occasionally, that periodic retraining be performed, so that a high degree of proficiency will be retained when respiratory equipment is actually used.

7.3. Contents of Training Program

Training in the use of any respirator shall cover at least the following:

1. Discussion of the airborne contaminants against which the wearer is to be protected

including their physical properties, TLVs, MPCs, physiological action, toxicity, and means of detection.

2. Discussion of the construction, operating principles, and limitations of the respirator and why it is the proper type for the particular purpose.

3. Discussion of the reasons for using the respirator and an explanation of why more positive control is not immediately feasible. This shall include recognition that every reasonable effort is being made to reduce or eliminate the need for respirators.

4. Instruction in procedures for assuring that the respirator is in proper working condition and an explanation of its capabilities and limitations.

5. Instruction in fitting the respirator properly and checking for adequacy of fit.

6. Instruction in the proper use and maintenance of the respirator.

7. Discussion of the application of various cartridges and canisters available for air-purifying respirators.

8. Instruction in emergency action to be taken in the event of malfunction of respiratory protective devices.

9. Review of radiation, radioactive contamination, and other hazards, including the use of other protective equipment which may be used with respirators.

10. Classroom and field training to recognize and cope with emergency situations.

11. Other special training as needed for special use, such as training of emergency teams.

7.4. Drills

Training shall include the use of the respirator under simulated conditions of exposure so that the wearer will develop a sense of confidence in his ability to use the device properly. Performance in these drills shall be reviewed with the trainees by a qualified observer.

8. FITTING OF RESPIRATORS

Fitting of respirators can be accomplished either with quantitative man tests or qualitative tests. Any sizeable respirator program or a program which uses respirators for highly hazardous conditions or materials should use quantitative tests for selecting the best-performing mask for each individual. Qualitative field fitting tests should be used prior to each entrance into a hazardous atmosphere to ascertain that an adequate fit has been obtained.

At least a qualitative fitting program, employing a challenge atmosphere, shall be used to determine which models of masks give each wearer the best protection.

8.1. Quantitative Man Tests

Quantitative man tests in a chamber of some type employ a challenge atmosphere of a known concentration. The wearer, fitted with an appropriate device for protection against the challenge atmosphere, is first given a qualitative test. Once an adequate fit is determined qualitatively, the wearer enters the chamber. A sampling tube, coming from the inside of the specially modified test respirator, is connected outside the chamber to an appropriate instrument for sampling and measuring the atmosphere within the mask. A technician can then measure leakage into the respirator while the wearer performs various exercises.

8.1.1. Polydisperse DOP Man Test System. A mobile, quantitative, polydisperse DOP respirator man test system developed by an ERDA contractor is illustrated in Fig. 8-1.

Fig. 8-1.
Polydisperse DOP man-test system.

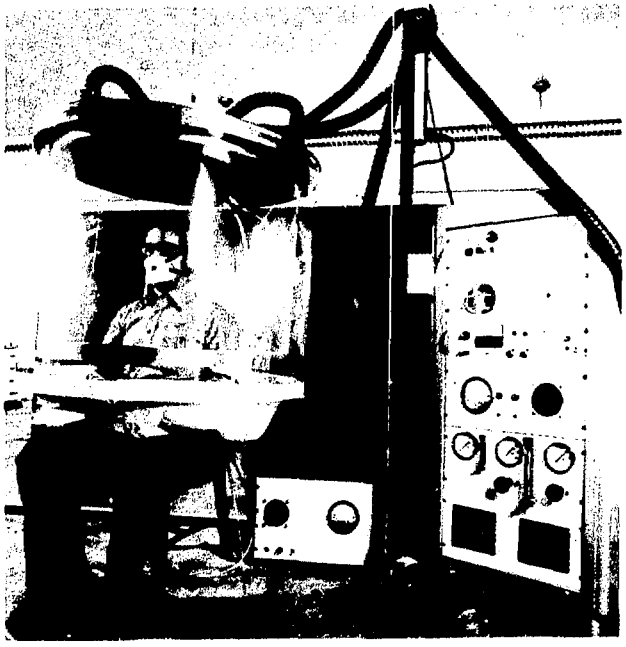

Fig. 8-2.
Polydisperse NaCl man-test system.

The major component, the "Polydisperse DOP Aerosol System" contains an air-generated DOP aerosol system, a 5-decade, forward light-scattering photometer, an air supply, and a sampling vacuum system. This unit operates on 115V, 60 Hz AC current and may be moved without difficulty to any location where electrical power is available.

The test chamber is a Harvard School of Public Health design that features an annular exhaust system to prevent aerosol contamination of the area outside the hood. This unit can be hung from the ceiling or from a portable frame. Flexible hose from the main unit delivers the DOP aerosol to the hood, and exhaust lines return the dynamic flow of aerosol to a high efficiency filter. A strip chart recorder is connected to the photometer output signal for a permanent record of test results.

The main advantages of this system are: (1) relatively low initial cost, (2) mobility, and (3) versatility. The air-pressure generated, polydisperse DOP aerosol is not heated,* and therefore does not generate decomposition products and is virtually odorless. The DOP aerosol concentration maintained for man testing is 25 ± 5 mg/m^3 for air-purifying respirators and may be increased to 100 mg/m^3 for testing respiratory protective devices offering a higher degree of protection.

The air-generated, polydisperse DOP man test system, illustrated in Fig. 8-1, is commercially available from two sources in similar configurations.

8.1.2. Sodium Chloride Test. In the United Kingdom and Canada, sodium chloride respirator man tests for all types of particulate respirators have been accepted as a standard procedure. In the U. S., development of a NaCl respirator man test system has been pursued by an ERDA contractor at the request of the National Institute for Occupational Safety and Health. The design of a mobile system was influenced by the experience and techniques developed in the United Kingdom and Canada. A polydisperse NaCl man test system is shown in Fig. 8-2. Models equivalent to this unit are available commercially.

