7. Air Monitoring

Contents

Introduction

Airborne contaminants can present a significant threat to worker health and safety. Thus, identification and quantification of these contaminants through air monitoring is an essential component of a health and safety program at a hazardous waste site. Reliable measurements of airborne contaminants are useful for:

- Selecting personal protective equipment.
- Delineating areas where protection is needed.
- Assessing the potential health effects of exposure
- Determining the need for specific medical monitoring. This chapter delineates the factors to consider when conducting air monitoring at a hazardous waste site. It presents strategies for assessing airborne contamination at hazardous waste sites and describes instruments and methods for measuring exposures.

Measuring Instruments

The purpose of air monitoring is to identify and quantify airborne contaminants in order to determine the level of worker protection needed. Initial screening for identification is often qualitative, i.e., the contaminant, or the class to which it belongs, is demonstrated to be present but the determination of its concentration (quantification) must await subsequent testing. Two principal approaches are available for identifying and/or quantifying airborne contaminants:

- The onsite use of direct-reading instruments.
- Laboratory analysis of air samples obtained by gas sampling beg, filter, sorbent, or wet-contaminant collection methods.

Direct-Reading Instruments

Direct-reading instruments were developed as early warning devices for use in industrial settings, where a leak or an accident could release a high concentration of a known chemical into the ambient atmosphere. Today, some direct-reading instruments can detect contaminants in concentrations down to one part contaminant per million parts of air (ppm), although quantitative data are difficult to obtain when multiple contaminants are present. Unlike air sampling devices, which are used to collect samples for subsequent analysis in a laboratory, direct reading instruments provide information at the time of sampling, enabling rapid decision-making.

Direct-reading instruments may be used to rapidly detect flammable or explosive atmospheres, oxygen deficiency, certain gases and vapors, and ionizing radiation. They are the primary tools of initial site characterization. The information provided by direct-reading instruments can be used to institute appropriate protective measures (e.g., personal protective equipment, evacuation), to determine the most appropriate equipment for further monitoring, and to develop optimum sampling and analytical protocols.

All direct-reading instruments have inherent constraints in their ability to detect hazards:

- They usually detect and/or measure only specific classes of chemicals.
- Generally, they are not designed to measure and/or detect airborne concentrations below 1 ppm.
- Many of the direct-reading instruments that have been designed to detect one particular substance also detect other substances (interference) and, consequently, may give false readings.

It is imperative that direct-reading instruments be operated, and their data interpreted, by qualified individuals who are thoroughly familiar with the particular device's operating principles and limitations and who have obtained the device's latest operating instructions and calibration curves. At hazardous waste sites, where unknown and multiple contaminants are the rule rather than the exception, instrument readings should be interpreted conservatively. The following guidelines may facilitate accurate recording and interpretation:

- Calibrate instruments according to the manufacturer's instructions before and after every use.
- Develop chemical response curves if these are not provided by the instrument manufacturer.
- Remember that the instrument's readings have limited value where contaminants are unknown. When recording readings of unknown contaminants, report them as "needle deflection" or "positive instrument response" rather than specific concentrations (i.e., ppm). Conduct additional monitoring at any location where a positive response occurs.
- A reading of zero should be reported as "no instrument response" rather than "clean" because quantities of chemicals may be present that are not detectable by the instrument.
- The survey should be repeated with several detection systems to maximize the number of chemicals detected.

Tables 7-1 and 7-2 list several direct-reading instruments and the conditions and/or substances they measure. The flame ionization detector (FID) and the photoionization detector (PID) (see Table 7-1) are commonly used at hazardous waste sites. However, some of these devices may not detect some particularly toxic agents, including hydrogen cyanide and hydrogen sulfide. Thus, these devices must be supplemented with other methods of detection.

Table 7-1. Some Direct-Reading Instruments for General Survey

INSTRUMENT	HAZARD MONITORED	APPLICATION	DETECTION METHOD	LIMITATIONS	EASE OF OPERATION	GENERAL CARE AND MAINTENANCE	TYPICAL OPERATING TIMES
Combustible Gas Indicator (CGI)	Combustible gases and vapors.	Measures the concentration of a combustible gas or vapor.	A filament, usually made of platinum, is heated by burning the combustible gas or vapor. The increase in heat is measured.	Accuracy depends, in part, on the difference between the calibration and sampling temperatures. Sensitivity is a function of the differences in the chemical and physical properties between the calibration gas and the gas being sampled. The filament can be damaged by certain com-pounds such as silicones, halides, tetraethyl lead, and oxygen-enriched atmospheres. Does not provide a valid reading under oxygen-deficient conditions.	Effective use requires that operator understand the operating principles and procedures.	Recharge or replace battery. Calibrate immedi-ately before use.	Can be used for as long as the battery lasts, or for the recommended interval between calibrations, whichever is less.
Flame Ionization Detector (FID) with Gas **Chromatography Option**	Many organic gases and vapors.	In survey mode, detects the total concentration of many organic gases and vapors. In gas chroma-tography (GC) mode, identifies and measures specific compounds.	Gases and vapors are ionized in a flame. A current is produced in proportion to the number of carbon atoms present.	Does not detect inorganic gases and vapors, or some synthetics. Sensitivity depends on the compound. Should not be used at temperatures less than 40^{o}F (4^{o}C). Difficult to absolutely	Requires experience to interpret data correctly, especially in the GC mode. Specific identifica-tion requires cali-bration with the specific analyte of interest.	Recharge or replace battery. Monitor fuel and/or combustion air supply gauges. Perform routine maintenance as described in the manual.	8 hours; 3 hours with strip chart recorder.

INSTRUMENT	HAZARD MONITORED	APPLICATION	DETECTION METHOD	LIMITATIONS	EASE OF OPERATION	GENERAL CARE AND MAINTENANCE	TYPICAL OPERATING TIMES
		In survey mode, all the organic com-pounds are ionized and detected at the same time. In GC mode, volatile species are sep-arated.		identify compounds. High concentrations of contaminants of oxygen-deficient atmospheres require system modification. In survey mode, readings can be only reported relative to the calibration standard used.		Check for leaks.	
Gamma Radiation Survey Instrument	Gamma radiation	Environmental radiation monitor.	Scintillation detector.	Does not measure alpha or beta radiation.	Extremely easy to operate, but requires experience to interpret data. Rugged, good in field use.	Must be calibrated annually at a specialized facility	Can be used for as long as the battery lasts, or for the recommended interval between calibrations whichever is less.
Portable Infrared (IR) Spectro-photometer	Many gases and vapors.	Measures concentration of many gases and vapors in air. Designed to quantify one- or two-component mixtures.	Passes different frequencies of IR through the sample. The fre-quencies adsorbed and specific for each compound.	In the field, must make repeated passes to achieve reliable results. Requires 115-volt AC power. Not approved for use in a potentially flammable or explosive atmosphere. Interference by water vapor and carbon	Requires personnel with extensive experience in IR spectrophotometry.	As specified by manufacturer.	

INSTRUMENT	HAZARD MONITORED	APPLICATION	DETECTION METHOD	LIMITATIONS	EASE OF OPERATION	GENERAL CARE AND MAINTENANCE	TYPICAL OPERATING TIMES
				dioxide. Certain vapors and high moisture may attach the instruments optics, which must then be replaced.			
Ultaviolet (UV) Photoionization Detector (PID)	Many organic and some inorganic gases and vapors.	Detects total concentrations of many organic and some inor-ganic gases and vapors. Some identi-fication of compounds is possible if more than one probe is used.	Ionizes molecules using UV radiation; produces a current that is propor-tional to the number of ions.	Does not detect methane. Does not detect a compound if the probe used has a lower energy level than the compound's ionization potential. Response may change when gases are mixed. Other voltage sources may interfere with measurements. Readings can only be reported relative to the calibration standard used. Response is affected by high humidity.	Effective use requires that the operator understand the operating prin-ciples and proced-ures, and be compe-tent in calibrating, reading, and interpreting the instrument.	Recharge or replace battery. Regularly clean lamp window. Regularly clean and maintain the instrument and accessories.	10 hours; 5 hours with strip chart recorder.

Table 7-2. Some Direct-Reading Instruments for Specific Survey

INSTRUMENT	HAZARD MONITORED	APPLICATION	DETECTION METHOD	LIMITATIONS	EASE OF OPERATION	GENERAL CARE AND MAINTENANCE	TYPICAL OPERATING TIMES
Direct-Reading Colorimetric Indicator Tubes	Specific gases and vapors.	Measures concentrations of specific gases and vapors.	The compound reacts with the indicator chemical in the tube, producing a stain whose length or color change is proportional to the compound's concentration.	The measured concentration of the same compound may vary among different manu-facturers' tubes. Many similar chemi-cals interfere. Greatest sources of error are (1) how the operator judges stain's end-point, and (2) the tube's limited accuracy. Affected by humidity.	Minimal operator training and expertise required.	Do not use a previously opened tube even if the indicator chemical is not stained.	
Oxygen Meter	Oxygen (O_2)	Measures the percentage of O_2 in air.	Uses an electrochemical sensor to measure the partial pressure of O_2 in the air and con-verts that reading to O_2 concen-tration.	Must be calibrated prior to use to com- pensate for altitude and barometric pressure. Certain gases, especially oxidants such as ozone, can affect read-ings. Carbon dioxide (CO_2) poisons the detector cell.	Effective use requires that the operator understand the operating principles and procedures.	Replace detector cell according to manufacturer's recommendations. Recharge or replace batteries prior to expiration of the specified interval. If the ambient air is more than 0.5% CO_2, replace the O_2 detector cell frequently.	8 to 12 hours.

Laboratory Analysis

Direct-reading personal monitors are available for only a few specific substances and are rarely sensitive enough to measure the minute (i.e., parts of contaminant per billion parts of air) quantities of contaminants which may, nevertheless induce health changes. Thus to detect relatively low-level concentrations of contaminants, long-term or "full-shift" personal air samples must be analyzed in a laboratory. Full-shift air samples for some chemicals may be collected with passive dosimeters, or by means of a pump which draws air through a filter or sorbent. Table 7-3 lists some sampling and analytical techniques used at hazardous waste sites.

Selection of the appropriate sampling media largely depends on the physical state of the contaminants. For example, chemicals such as PCBs (polychlorinated biphenyls) and PNAs (polynuclear aromatic hydrocarbons) occur as both vapors and particulate-bound contaminants. A dual-media system is needed to measure both forms of these substances. The volatile component is collected on a solid adsorbent and the nonvolatile component is collected on a filter. More than two dozen dual-media sampling techniques have been evaluated by NIOSH [l,2].

A major disadvantage of long-term air monitoring is the time required to obtain data. The time lag between sampling and obtaining the analysis results may be a matter of hours, if an onsite laboratory is available, or days, weeks, even months, if a remote laboratory is involved. This can be significant problem if the situation requires immediate decisions concerning worker safety.

Also, by the time samples are returned from a remote laboratory, the hazardous waste site cleanup may have progressed to a different stage or to a location at which different contaminants or different concentrations may exist. Careful planning and/or the use of a mobile laboratory on site may alleviate these problems.

Mobile laboratories may be brought on site to classify hazardous wastes for disposal. A mobile laboratory is generally a trailer truck that houses analytical instruments capable of rapidly classifying contaminants by a variety of techniques. Typical instruments include gas chromatographs, spectrofluorometers, and infrared spectrophotometers. When not in use in the mobile laboratory, these devices can be relocated to fixed-base facilities. Onsite laboratory facilities and practices should meet standards of good laboratory safety.

Usually, a few of the field samples collected are analyzed on site to provide rapid estimates of the concentration of airborne contaminants. These data can be used to determine the initial level of worker personal protection necessary to modify field sampling procedures and to guide the fixed-base laboratory analysis. If necessary, samples screened in the mobile laboratory can be subsequently reanalyzed in sophisticated fixed-base laboratories. The mobile laboratory also provides storage space, countertop staging areas for industrial hygiene equipment, and facilities for recharging self-contained breathing apparatus.