The NaCl aerosol concentration is measured by the response of a photomultiplier tube to the yellow sodium line (589 nm) excited in a propane flame. The ratio of the NaCl aerosol concentration leaking into the facepiece to the concentration in the test chamber is monitored by a recorder built into the electronics cabinet. The test chamber is identical to that described in the section on the polydisperse DOP man test system. This unit will measure facepiece leakage as low as 0.02%.

The principal advantage of a NaCl respirator man test system is the use of low concentrations (15 ± 2.5 mg/m^3) of a nontoxic, solid, odor-free aerosol. The rapid response of the flame photometer to facepiece leakage is equal to that of DOP systems even though the sampling rate is much lower (8 lpm for DOP, 1 lpm for NaCl), causing less interference with the normal functioning of the respirator. The NaCl aerosol may be used for respirator man tests with dust, fume, or high efficiency filters without concern about overexposure of the test subject.

8.1.3. Freon-12 Test. A Freon-12 man test system has been developed and used successfully at an ERDA installation with the use of halide detector which was intended primarily for use by industrial hygienists for field studies with halanated hydrocarbons. Freon-12 has a TLV of 1000 ppm, is nonflammable, highly inert, and relatively nontoxic. Particle size is not a problem with a gas such as Freon-12 and it is easy to control the concentration.

To perform a man test the respirator must be equipped with an external supply of clean air since Freon-12 is not captured by conventional chemical sorption cartridges. The low

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*NOTE: Thermally generated monodisperse DOP is not recommended for man tests because of the unknown toxicity of the decomposition products.

sampling rate (~1350 cm^3/min does not interfere with the functioning of the respirator, but it does not have sufficiently rapid instrument response time to record the breathing cycle (inhalation-exhalation) or indicate head and facial movements that cause facepiece leakage. The man test data output can be recorded and analyzed to determine an overall integrated test average. Considering that the Freon-12 test system is not sensitive to the breathing cycle and that it requires an additional air supply system, the NaCl test method is preferred.[14]

8.1.4. Simulated Work Conditions. The more closely that working conditions can be duplicated during quantitative fitting tests, the more useful the test results. Testing a man for fit who is standing perfectly still will not reveal leaks that can occur from moving the head or from mask slippage due to perspiration.

Minimum movements that should be performed during a quantitative test are:

1. Normal breathing.
2. Deep breathing.
3. Moving head from side-to-side (slowly).
4. Moving head up-and-down (slowly).

5a. Smile (for quarter and half masks only).

5b. Frown (for full face masks only).

6. Talking (e.g., reading a short passage aloud).
7. Normal breathing (to recheck seal after movements). The use of a treadmill to simulate work stress may also be beneficial during fitting tests; however, any test which physically stresses the subject should be approved by the contractor's medical department.

8.1.5. Fitting Chambers. Various types of chambers can be used for quantitative and qualitative tests.

8.1.5.1. Test Rooms. A room works well, provided that there is sufficient window space to allow the technician to observe the wearer. A means of communication is also required. While the room-size chamber allows more vigorous exercise enabling the technician to check for leakage from mask slippage due to perspiration and movement, a greater volume of the challenge atmosphere is required to maintain an adequate concentration. A test room is shown in Fig. 8-3.

8.1.5.2. Test Booths. A booth such as an audiometric booth or telephone-style booth is easily converted for use as a fitting chamber.

8.1.5.3. Plastic Hoods. Plastic hoods work well. Figure 8-1 shows a hood large enough for any respirator. The hood can be raised and lowered by an electric motor for entering and leaving. A treadmill can be used with the hood.

8.2. Qualitative Tests

When quantitative fitting test equipment is not available, some form of qualitative test is required. It is preferable to use a chamber with a challenge atmosphere such as isoamyl acetate in order to perform exercises. Various kinds of chambers can be used. Rooms or booths are very good. One manufacturer makes a plastic hood and aerosol generator which fit into a suitcase for easy portability.

One of the best qualitative fitting chambers for SCBA is a converted boxcar located at Lawrence Livermore Laboratory in California. The challenge atmosphere is supplied

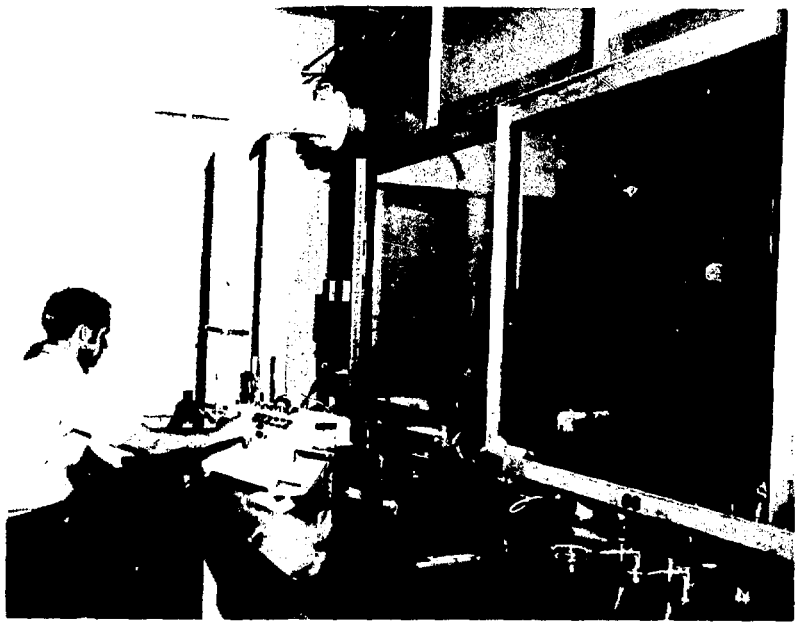

Fig. 8-3.
Respirator test room.

from a pot-bellied stove in which wet straw is burned and piped into the boxcar. The trainees, wearing SCBA, are first exercised outside the building by running and roiling barrels that are half filled with sand. They then enter the boxcar and read various dials located up on platforms and under low overheads so that climbing and crawling is required. Oxygen and carbon monoxide readings are taken by each trainee, so that he is aware of the concentrations present. Emergency conditions are simulated with dummy victims needing first aid.