Site Monitoring

Priorities for air monitoring should be based on the information gathered during initial site characterization (see Chapter 6). This information serves as the basis for selecting the appropriate monitoring equipment and personal protective equipment (PPE) to use when conducting site monitoring. Depending on site conditions and project goals, four categories of site monitoring may be necessary: monitoring for IDLH and other dangerous conditions, general onsite monitoring, perimeter monitoring, and periodic monitoring.

Table 7-3. Some Sample Collection and Analytical Methods

SUBSTANCE	COLLECTION DEVICE[a]	ANALYTICAL METHOD[b]	TYPICAL DETECTION LIMIT OF ANALYTIC INSTRUMENT (λg)
Anions:	Prewashed silica gel tube	Ion chromatography	
Bromide			10
Chloride			5
Fluoride			5
Nitrate			10
Phosphate			20
Sulfate			10
Aliphatic Amines	Silica gel	GC/NPD	10
Asbestos	MCEF	PCM	100[c]
Metals	MCEF	ICP-AES	0.5
Organics	Charcoal tube	GC/MS	10
Nitrosamines	Thermosorb/N	GC/TEA	0.01
Particulates	MCEF	Gravimetric	
PCBs	GF filter and florisil tube	GC-ECD	0.001
Pesticides	13-mm GF filter and chromosorb 102 Tube	GC/MS	0.05

[a] MCEF = mixed cellulose ester filter.
GF = glass fiber filler
[b] GC/NPD = gas chromatography and nitrogen/phosphorus detector; PCM = phase contrast microscopy; ICP-AES = inductively coupled plasma atomic emission spectrometry; GM/MS = gas chromatography and mass spectrometry; GC/TEA = gass chromatography using a thermal energy analyzer; GC-ECD = gas chromatography using an electrical conductivity detector.
[c] Units in fibers per mm^2 of filter (Method No. 7400 from the NIOSH Manual of Analytical Methods, 3rd edition).

Monitoring for IDLH and Other Dangerous Conditions

As a first step, air monitoring should be conducted to identify any IDLH and other dangerous conditions, such as flammable or explosive atmospheres, oxygen-deficient environments, and highly toxic levels of airborne contaminants. Direct-reading monitoring instruments will normally include combustible gas indicators, oxygen meters, colorimetric indicator tubes, and organic vapor monitors. Other monitoring instruments may be necessary based on the initial site characterization. When time permits, air samples should be collected for laboratory analysis. Extreme caution should be exercised in continuing a site survey when atmospheric hazards are indicated. Monitoring personnel should be aware that conditions can suddenly change from nonhazardous to hazardous.

Acutely hazardous concentrations of chemicals may persist in confined and low-lying spaces for long periods of time. Look for any natural or artificial barriers, such as hills, tall buildings, or tanks, behind which air might be still, allowing concentrations to build up. Examine any confined spaces such as cargo holds, mine shafts, silos, storage tanks, box cars, buildings, bulk tanks, and sumps where chemical exposures capable of causing acute health effects are likely to accumulate. Low-lying areas, such as hollows and trenches, are also suspect. Monitor these spaces for IDLH and other dangerous conditions. Also consider whether the suspected contaminants are lighter or heavier than air. Then, based on the type of contaminants present, consider sampling on hilltops, under any cover or canopy where workers might work or congregate, and in trenches and low-lying areas.

In open spaces, toxic materials tend to be emitted into the atmosphere, transported away from the source, and dispersed. Thus acutely hazardous conditions are not likely to persist in open spaces for extended periods of time unless there is a very large (and hence, readily identifiable) source, such as an overturned tankcar. Open spaces are therefore generally given a lower monitoring priority.

General Onsite Monitoring

Air sampling should be conducted using a variety of media to identify the major classes of airborne contaminants and their concentrations. The following sampling pattern can be used as a guideline. First, after visually identifying the sources of possible generation, collect air samples downwind from the designated source along the axis of the wind direction. Work upwind, until reaching or getting as close as possible to the source. Level B protection (see Table 8-6 in Chapter 8) should be worn during this initial sampling. Levels of protection for subsequent sampling should be based upon the results obtained and the potential for an unexpected release of chemicals.

After reaching the source, or finding the highest concentration, sample cross-axis of the wind direction to determine the degree of dispersion. Smoke plumes, or plumes of instrument-detectable airborne substances, may be released as an aid in this assessment. To ensure that there is no background interference and that the detected substance(s) are originating at the identified source, also collect air samples upwind of the source.

Perimeter Monitoring

Fixed-location monitoring at the "fenceline" or perimeter, where personal protective equipment is no longer required, measures contaminant migration away from the site and enables the Site Safety Officer to evaluate the integrity of the site's clean areas. Since the fixed-location samples may reflect exposures either upwind or downwind from the site, wind speed and direction data are needed to interpret the sample results.

Periodic Monitoring

Site conditions and thus atmospheric chemical conditions may change following the initial characterization. For this reason, monitoring should be repeated periodically, especially when:

- Work begins on a different portion of the site.
- Different contaminants are being handled.
- A markedly different type of operation is initiated (e.g., barrel opening as opposed to exploratory well drilling).
- Workers are handling leaking drums or working in areas with obvious liquid contamination (e.g., a spill or lagoon).

Personal Monitoring

The selective monitoring of high-risk workers, i.e., those who are closest to the source of contaminant generation, is highly recommended. This approach is based on the rationale that the probability of significant exposure varies directly with distance from the source. If workers closest to the source are not significantly exposed, then all other workers are, presumably, also not significantly exposed and probably do not need to be monitored.

Since occupational exposures are linked closely with active material handling, personal air sampling should not be necessary until site mitigation has begun. Personal monitoring samples should be collected in the breathing zone and, if workers are wearing respiratory protective equipment, outside the facepiece. These samples represent the actual inhalation exposure of workers who are not wearing respiratory protection and the potential exposure of workers who are wearing respirators. It is best to use pumps that automatically maintain a constant flow rate to collect samples, since it is difficult to observe and adjust pumps while wearing gloves, respirators, and other personal protective equipment. Pumps should be protected with disposable coverings, such as small plastic bags, to make decontamination procedures easier.