The major disadvantage of a qualitative test is relying on the wearer to determine mask leakage. The threshold of odor of various challenge atmospheres varies among different people and thus, some wearers may not detect a significant leak. A wearer without proper training may claim a leak on a less comfortable mask when none exists and claim no leak on a device which he prefers when it is actually not sealing properly.

8.2.1. Isoamyl Acetate Test. Isoamyl acetate has been used by MESA/NIOSH as a qualitative means of evaluating half-face and full facepiece fit on air-purifying respirators. Such respirators must be fitted with appropriate organic vapor canisters or cartridges for this test. This material, commonly known as banana oil, can be detected by odor in very low vapor concentrations for semi-quantitative testing. An air concentration of 100 ppm of isoamyl acetate (IAA) is recommended for testing half-masks and 1000 ppm for full face masks. (See Refs. 2 and 3 for details.) If a person wearing a respirator can enter and remain in the test atmosphere simulating work activities without detecting the odor of IAA, the respirator is properly fitted. If he detects the odor of IAA, he should retreat to fresh air, readjust the facepiece, and then repeat the test. If leakage is still noted, he should retreat to fresh air and re-check the respirator as previously outlined.

The organic vapor cartridges must, of course, be replaced with high efficiency filters for use against particulates.

Testing the reliability of the face fit in the field can be done using IAA on a stencil brush or on cotton and waving it gently near the periphery of the facepiece and cartridge. Spray cans of IAA are also available. This test must be used continuously for it requires complete understanding and cooperation of the person being tested. Personnel must be tested to determine their ability to detect the IAA at low concentrations and during the test must be protected from overexposure to prevent fatigue. Only skilled personnel should use the semi-quantitative fitting test.

8.2.2. Irritant Smoke Test. A qualitative method for checking facial fit of air-purifying respirators using high efficiency particulate filters involves exposing the wearer to an irritating aerosol of stannic chloride (titanium tetra-chloride has also been used) generated with a commercially available smoke tube. This procedure is said to provide the same sensitivity as the IAA method and can also be used in the field.

In using these generators the wearer should be cautioned to keep his eyes closed and to breathe very shallowly at the beginning of the test, because the smoke is highly irritating. The tube should be no closer than two inches to the eyes, canister or facepiece at any time.

8.2.3. User Fit Tests. When it is impossible to perform the field tests using IAA or stannic chloride, either of the following less satisfactory tests may be substituted and should be performed just prior to actual use of the equipment. These tests should be used with considerable caution since small leaks, which may be significant (around eyepieces, lens frames, speaking diaphragms, etc.), may remain undetected. Furthermore, pushing on the facepiece as described below may also close off a facepiece-to-face seal leak.

The negative pressure test is performed by closing off the inlet opening of the canister or the breathing tube by covering it with the palm of the hand or by replacing the tape seal. Gently inhale so that the facepiece collapses slightly, and hold the breath for 10 seconds. If the facepiece remains in its slightly collapsed condition and no inward leakage of air is detected, the tightness of the respirator is satisfactory.

The positive pressure test is performed by blocking the exhalation valve and exhaling gently so that a slight positive pressure is built up inside the facepiece using the palm of the hand to block the exhalation valve. The exhalation valve cover may have to be removed. If no outward leakage of air is detected at the periphery of the facepiece, the face fit is satisfactory. Note: With certain devices, removal of the exhalation valve cover is very difficult, making this test almost impossible to perform. Care must be taken not to damage the exhalation valve when the cover is replaced.

9. MAINTENANCE

9.1. Minimal Acceptable Maintenance Program

The primary purpose of the maintenance program is to ensure that respiratory protective equipment is kept in good operating condition. A program of continuous maintenance and inspection is imperative.

The minimal acceptable maintenance program shall include the following operations: inspection, testing, and repair; storage; inventory; issuance of devices; replacement of filter and/or sorbent canisters and cartridges; surveys for contamination; decontamination; cleaning and disinfection; provision of a pure, uncontaminated air or oxygen supply; and maintenance of auxiliary equipment.

9.2. Inspection, Testing and Repair

An inspection, testing, and repair program shall be established in order to ensure the operability of respiratory protective equipment. The program shall include the following elements:

1. All respirators shall be inspected routinely before and after each use. Devices stored for emergency use shall be inspected after each use and at least monthly to assure that they are in satisfactory working condition. A record of inspection dates and findings shall be kept on all emergency-use devices. Routinely used and personal-issue devices shall be inspected before and after each use and at least monthly. Inspection shall include a check on the tightness of connections and the condition of the facepiece, headbands, valves, connecting tube and canisters. Special attention shall be given to rubber or elastomer parts, to ensure that they are pliable and flexible and not deteriorating during storage.

Self-contained breathing apparatus shall be inspected monthly to ascertain that air and oxygen cylinders are fully charged, facepiece assemblies are totally functional and properly stored, the harness assemblies are in good condition, and that the regulators and warning devices function properly.

2. Portions of respiratory protective devices such as regulators, valves, warning devices and cylinders shall be tested periodically for proper function in accordance with the manufacturer's instructions or applicable standards.

3. Inspection and testing shall be carefully supervised and performed only by responsible and thoroughly trained individuals.

4. Repair of any component of a respiratory protective device shall be undertaken only by persons thoroughly familiar with the device and instructed in the type of repair to be performed. No attempt shall be made to replace components or to make adjustments or repairs beyond the manufacturer's recommendations. No attempt shall be made to repair or adjust pressure-reducing valves or regulators. These items shall be returned to the manufacturer or to a mechanic trained by the manufacturer for adjustment or repair.

5. Components of respiratory protective devices shall be changed on a replacement schedule as required by the conditions of use and in no case exceeding the recommendations of the manufacturer.