Personal monitoring may require the use of a variety of sampling media. Unfortunately, single workers cannot carry multiple sampling media because of the added strain and because it is not usually possible to draw air through different sampling media using a single portable, battery-operated pump. Consequently, several days may be required to measure the exposure of a specific individual using each of the media [3, 4]. Alternatively, if workers are in teams, a different monitoring device can be assigned to each team member. Another method is to place multiple sampling devices on pieces of heavy equipment. While these are not personal samples, they can be collected very close to the breathing zone of the heavy equipment operator and thus would be reasonably representative of personal exposure. These multimedia samples can yield as much information as several personal samples [5].

When considering employee monitoring, procedures and protocols found in OSHA's Industrial Hygiene Technical Manual may be useful [6].

Variables of Hazardous Waste Site Exposure

Complex, multi-substance environments such as those associated with hazardous waste sites pose significant challenges to accurately and safely assessing airborne contaminants. Several independent and uncontrollable variables, most notably temperature and weather conditions, can affect airborne concentrations. These factors must be considered when developing an air monitoring program and when analyzing data. Some demonstrated variables include:

- Temperature. An increase in temperature increases the vapor pressure of most chemicals.
- Windspeed. An increase in wind speed can affect vapor concentrations near a free-standing liquid surface Dusts and particulate-bound contaminants are also affected.
- Rainfall. Water from rainfall can essentially cap or plug vapor emission routes from open or closed containers, saturated soil, or lagoons, thereby reducing airborne emissions of certain substances.
- Moisture. Dusts, including finely divided hazardous solids, are highly sensitive to moisture content. This moisture content can vary significantly with respect to location and time and can also affect the accuracy of many sampling results.
- Vapor emissions. The physical displacement of saturated vapors can produce short-term, relatively high vapor concentrations. Continuing evaporation and/or diffusion may produce long-term low vapor concentrations and may involve large areas.
- Work activities. Work activities often require the mechanical disturbance of contaminated materials, which may change the concentration and composition of airborne contaminants.

References

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8. Personal Protective Equipment (PPE)

Contents

Introduction

Anyone entering a hazardous waste site must be protected against potential hazards. The purpose of personal protective clothing and equipment (PPE)[1] is to shield or isolate individuals from the chemical, physical, and biologic hazards that may be encountered at a hazardous waste site. Careful selection and use of adequate PPE should protect the respiratory system, skin, eyes, face, hands, feet, head, body, and hearing. This chapter describes the various types of PPE that are appropriate for use at hazardous waste sites, and provides guidance in their

[1] The term PPE is used in this manual to refer to both personal protective clothing and equipment.

selection and use. The final section discusses heat stress and other key physiological factors that must be considered in connection with PPE use.

Use of PPE is required by Occupational Safety and Health Administration (OSHA) regulations in 29 CFR Part 1910 (see Table 8-1) and reinforced by U.S. Environmental Protection Agency (EPA) regulations in 40 CFR Part 300 which include requirements for all private contractors working on Superfund sites to conform to applicable OSHA provisions and any other federal or state safety requirements deemed necessary by the lead agency overseeing the activities.

No single combination of protective equipment and clothing is capable of protecting against all hazards. Thus PPE should be used in conjunction with other protective methods. The use of PPE can itself create significant worker hazards, such as heat stress, physical and psychological stress, and impaired vision, mobility, and communication. In general, the greater the level of PPE protection, the greater are the associated risks. For any given situation, equipment and clothing should be selected that provide an adequate level of protection. Over-protection as well as under-protection can be hazardous and should be avoided.

Developing a PPE Program

A written PPE program should be established for work at all hazardous waste sites. (OSHA requires a written program for selection and use of respirators 129 CFR Part 1910.1341). Some of the relevant regulations, listed in Table 8-1, are cited throughout the text. The word "shall" is used only when the procedure is mandated by law.

The two basic objectives of any PPE program should be to protect the wearer from safety and health hazards, and to prevent injury to the wearer from incorrect use and/or malfunction of the PPE. To accomplish these goals, a comprehensive PPE program should include hazard identification; medical monitoring; environmental surveillance; selection, use, maintenance, and decontamination of PPE; and training. These subjects are discussed in this chapter and in Chapters 2, 4, 5, 6, 7, and 10.

The written PPE program should include policy statements, procedures, and guidelines. Copies should be made available to all employees, and a reference copy should be available at each work site. Technical data on equipment, maintenance manuals, relevant regulations, and other essential information should also be made available.

Program Review and Evaluation

The PPE program should be reviewed at least annually. Elements which should be considered in the review include:

- A survey of each site to ensure compliance with regulations applicable to the specific site involved.
- The number of person-hours that workers wear various protective ensembles.
- Accident and illness experience.
- Levels of exposure.
- Adequacy of equipment selection.
- Adequacy of the operational guidelines.
- Adequacy of decontamination, cleaning, inspection, maintenance, and storage programs.
- Adequacy and effectiveness of training and fitting programs.
- Coordination with overall safety and health program elements.
- The degree of fulfillment of program objectives.

- The adequacy of program records.
- Recommendations for program improvement and modification.
- Program costs.

The results of the program evaluation should be made available to employees and presented to top management so that program adaptations may be implemented.

Table 8-1. OSHA Standards for Use of PPE

TYPE OF PROTECTION	REGULATION	SOURCE
General	29 CFR Part 1910.132	41 CFR Part 50-204.7 General Requirements for Personal Protective Equipment
	29 CFR Part 1910.1000	41 CFR Part 50-204.50, except for Table Z-2, the source of which is American National Standards Institute, Z37 series[a]
	29 CFR Part 1910.1001-1045	OSHA Rulemaking
Eye and Face	29 CFR Part 1910.133(a)	ANSI Z87.1-1968[a] Eye and Face Protection
Noise Exposure	29 CFR Part 1910.95	41 CFR Part 50-204.10 and OSHA Rulemaking
Respiratory	29 CFR Part 1910.134	ANSI Z88.2-1969[a] Standard Practice for Respiratory Protection
Head	29 CFR Part 1910.135	ANSI Z88.2-1969[a] Standard Practice for Industrial Head Protection
Foot	29 CFR Part 1910.136	ANSI Z41.1-1967[a] Men's Safety Toe Footwear
Electrical Protective Devices	29 CFR Part 1910.137	ANSI Z9.4-1968. Ventilation and Safe Practices of Abrasive Blasting Operations

[a]American National Standards Institute (ANSI), 1430 Broadway, New York, NY 10018. ANSI regularly updates its standards. The ANSI standards in this table are those that OSHA adopted in 1971. Since the ANSI standards which were then adopted had been set in 1967-1969, those standards, now required under OSHA, may be less stringent than the most recent ANSI standards.

Selection of Respiratory Equipment

Respiratory protection is of primary importance since inhalation is one of the major routes of exposure to chemical toxicants. Respiratory protective devices (respirators) consist of a facepiece connected to either an air source or an air-purifying device. Respirators with an air source are called atmosphere-supplying respirators (Figure 8-1) and consist of two types:

- Self-contained breathing apparatus (SCBAs) which supply air from a source carried by the user.

- Supplied-air respirators (SARs) which supply air from a source located some distance away and connected to the user by an air-line hose. Supplied-air respirators are sometimes referred to as air-line respirators.

Air-purifying respirators (Figure 8-2), on the other hand, do not have a separate air source. Instead, they utilize ambient air which is "purified" through a filtering element prior to inhalation.

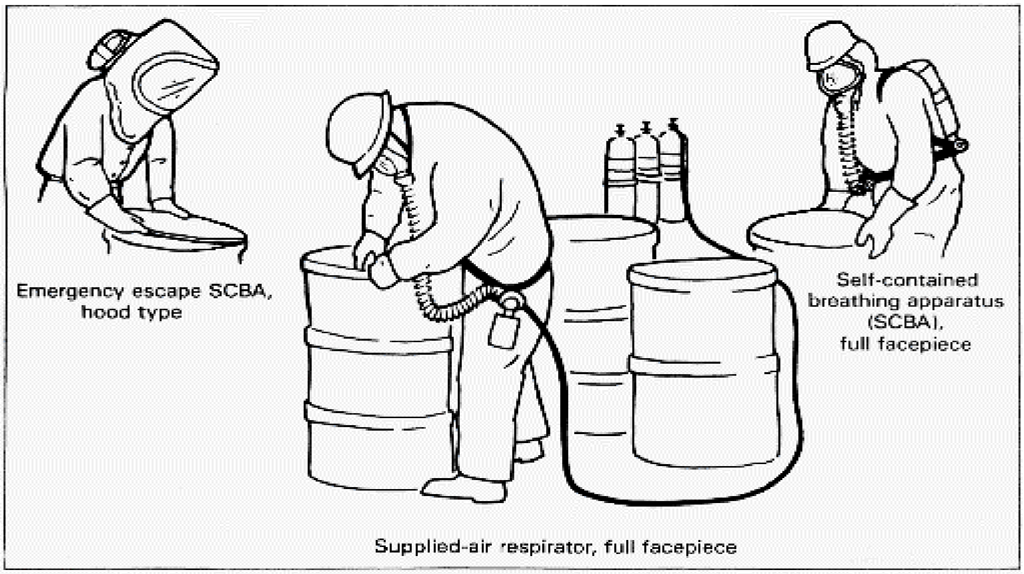


Figure 8-1. Types of Atmosphere-Supplying Respirators.

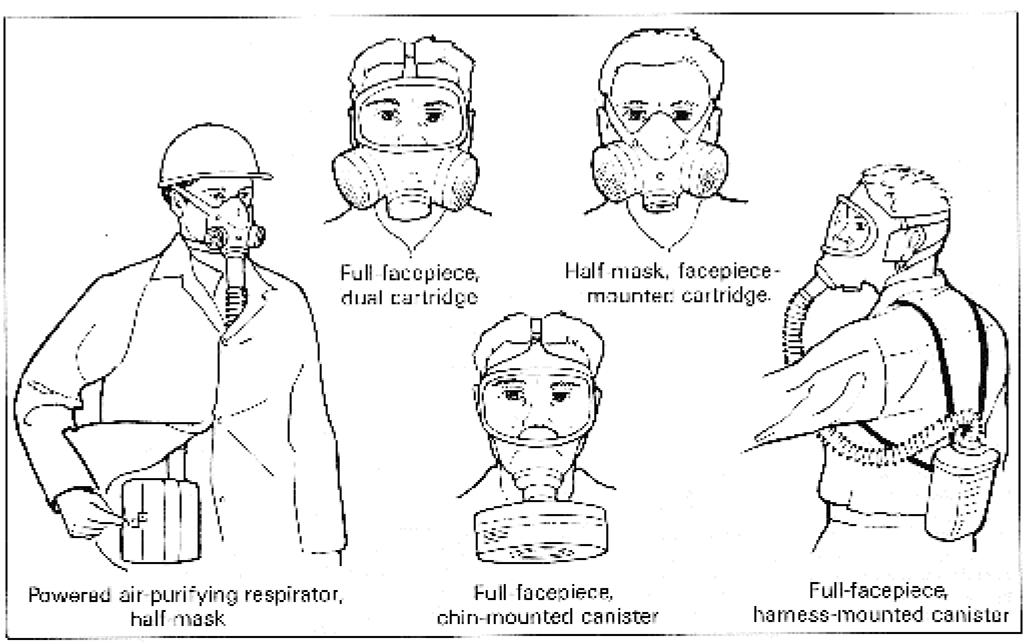


Figure 8-2. Types of Air-Purifying Respirators.

SCBAs, SARs, and air-purifying respirators are further differentiated by the type of air flow supplied to the facepiece:

- *Positive-pressure respirators* maintain a positive pressure in the facepiece during both inhalation and exhalation. The two main types of positive-pressure respirators are pressure-demand and continuous flow. In pressure-demand respirators, a pressure regulator and an exhalation valve on the mask maintain the mask's positive pressure except during high breathing rates. If a leak develops in a pressure-demand respirator, the regulator sends a continuous flow of clean air into the facepiece, preventing penetration by contaminated ambient air. Continuous-flow respirators (including some SARs and all powered air purifying respirators [PAPRs]) send a continuous stream of air into the facepiece at all times. With SARs, the continuous flow of air prevents infiltration by ambient air, but uses the air supply much more rapidly than with pressure-demand respirators. Powered air-purifying respirators (PAPRs) are operated in a positive-pressure continuous-flow mode utilizing filtered ambient air. (However, at maximal breathing rates, a negative pressure may be created in the facepiece of a PAPR.)
- *Negative-pressure respirators* draw air into the facepiece via the negative pressure created by user inhalation. The main disadvantage of negative pressure respirators is that if any leaks develop in the system (i.e., a crack in the hose or an ill-fitting mask or facepiece), the user draws contaminated air into the facepiece during inhalation.