9.3. Storage

After cleaning, inspection, testing, and repair, the respiratory protective equipment shall be placed in storage in plastic or paper bags or storage cases. Care shall be taken that the equipment is not exposed to direct sunlight, heat, extreme cold, or excessive moisture and other physiochemical environments likely to cause damage. Emergency use devices placed at stations and work areas shall be clearly marked and stored so as to be quickly accessible at all times. Devices in proper condition for re-use shall be clearly identified and separated from units to be repaired. The respirators shall be packed or stored so that they will not be damaged by adjacent equipment or distorted out of their normal configuration.

9.4. Inventory and Control

Inventory and control procedures shall be established as a means of identifying the stock level of all respiratory protective devices and replacement parts of any respirator.

9.5. Issuance of Respirators

Procedures for issuance of respiratory protective equipment shall be established so that the correct respirator is used for each job. This is usually accomplished by having the respirator type specified either in the work procedures or by the qualified individual supervising the respiratory protective equipment program. It is essential that the individual using or supervising the use and issuance of respirators be adequately trained to ensure that the correct respiratory equipment be used for each job.

Where desirable, individuals may have a permanently assigned respirator which should be durably marked to indicate to whom it was assigned. This marking shall not affect the respirator performance in any way.

9.6. Contamination Surveys/Decontamination

All respiratory protective equipment used for protection against radioactive contaminants shall be surveyed prior to cleaning and disinfection. Respirator facepieces or hoods may be re-used by the same individual on the same working day, provided that (1) the beta-gamma contamination level on any surface of the facepiece or hood does not exceed 0.2 millirad per hour above background at contact or (2) the alpha contamination level does not exceed 100 dpm per 100 cm^2.

Respirators returned for reissuance or use at another time shall show no contamination as determined by standard swipe or smear techniques and shall not exceed 100 dpm per 100 cm^2 fixed alpha or 1000 dpm per 100 cm^2 of beta-gamma above background at contact on any accessible surface.

9.7. Cleaning and Disinfection

Respirators shall be exchanged periodically for cleaning and inspection. In a large program where respirators are used routinely, this period could be daily; in small programs with only occasional use, the period could be weekly or longer; however, it should not exceed 30 days. When respirators are individually assigned, they should be durably marked to ensure that the worker will receive the same device on reissuance. Each worker should be briefed on the cleaning procedure and assured that he will always receive a clean and disinfected respirator. Such assurances are of the greatest significance when respirators are not individually assigned to workers. Emergency devices shall be cleaned after each use.

It is generally accepted that washing with a good detergent in warm water (by hand brushing or use of a specially adapted washing machine), rinsing and air-drying in a clean place is a sound cleaning procedure. Care should be taken not to damage the respirator by excessive heating or agitation in the washing solution. The disinfection procedure need not be followed for respirators issued on an individual basis.

A procedure that may be followed in cleaning air-purifying respirators is:

(1) Remove the filters, cartridges, or canister.
(2) Wash in cleaner-sanitizer solution at 120 -140°F (maximum).
(3) Rinse completely in clean, warm or hot water (140°F maximum).
(4) Air-dry in a clean area.
(5) Inspect valves, headbands, and other parts; replace with new parts if defective.
(6) Insert new or retested filters and cartridges; make sure seal is tight.
(7) Place in a plastic bag for storage.

Cleaner-sanitizer solutions that effectively clean the respirator and contain a bactericidal agent are available. The bactericidal agent is generally a quaternary ammonium compound. The respirator may be immersed in the cleaner-sanitizer solution,

rinsed well in clean, warm (140°F maximum) water to remove all sanitizer solution and air- or machine-dried.

It is good practice to disinfect respirators in addition to washing them before they are reissued, especially if they will be used by different individuals. In addition to commercial cleaner-sanitizers, other compounds considered reliable for disinfecting respirators are: (1) a hypochlorite solution (50 ppm of chlorine, immersion time 2 min), or (2) an aqueous solution of iodine (50 ppm iodine, 2 min immersion). A concentration of 200 ppm of quaternary ammonium compounds in water with less than 500 ppm total hardness is generally an effective disinfecting solution. The disadvantages of the quaternary ammonium compounds are: (1) different concentrations of salts are required to achieve a disinfecting solution with water of varying composition, and (2) the possibility of dermatitis if the quaternary ammonium salts are not completely rinsed from the respirator.

Cleaning and disinfecting agents or solvents that can damage parts of a respiratory protective device shall not be used.

9.8. Maintenance of Air or Oxygen Supplies

Procedures for the maintenance of a supply of respirable air or oxygen shall be included as part of the respiratory protective equipment program. The air or oxygen cylinder supply shall be inventoried periodically to ensure that a sufficient supply is available.

All fittings and components shall be standardized so that the introduction of gases other than pure breathing air or pure breathing oxygen into a respirator system is impossible. Every compressed gas cylinder containing pure breathing air or pure breathing oxygen shall be appropriately labeled. When a compressor is used, it must be properly monitored and attended to ensure that the air intake remains in an uncontaminated atmosphere. A separate breathing air supply and distribution system shall be used and the ordinary plant supply of compressed air in any building shall not be used for breathing purposes (due to possible presence of carbon monoxide, oil vapor, and other contaminants) unless it has been specially modified and properly adapted for such use and specifically approved for this purpose by the qualified person supervising the respiratory protective equipment program. The maintenance of a breathing air or oxygen supply shall be performed by trained individuals. Adequate numbers of personnel must be assigned to attend and monitor air supplies, hoses, and communication lines and to keep workers using the respiratory equipment under precautionary surveillance by signal, verbal, or line-of-sight communication.

10. QUALITY ASSURANCE

The purpose of a quality assurance (QA) program is, as the title implies, to ensure against the use of defective or faulty devices. A proper and complete QA program must include inspection and testing of both new and used devices. Written procedures shall be established to maintain uniformity of the program.

10.1. New Equipment

Quality assurance inspection and testing of new equipment should be done upon receipt of equipment.

10.1.1. Air-Purifying Devices. Air-purifying devices should be inspected as follows:

10.1.1.1. Facepieces. Half-mask facepieces should be inspected to ascertain:

1. Four-point strap suspension (shall be specified on order). Only 4-point suspension is acceptable.
2. Rubber or elastic strap material. Elastic straps are recommended and should be specified on order.
3. Single or dual cartridge facepiece (should be specified on order).
4. Integrity of valves and seats.
5. Presence and integrity of cartridge gasket or gaskets (as required).
6. Integrity of facepiece (absence of tears, mold defects, or deformation).

Full facepieces require more attention than the half-mask facepieces due to the intricacy of the valves and speaking diaphragm assembly available on most. Inspection of full facepieces should include:

1. Straps and suspension.
2. Facepiece material (i.e., neoprene, silicone, etc.) (should be specified on order).
3. Integrity of facepiece (absence of tears, mold defects, or deformation).
4. Canister or cartridge mounts (cheek, chin, chest) (should be specified on order).
5. Canister or cartridge gaskets (where applicable).
6. Inhalation and exhalation valve and seat integrity.
7. Speaking diaphragm assembly (Mylar diaphragm, diaphragm gasket, assembly tightness). A simple vacuum test on the assembly is quite effective.
8. Lens (scratches, cracks, blemishes).
9. Check of all clamps and connections for tightness. Where leak test equipment is available, it is advisable to test the complete facepiece assembly for leaks.

10.1.1.2. Cartridges, Canisters, and Filters. Cartridges, canisters, and filters should be visually inspected for damage from handling and shipping. Presence of proper labels should be checked and the protection afforded should be checked against the label on the storage container. (Note: High efficiency particulate filters must be at least 99.97% efficient by testing with a monodisperse 0.3 μm DOP aerosol. Arrangements shall be made to check a portion of each filter shipment for efficiency.

When chest or back-mounted canisters are used, the canister harness assembly and corrugated breathing tube or tubes shall be inspected for defects.

10.1.1.3. Powered Air-Purifying Units. A powered air-purifying filter is connected to a facepiece, hood, or helmet by means of a corrugated breathing tube. In addition to inspection and testing of the facepieces, hoods, or helmets on the units, the blower must be checked for adequate airflow and the tubing must be inspected for cracks or other defects and tightness of connections.

10.1.2. Air Line Respirators.

10.1.2.1. Facepieces, Hoods, Helmets and Suits. Inspection and testing of facepieces of supplied-air devices should be as outlined in 10.1.1. An additional step must be added to include the corrugated breathing tube which shall be checked for holes or defects in the rubber and tightness of the connections on both ends.

Hoods and suits should be checked for tears and defects in the fabric, presence of zippers and snaps as required. and integrity of air distribution and exhaust systems.

10.1.2.2. Regulators. Supplied-air regulators shall be visually inspected and dynamically tested.

If factory-trained repair technicians and factory-approved test equipment are not available, the regulator shall be returned to the factory every three years for repair and inspection.

10.1.2.3. Compressors. Compressors used to provide air for atmosphere-supplying respirators should be inspected and tested to ascertain:

1. Proper intake filters.
2. Moisture traps.
3. Sufficient reserve air storage (where required).
4. Carbon monoxide alarm presence and proper function (for oil-type compressors).
5. Adequate air output for equipment to be used.
6. Heat alarm function (for oil-type compressors).

Oil-type compressors may be used only if fitted with either a continuous carbon monoxide monitor and/or high temperature alarm. Diaphragm and water-seal pumps are recommended since they will not create an oil-mist or carbon monoxide-contaminated air supply.

The intake to the compressor shall be located in an area which can be predicted to remain uncontaminated in case of an emergency.

10.1.2.4. Air Line Hose. Air line hoses should be inspected for:

1. Contaminants (mold powder, ground rubber, etc.) inside of hose.
2. Fittings and connections must not be compatible with other gas systems.
3. Cuts, breaks or weak spots in hose.
4. Tightness of fittings.

10.1.3. Self-Contained Breathing Apparatus (SCBA). SCBA the most complicated of respiratory protective devices, require more extensive inspection and testing than other devices. Owing to the intricacy of the parts of the SCBA, visual inspection is not sufficient to find defective units. Inspection and testing of SCBA must be done by individuals familiar with the particular device.

10.1.3.1. Facepiece Assemblies. Facepiece assemblies shall be inspected as outlined in 10.1.1. with the addition of inspection of the breathing tube and the facepiece to regulator connector. Attention shall be given to the exhalation valves of those devices having a pressure demand mode of operation.

10.1.3.2. Regulators and Alarms. Regulators and alarms of SCBA shall be visually inspected and a simple test performed to check proper regulator function and integrity of the regulatory diaphragm. The alarm should be activated to test proper function.

A method for testing regulator function and diaphragm integrity is as follows:

First make sure that bypass valve is closed.

1. Demand only units.
   a. Open cylinder valve.
   b. Suck on regulatory outlet (air should flow).
   c. Blow gently on outlet (no air should pass through).

2. Demand/Pressure-Demand Units.
   a. Select demand mode of operation.
   b. Follow steps a, b, and c of 1. above.
   c. Cover outlet of regulator with hand.
   d. Select pressure demand mode of operation (no air should flow).
   e. Remove hand from outlet (air should flow freely).

3. Pressure-Demand Only Units.
   a. Blow gently on outlet (no air should pass through).
   b. Open cylinder valve.
   c. Cover regulatory outlet with hand.
   d. Open main line valve on regulator (no air should flow).
   e. Remove hand from outlet (air should flow freely).

10.1.3.3. Other Associated Equipment. Other parts of SCBA which must be checked are:

1. Cylinder - check pressure, check cylinder valve for leaks, inspect cylinder valve lock for presence and function.
2. Back-pack and harness assembly - inspect integrity of straps, buckles and fasteners, check back-pack cylinder lock assembly for function.

10.1.3.4. Recirculating Devices (Closed Circuit Apparatus).

1. Breathing bags - visually inspect for tears and defects, then inflate and check for leaks.
2. CO_2 Sorbent - make certain that used sorbent is removed from unit before storage. (Do not refill with sorbent until immediately prior to use of unit.) Note that seals on sorbent containers are in place.
3. O_2 Generating Canister - never store oxygen generating unit with O_2 generating canister in place. Place canister into unit immediately prior to use. Make certain that canisters are properly sealed.
4. Check canister seals on unit.