When atmosphere-supplying respirators are used, only those operated in the positive-pressure mode are recommended for work at hazardous waste sites. Table 8-2 lists the relative advantages and disadvantages of SCBAs, SARs, and air-purifying respirators.

Different types of facepieces are available for use with the various types of respirators. The types generally used at hazardous waste sites are full facepieces and half masks.

- *Full-facepiece masks* cover the face from the hairline to below the chin. They provide eye protection.
- *Half masks* cover the face from below the chin to over the nose and do not provide eye protection.

Federal regulations require the use of respirators that have been tested and approved by the Mine Safety and Health Administration (MSHA) and NIOSH. Testing procedures are described in 30 CFR Part 11. Approval numbers are clearly written on all approved respiratory equipment; however, not all respiratory equipment that is marketed is approved. Periodically, NIOSH publishes a list, entitled *NIOSH Certified Equipment List* of all approved respirators and respiratory components [1].

Table 8-2. Relative Advantages and Disadvantages of Respiratory Protective Equipment

TYPE OF RESPIRATOR	ADVANTAGES	DISADVANTAGES
ATMOSPHERE-SUPPLYING		
Self-Contained Breathing Apparatus (SCBA)	• Provides the highest available level of protection against airborne contaminants and oxygen deficiency • Provides the highest available level of protection under strenuous work conditions.	• Bulky, heavy (up to 35 pounds). • Finite air supply limits work duration. • May impair movement in confined spaces.
Positive-Pressure Supplied-Air Respirator (SAR) (also called air-line respirator)	• Enables longer work periods than an SCBA • Less bulky and heavy than a SCBA. SAR equipment weighs less than 5 pounds (or around 15 pounds if escape SCBA protection is included). • Protects against most airborne contaminants.	• Not approved for use in atmospheres immediately dangerous to life or health (IDLH) or in oxygen-deficient atmospheres unless equipped with an emergency egress unit such as an escape-only SCBA that can provide immediate emergency respiratory protection in case of air-line failure. • Impairs mobility • MSHA/NIOSH certification limits hose length to 300 feet (90meterss). • As the length of the hose is increased, the minimum approved air flow may not be delivered at the facepiece. • Air line is vulnerable to damage, chemical contamination, and degradation. Decontamination of hoses may be difficult. • Worker must retrace steps to leave work area. • Requires supervision/monitoring of the air supply line.

Table 8-2. (cont)

TYPE OF RESPIRATOR	ADVANTAGES	DISADVANTAGES
AIR-PURIFYING		
Air-Purifying Respirator (including powered air-purifying respirators [PAPRs])	• Enhanced mobility • Lighter in weight than an SCBA. Generally weights 2 pounds (1 kg) or less (except for PAPRs).	• Cannot be used in IDLH or oxygen-deficient atmospheres (less than 19.5 percent oxygen at sea level). • Limited duration of protection. May be hard to gauge safe operating time in field conditions. • Only protects against specific chemicals and up to specific concentrations. • Use requires monitoring of contaminant and oxygen levels. • Can only be used (1) against gas and vapor contaminants with adequate warning properties, or (2) for specific gases or vapors provided that the service is known and a safety factor is applied or if the unit has an ESLI (end-of-service-life indicator).

Protection Factor

The level of protection that can be provided by a respirator is indicated by the respirator's protection factor. This number, which is determined experimentally by measuring facepiece seal and exhalation valve leakage, indicates the relative difference in concentrations of substances outside and Inside the facepiece that can be maintained by the respirator. For example, the protection factor for full-facepiece air-purifying respirators is 50. This means, theoretically, that workers wearing these respirators should be protected In atmospheres containing chemicals at concentrations that are up to 50 times higher than the appropriate limits. One source of protection factors for various types of atmosphere-supplying (SCBA and SAR) and air-purifying respirators can be found in American National Standards Institute (ANSI) standard ANSI Z88.2-1980.

At sites where the identity and concentration of chemicals in air are known, a respirator should be selected with a protection factor that is sufficiently high to ensure that the wearer will not be exposed to the chemicals above the applicable limits. These limits include the American Conference of Governmental Industrial Hygienists' Threshold Limit Values (TLVs), OSHA's Permissible Exposure Limits (PELs), and the NIOSH Recommended Exposure Limits (RELs) (see Table 6-4 in Chapter 6). These limits are designed to protect most workers who may be exposed to chemicals day after day throughout their working life. The OSHA PELs are legally enforceable exposure limits, and are the minimum limits of protection that must be met.

It should be remembered that the protection provided by a respirator can be compromised in several situations, most notably, (1) if a worker has a high breathing rate, (2) if the ambient temperature is high or low, or (3) if the worker has a poor facepiece-to-face seal. At high breathing rates, positive-pressure SCBAs and SARs may not maintain positive pressure for brief periods during peak inhalation. Also, at high work rates, exhalation valves may leak. Consequently, positive-pressure respirators working at high flow rates may offer less protection than when working at normal rates.

A similar reduction in protection may result from high or low ambient temperatures. For example, at high temperatures excessive sweat may cause a break in the face-to-facepiece seal. At very low temperatures, the exhalation valve and regulator may become ice-clogged due to moisture in the breath and air. Likewise, a poor facepiece seal -due to such factors as facial hair, missing teeth, scars, lack of or improper fit testing, etc. -can result in the penetration of air contaminants.