It is virtually impossible to inspect and test self-contained breathing apparatus properly without actually donning the unit. When factory-approved test equipment and factory-trained personnel are available, it is advised that new units be tested before placing in use.

While complete test and inspection procedures for each device available cannot be given in this guide, such tests and inspections should be made. Complete inspection procedures are packed with most devices or are available from the manufacturer.

10.2. Inspections and Tests After Cleaning and Maintenance

The procedures for inspection and testing of cleaned and repaired devices are the same as outlined in the preceding new equipment section, except that a leak test shall be performed on all cleaned or repaired devices. This leak check may vary from a simple field

test of the device (a test using irritant smoke or IAA to check the device prior to its use), to a sophisticated leak check employing test heads on which the device is mounted and probe-tested using a specially generated aerosol or gas with the appropriate detection equipment. Examples of this equipment are:

1. DOP aerosol with light-scattering photometric detection equipment. (See Sec. 9.1.1.)
2. Sodium chloride aerosol with flame photometer detector. (See Sec. 9.1.2.)

10.3. Periodic Checks of Items in Storage

Periodic checks of items in storage should be performed to ensure that they are in usable condition. Checks should ensure that the facepiece rubber is not becoming distorted, rubber parts are not hardening or deteriorating, sorbent canisters have not passed their shelf life and breathing-air or oxygen cylinders contain sufficient pressure. These checks are particularly important for devices stored for emergency use. (See Sec. 10.2.(A).)

11. BIOASSAY PROGRAMS

Where available, bioassay programs are used to evaluate the amounts of contaminant material in the body as a result of inhalation, ingestion, absorption, or injection. From such a program the intake of the material may be estimated. A bioassay program performed by an accredited laboratory can verify the effectiveness of respiratory protection programs.

11.1. Bioassay Techniques

Details on techniques for bioassay and subsequent determination of the intake of contaminants by the body constitute a separate field of study not included in this manual. A brief summary of the samples used is given below:

11.1.1. Sampling. Urine, fecal, breath, hair and blood samples can be used for radioactive and nonradioactive contaminants. For radioactive contaminants, there are also nose and throat swabs and whole body counting.

11.1.1.1. Summary. The choice of monitoring techniques to be used for an adequate bioassay program will depend mainly upon the characteristics of the material to which personnel might be exposed. The frequency of respiratory protection usage and duration of exposure also affect the bioassay program.

11.1.2. Analysis. All analyses must be performed by a qualified laboratory. The limits of the analytical technique must be known and the mechanism of detoxification or excretion must be understood.

11.2. Bioassay Sampling

It is desirable to obtain base-line measurements on each individual prior to work assignment in potentially contaminated atmospheres. Subsequent sampling must be

frequent enough to account for all the potential hazards. Sample collection following exposure must be timed to permit evaluation of the total intake and resultant dose.

Additional bioassay should be performed if air sampling data, accident, or equipment failure indicates that an individual might have taken into his body an appreciable quantity of material.

12. ADMINISTRATION

An effective respirator program must be based on well-conceived administrative and supervisory practices and guides. Although detailed formats for such practices and guides vary from one installation to another, certain important broad administrative areas, briefly discussed as follows, should be included.

12.1. Qualifications of Responsible Person

Responsibility for the respirator program shall be vested in one individual. The respirator program shall be under the direction of a health physicist, industrial hygienist, safety engineer, or other person similarly qualified. Regardless of his organizational position, the individual in charge of the respirator program must have the ability, training, or experience to (1) evaluate the total hazard and the job, (2) recommend engineering controls if appropriate, (3) if control cannot be otherwise obtained, specify respiratory protection, and (4) deny the use of respirators if conditions should so warrant. The responsible person should have, in addition to his other qualifications, at least one year of field experience in the use of respirators.

12.2. Procedures and Standards

Procedures shall be prepared in writing regarding all phases of the respirator program including: descriptions of equipment, information regarding issuance, maintenance, selection, use and return of equipment; use during emergencies and training techniques. Information regarding air sampling and bioassay programs shall be included or referenced.

12.3. Evaluation of Program Effectiveness

Continuous feedback of a respirator program's effectiveness is necessary in order to determine its value. Some suggested methods to obtain such feedback are:

12.3.1. Wearer Acceptance. Comfort, ability to breathe without objectionable effort, adequate visibility, ability to communicate, ability to perform tasks without undue interference, and confidence in the facepiece fit all contribute to acceptance of the devices by the wearers. Discussions with users at plant safety committee meetings, on inspections or tours through the plant, and at training sessions can bring to light complaints which should be investigated.

12.3.2. Evaluation of Protection. Bioassay results, correlated with air sampling results, are an effective means of program evaluation. Any evidence of a rise in exposure levels which could be linked to inhalation should be investigated immediately, even if

within permissible exposure limits. Any positive facepiece interior smear results should be investigated, including immediate bioassay sampling of the worker involved.

12.4. Records

Records systems shall be established for four main purposes:

12.4.1. Analysis of Adequacy of Respirator Program. Such analysis can only be made by periodic review of respirator usage including identification of the hazard, specification and use of the respirators, and analysis of results of bioassay and air sampling programs. These latter programs should include records of accurate and continuous monitoring of spaces whenever work is performed and records of individual worker internal exposure.

12.4.2. Procurement Information. Periodic review of respirator usage is needed to provide information for re-ordering of canisters and other replacement parts and to establish a replacement table for respirator components where needed.

12.4.3. Maintenance Information. Maintenance records are needed to provide knowledge of the out-of-service time for respirators, common failure of particular respirator types, and personal complaints on respirator design.

12.4.4. Training and Fitting Records. Training and fitting records are necessary for all workers who might use respiratory protective equipment in order to schedule refresher courses and refitting, and to know what makes of masks each person can wear. In addition, it is recommended that each person be issued a wallet-sized card listing those devices which adequately fit him. The wallet cards can save time in the field, particularly in the event of an emergency, in checking for acceptable mask issuance.