Self-Contained Breathing Apparatus (SCBA)

A self-contained breathing apparatus (SCBA) usually consists of a facepiece connected by a hose and a regulator to an air source (compressed air, compressed oxygen, or an oxygen-generating chemical) carried by the wearer (see Figure 8-1). Only positive-pressure SCBAs are recommended for entry into atmospheres that are immediately dangerous to life and health (IDLH). SCBAs offer protection against most types and levels of airborne contaminants. However, the duration of the air supply is an important planning factor in SCBA use (see PPE Use later in this chapter). This is limited by the amount of air carried and its rate of consumption. Also, SCBAs are bulky and heavy, thus they increase the likelihood of heat stress and may impair movement in confined spaces. Generally, only workers handling hazardous materials or operating in contaminated zones require SCBAs. Under MSHA regulations in 30 CFR Part 11.70(a), SCBAs may be approved (1) for escape only, or (2) for both entry into and escape from a hazardous atmosphere. The types of SCBAs and their relative advantages and disadvantages are described in Table 8-3.

Escape-only SCBAs are frequently continuous-flow devices with hoods that can be donned to provide immediate emergency protection. Employers should provide and ensure that employees carry an escape SCBA where such emergency protection may be necessary.

Entry-and-escape SCBA respirators give workers untethered access to nearly all portions of the worksite, but decrease worker mobility, particularly in confined areas, due to both the bulk and weight of the units. Their use is particularly advisable when dealing with unidentified and unquantified airborne contaminants. There are two types of entry-and-escape SCBAs: (1) open-circuit and (2) closed-circuit. In an open-circuit SCBA, air is exhaled directly into the ambient atmosphere. In a closed-circuit SCBA, exhaled air is recycled by removing the carbon dioxide with an alkaline scrubber and by replenishing the consumed oxygen with oxygen from a solid, liquid, or gaseous source

As required by MSHA/NIOSH 30 CFR Part 11.80, all compressed breathing gas cylinders must meet minimum U.S. Department of Transportation requirements for interstate shipment. (For further information, see 49 CFR Parts 173 and 178.) All compressed air, compressed oxygen, liquid air, and liquid oxygen used for respiration shall be of high purity and must meet all requirements of OSHA 29 CFR Part 1910.134(d). In addition, breathing air must meet or exceed the requirements of Grade D breathing air as specified in the Compressed Gas Association pamphlet G-7.1 and ANSI Z86.1-1973.

Table 8-3. Types of Self-Contained Breathing Apparatus (SCBA)

TYPE	DESCRIPTION	ADVANTAGES	DISADVANTAGES	COMMENTS
ENTRY-AND-ESCAPE SCBA				
Open-Circuit SCBA	Supplies clean air to the wearer from a cylinder. Wearer exhales air directly to the atmosphere.	Operated in a positive-pressure mode, open-circuit SCBAs provide the highest respiratory protection currently available. A warning alarm signals when only 20 to 25 percent of the air supply remains.	Shorter operating time (30 to 60 minutes) and heavier weight (up to 35 lbs [13.6 kg]) than a closed-circuit SCBA.	The 30- to 60-minute operating time may vary depending on the size of the air tank and the work rate of the individual.
Closed-Circuit SCBA (Rebreather)	These devices recycle exhaled gases (CO_2, O_2, and nitrogen) by removing CO_2 with an alkaline scrubber and replenishing the consumed oxygen with oxygen from a liquid or gaseous source.	Longer operating time (up to 4 hours), and lighter weight (21 to 30 lbs [9.5 to 13.6 kg]) than open-circuit apparatus. A warning alarm signals when only 20 to 25 percent of the oxygen supply remains. Oxygen supply is depleted before the CO_2 sorbent scrubber supply, thereby protecting the wearer from CO_2 breakthrough.	At very cold temperatures, scrubber efficiency may be reduced and CO_2 breakthrough may occur. Units retain the heat normally exchanged in exhalation and generate heat in the CO_2 scrubbing operations, adding to the danger of heat stress. Auxiliary cooling devices may be required. When worn outside an encapsulating suit, the breathing bag may be permeated by chemicals, contaminating the breathing apparatus and the respirable air. Decontamination of the breathing bag may be difficult.	Positive-pressure closed-circuit SCBAs offer substantially more protection than negative-pressure units, which are not recommended on hazardous waste sites. While these devices may be certified as closed-circuit SCBAs, NIOSH cannot certify closed-circuit SCBAs as positive-pressure devices due to limitations in certification procedures currently defined in 30 CFR Part 11.
ESCAPE-ONLY SCBA	Supplies clean air to the wearer from either an air cylinder or from an oxygen-generating chemical. Approved for escape purposes only.	Lightweight (10 pounds [4.5 kg] or less) low bulk, easy to carry. Available in pressure-demand and continuous-flow-modes.	Cannot be used for entry.	Provides only 5 to 15 minutes of respiratory protection, depending on the model and wearer breathing rate.

Key questions to ask when considering whether an SCBA is appropriate are:

- Is the atmosphere IDLH or is it likely to become IDLH? If yes, a positive-pressure SCBA should be used. A positive-pressure SAR with an escape SCBA can also be used.
- Is the duration of air supply sufficient for accomplishing the necessary tasks? If no, a larger cylinder should be used, a different respirator should be chosen, and/or the Work Plan should be modified.
- Will the bulk and weight of the SCBA interfere with task performance or cause unnecessary stress? If yes, use of an SAR may be more appropriate if conditions permit.
- Will temperature effects compromise respirator effectiveness or cause added stress in the worker? If yes, the work period should be shortened or the mission postponed until the temperature changes.

Supplied-Air Respirators (SARs)

Supplied-air respirators (also known as air-line respirators) supply air, never oxygen, to a facepiece via a supply line from a stationary source (see Figure 8-1). SARs are available in positive-pressure and negative-pressure modes. Pressure-demand SARs with escape provisions provide the highest level of protection (among SARs) and are the only SARs recommended for use at hazardous waste sites. SARs are not recommended for entry into IDLH atmospheres (MSHA/NIOSH 30 CFR Part 11) unless the apparatus is equipped with an escape SCBA.