12.5. Methods of Staying Abreast of New Developments in the Field

With the rapid advancements in the respirator field that are occurring, both in equipment and regulations, it is essential for the program administrator to stay up-to-date. Some methods of acquiring current information are:

1. The Federal Register prints all changes in Federal regulations. Various periodic health and safety newsletters and abstracting services report on the changes directly affecting industrial health and safety regulations.
2. Health and safety professional societies such as the American Industrial Hygiene Association, Health Physics Society, National Fire Protection Association, American Society of Safety Engineers and others notify their members in newsletters and journals of new developments. Membership in one or more of these societies is recommended to those in charge of respirator programs.
3. ERDA, MESA, NIOSH and OSHA frequently publish documents on different aspects of respirators. For example, every criteria document published by NIOSH has a section on recommended respiratory protective devices for the substance about which the document was written.

13. SPECIAL PROBLEMS

In addition to the normal problems associated with properly fitting a group of workers with respiratory protection, there are a few specific problems which can be avoided by following a few basic guidelines. Among these are facial hair, dentures, prescription glasses, and the wearing of other types of protective headgear such as surgeons' caps, bumpcaps, hardhats, goggles, and faceshields. Other problems are the use of respirators in extreme temperatures and during emergencies.

13.1. Communications

Although conventional respirators distort the human voice to some extent, adequate communications can be maintained in relatively quiet areas. In noisy areas, modifications and special attachments for facepieces are available to improve the quality of the communications. A description of the various options is available in ANSI Standard Z88.2-1969, Sec. 9.5.

13.2. Prescription Glasses

Prescription or safety glasses may be worn with half-mask respirators, although there is likely to be some interference with the mask at the bridge of the nose. This interference can be minimized by careful choice of mask and proper fitting and training.

Glasses with standard temple bars shall not be worn with full facepiece respirators, as the extension of the temple bars through the sealing surface of the facepiece will cause leakage. If prescription glasses must be worn, all MESA/NIOSH approved full facepieces are required to provide for optional use of corrective spectacles or lenses without temple bars which break the facepiece-to-face seal or which shall not reduce the respiratory protective qualities of the facepiece.

Contact lenses shall not be worn with full facepiece respirators. These devices present a distinct hazard to the individual because of the possibility of the lenses slipping due to pressure on the outside corners of the eyes from a full-face mask or a speck of dirt getting under them while the respirator is being worn. Corrective action would entail removing the respirator, which means the individual would either have to leave the contaminated atmosphere or run the risk of exposure by removing the respirator in the contaminated area.

13.3. Facial Hair

Persons using tight-fitting (facepiece) respirators shall not have any facial hair which interferes with the sealing surface of the respirator. Any intrusion of facial hair into the sealing surface of the respirator results in an increase in leakage.[31] Problem areas, other than full facial hair, are beards and moustaches with half-mask facepieces and long, wide sideburns on full facepieces.

Individuals who have facial hair styles which might interfere with the sealing surface of a respirator must be closely supervised. Over a short period of time (even days), the facial hair could extend into the critical seal area. Any worker who has facial hair which intrudes into the area where the respirator seals against the face shall not be fitted with a respirator. Additionally, any worker who is not clean-shaven shall not be allowed to wear a respirator, even though he has previously obtained a satisfactory fit with the particular device. This does not apply to loose-fitting enclosures such as hoods, blouses, or suits.

The above requirement does not mean that all facial hair must be forbidden when respirators are worn, as a modest moustache or sideburns may be permitted if they do not interfere with the sealing surface of the respirator. Each case must be considered individually, but it is incumbent upon the supervisor to ensure that the respirator is sealing properly while, at the same time, having regard for the personal feelings of the individual. Good relations can be maintained by taking the time to carefully explain the danger of increased facepiece leakage due to facial hair. If a means is available for quantitatively assessing the amount of leakage it should be used. A demonstration of this type can be very convincing.

13.4. Dentures

Dentures, either partial or full, can be worn with respirators subject to certain restrictions. Full dentures generally present few problems other than some possible discomfort to the individual when wearing a half-mask or full facepiece respirator. In fact, it is recommended that full dentures not be removed because of the distortion of jaw without them. This can cause leakage in the chin area.

Partial dentures may or may not be worn with a respirator, depending upon the configuration. If there is a possibility that the partial dentures could be swallowed, then they should be removed. The wearing of dentures with hoods, suits, and blouses is not a problem.

13.5. Protective Headgear

Use of other types of protective headgear is permitted with respirators but certain precautions shall be observed. The additional headgear shall not interfere with the normal method of wearing the respirator. This means that the respirator head straps or headharness will lie next to the head in their normal position, and other protective headgear will go over them. Surgeons caps used for protection against contamination may be worn under the head straps or harness, but care must be exercised to ensure that the front of the cap does not intrude under the sealing surface of a full facepiece in the forehead area.

Goggles may be worn with half-masks only if they do not interfere with the normal sealing of the mask in the nasal bridge area. Goggles shall never be worn with full facepiece respirators. The strap holding the goggles to the face, out of necessity, will pass under the sealing edge in the temple area and cause leakage. A full facepiece granted a MESA/NIOSH approval, must have an impact resistant, shatterproof lens or eyepieces.

Faceshields can be worn with half-mask or full facepiece respirators depending on the individual design. The shield must not interfere with the normal position of the respirator on the face.

13.6. Use in Extremes of Temperatures

The use of respirators in temperatures below 32°F can result in freezing of exhalation valves and fogging of the lenses in full facepieces. Use in high temperatures causes added stress on the individual.

ANSI Standard Z88.2-1969, Sec. 9.3, describes steps which can be taken to minimize the effect of both low and high temperatures on respirators. These steps include:

1. Anti-fog compounds to coat the inside of the lens.
2. Nose cups to direct exhaled air directly through the exhalation valve.
3. Use of dry breathing air with SCBA or air line equipment. (The dew point of the breathing air shall be appropriate to the ambient temperature.)

REFERENCES

1. Herbert E. Stokinger, "The Modus Operandi of Threshold Limits Committee of ACGIH," Amer. Ind. Hyg. Assoc. J. 25, pp. 589-594 (1964).

2. International Commission on Radiological Protection, "Report of Committee II on Permissible Dose for Internal Radiation (1959)," ICRP Publication 2 Pergamon Press, London (1960).

3. International Commission on Radiological Protection, "Recommendations of the International Commission on Radiological Protection (As Amended 1959 and Revised 1962)," ICRP Publication 6, Pergamon Press MacMillan, London (1964).

4. International Commission on Radiological Protection, "Recommendations of the International Commission on Radiological Protection Adopted September 17 (1965)," ICRP Publication 9, Pergamon Press, London (1966).

5. National Council on Radiation Protection and Measurements, "NCRP Report No. 39, Basic Radiation Protection Criteria " (1971), pp. 58-64.

6. Federal Radiation Council, "Report No. 1, Background Material for the Development of Radiation Protection Standards " (1960).

7. Amer. Conf. of Gov't. Ind. Hyg., "Threshold Limit Values for 1975," ACGIH, 1014 Broadway, Cincinnati, OH.

8. National Council on Radiation Protection and Measurements "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposures," NBS Handbook 69 (National Bureau of Standards, 1959; published with addendum I. 1963).

9. American National Standards Institute, "American National Standard Practices for Respiratory Protection, Z88.2," American National Standards Institute, 1430 Broadway, New York, NY, 10018 (1969).

10. D. C. Stevens and J. B. Kitchie, "Evaluation of Airhoods and Airblouses Used at A.E.R.E.," report A.E.R.E. -R5184, Atomic Energy Research Establishment, Harwell, England (1966).

11. American Industrial Hygiene Association - American Conference of Governmental Industrial Hygienists, "Respiratory Protective Devices Manual " (Braun and Brumfield, Inc., Ann Arbor, MI, 1963).

12. Title 30, Code of Federal Regulations, Part 11, "Respiratory Protective Apparatus, Tests for Permissibility, Fees, Filter-type Dust Fume, and Mist Respirators," U. S. Bureau of Mines Schedule 21B, January 19, 1965 and Amended March 23, 1965.

13. F. E. Adley and D. E. Wisehart, "Methods of Performance Testing of Respiratory Protective Equipment," Amer. Ind. Hyg. Assoc. J. **23**, p. 251 (July-August, 1962).

14. C. N. Davies, (Ed.) "Design and Use of Respirators," Pergamon Press (MacMillan, London, 1962).

15. E. C. Hyatt, "Air-Purifying Respirators for Protection Against Airborne Radioactive Contaminants," **Health Physics 9, 425-432 (1963).**

16. L. Silverman and W. A. Burgess, "Respiratory Protective Equipment, A Final Report," USERDA report NYO-9323, Harvard School of Public Health (June, 1964).

17. R. F. Hounan, D. J. Morgan, D. T. O'Connor, and R. J. Sherwood, "The Evaluation of Protection Provided by Respirators," **Ann. Occup. Hyg. 7, 353-363 (1964).**

18. D. J. Morgan, "A Method of Testing the Efficiency of a Respirator Using a Halogenated Hydrocarbon Test Gas," report A.E.R.E. -R4485 (1964).

19. E. E. Plumb, E. L. Mendenhall, and M. C. Robbins, "Evaluation of Protective Clothing and Equipment for Operations in Oxygen-Rich or Deficient Atmospheres Approaching -100°F," Amer. Ind. Hyg. Assoc. J. **27**, pp. 29-38 (1966).

20. J. M. White and R. J. Beal, "The Measurement of Leakage of Respirators," Amer. Ind. Hyg. Assoc. J. **27**, pp. 239-242 (1966).

21. H. L. Green, "1965 Yant Award: Respiratory Protection Against Particulates-Problems Solved and Unsolved," Amer. Ind. Hyg. Assoc. J. **26**, pp. 203-211 (1965).

22. Pamphlet G7.1, "Commodity Specification for Air," Compressed Gas Association, Inc.

23. H. L. Butler and R. W. VanWyck, "Integrity of Vinyl Plastic Suits in Tritium Atmospheres," **Health Physics 2, 195-198 (July 1959).**

24. H. L. Butler and R. W. VanWyck, "Protective Clothing Program at the Savannah River Plant," Amer. Ind. Hyg. Assoc. J. **21**, p. 55 (1960).

25. J. J. Croley, Jr., "Specialized Protective Clothing Developed at the Savannah River Plant," Amer. Ind. Hyg. Assoc. J. **28**, pp. 51-55 (1967).

26. J. E. Dummer, Jr. (Ed.), "General Handbook for Radiation Monitoring,"LA-1835 **(3rd Ed.), Los Alamos Scientific Laboratory (U. S. Govt. Printing Office, 1958).**

27. R. F. Hounan, "A Method for Evaluating the Protection Afforded When Wearing a Respirator," report A.E.R.E. -R 4125 (Atomic Energy Research Establishment, Harwell, England, 1962).

28. W. A. Burgess, L. Silverman, and F. Stein, "A New Technique for Evaluating Respirator Performance," Amer. Ind. Hyg. Assoc. J. **22**, p. 422 (1961).

29. E. C. Hyatt, "Current Problems and New Developments in Respiratory Protection," Amer. Ind. Hyg. Assoc. J. **24**, pp. 295-304 (1963).

30. "Field Test Method for Fitting Respirators," National Safety News **100**, 3:41 (Sept. 1969).

31. E. C. Hyatt, J. A. Pritchard, C. P. Richards, and L. A. Geoffrion, "The Effect of Facial Hair on Respirator Performance," Amer. Ind. Hyg. Assoc. J. **34**, p. 135-142 (1973).

32. "Report of the ICRP Task Group on Lung Dynamics," Health Physics **12**, p. 173 (1966).

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