The air source for supplied-air respirators may be compressed air cylinders or a compressor that purifies and delivers ambient air to the facepiece. SARs suitable for use with compressed air are classified as "Type C" supplied-air respirators as defined in MSHA/NIOSH 30 CFR Part 11. All SAR couplings must be incompatible with the outlets of other gas systems used on site to prevent a worker from connecting to an inappropriate compressed gas source (OSHA 29 CFR 1910.134(d)).

SARs enable longer work periods than do SCBAs and are less bulky. However, the air line impairs worker mobility and requires workers to retrace their steps when leaving the area. Also, the air line is vulnerable to puncture from rough or sharp surfaces, chemical permeation, damage from contact with heavy equipment, and obstruction from failing drums, etc. To the extent possible, all such hazards should be removed prior to use. When in use, air lines should be kept as short as possible (300 feet [91 meters] is the longest approved hose length for SARs), and other workers and vehicles should be kept away from the air line.

The use of air compressors as the air source for an SAR at a hazardous waste site is severely limited by the same concern that requires workers to wear respirators: that is, the questionable quality of the ambient air. Onsite compressor use is limited by OSHA standards (29 CFR Part 1910.134[d]).

Key questions to ask when considering SAR use are:

- Is the atmosphere IDLH or likely to become IDLH? If yes, an SAR/SCBA combination or SCBA should be used.
- Will the hose significantly impair worker mobility? If yes, the work task should be modified or other respiratory protection should be used.
- Is there a danger of the air line being damaged or obstructed (e.g., by heavy equipment, failing drums, rough terrain, or sharp objects) or permeated and/or degraded by chemicals (e.g., by pools of chemicals)? If yes, either the hazard should be removed or another form of respiratory protection should be used.
- If a compressor is the air source, is it possible for airborne contaminants to enter the air system? If yes, have the contaminants been identified and are efficient filters and/or

sorbents available that are capable of removing those contaminants? If no, either cylinders should be used as the air source or another form of respiratory protection should be used.

- Can other workers and vehicles that might interfere with the air line be kept away from the area? If no, another form of respiratory protection should be used.

Combination SCBA/SAR

A relatively new type of respiratory protection is available that uses a regulator to combine the features of an SCBA with an SAR. The user can operate the respirator in the SCBA or SAR mode, through either the manual or automatic switching of air sources. This type of respirator allows entry into and exit from an area using the self contained air supply, as well as extended work periods within a contaminated area while connected to the air line. It is particularly appropriate for sites where workers must travel an extended distance to a work area within a hot zone and remain within that area for relatively long work periods (e.g., drum sampling). In such situations, workers would enter the site using the SCBA mode, connect to the air line during the work period, and shift back to the SCBA mode to leave the site.

The combination SCBA/SAR should not be confused with an SAR with escape provisions. The primary difference is the length of air time provided by the SCBA; the combination system provides up to 60 minutes of self-contained air, whereas the escape SCBA contains much less air, generally enough for only 5 minutes. NIOSH certification of the combination unit allows up to 20 percent of the available air time to be used during entry, while the SAR with escape provision is certified for escape only.

Air-Purifying Respirators

Air-purifying respirators consist of a facepiece and an air-purifying device, which is either a removable component of the facepiece or an air-purifying apparatus worn on a body harness and attached to the facepiece by a corrugated breathing hose (see Figure 8-2). Air-purifying respirators selectively remove specific airborne contaminants (particulates, gases, vapors, fumes) from ambient air by filtration, absorption, adsorption, or chemical reactions. They are approved for use in atmospheres containing specific chemicals up to designated concentrations, *and not for IDLH atmospheres*. Air-purifying respirators have limited use at hazardous waste sites and can be used only when the ambient atmosphere contains sufficient oxygen (19.5 percent) (30 CFR Part 11.90[a]). Table 8-4 lists conditions that may exclude the use of air-purifying respirators.

Air-purifying respirators usually operate only in the negative-pressure mode except for powered air-purifying respirators (PAPRs) which maintain a positive facepiece pressure (except at maximal breathing rates). There are three types of air-purifying devices: (1) particulate filters; (2) cartridges and canisters, which contain sorbents for specific gases and vapors; and (3) combination devices. Their efficiencies vary considerably even for closely related materials [2].

Cartridges usually attach directly to the respirator facepiece. The larger-volume canisters attach to the chin of the facepiece or are carried with a harness and attached to the facepiece by a breathing tube. Combination canisters and cartridges contain layers of different sorbent materials and remove multiple chemicals or multiple classes of chemicals from the ambient air. Though approved against more than one substance, these canisters and cartridges are tested

Table 8-4. Conditions that Exclude or May Exclude Use of Air-Purifying Respirators

- Oxygen deficiency.
- IDLH concentrations of specific substances.
- Entry into an unventilated or confined area where the exposure conditions have not been characterized.
- Presence or potential presence of unidentified contaminants.
- Contaminant concentrations are unknown or exceed designated maximum use concentration(s).
- Identified gases or vapors have inadequate warning properties *and* the sorbent service life is not known *and* the unit has no end-of-service-life (ESLI) indicator.
- High relative humidity (may reduce the protection offered by the sorbent).

or more substances has not been demonstrated. Filters may also be combined with cartridges to provide additional protection against particulates. A number of standard cartridges and canisters are commercially available. They are color-coded to indicate the general chemicals or classes of chemicals against which they are effective (29 CFR Part 1910.134[g]).

MSHA and NIOSH have granted approvals for manufacturers' specific assemblies of air-purifying respirators for a limited number of specific chemicals. Respirators should be used only for those substances for which they have been approved. Use -of a sorbent shall not be allowed when there is reason to suspect that it does not provide adequate sorption efficiency against a specific contaminant. In addition, it should be noted that approval testing is performed at a given temperature and over a narrow range of flow rates and relative humidities [3]; thus protection may be compromised in nonstandard conditions. The assembly that has been approved by MSHA and NIOSH to protect against organic vapors is tested against only a single challenge substance, carbon tetrachloride; its effectiveness for protecting against other vapors has not been demonstrated.

Most chemical sorbent canisters are imprinted with an expiration date. They may be used up to that date as long as they were not opened previously. Once opened, they begin to absorb humidity and air contaminants whether or not they are in use. Their efficiency and service life decreases and therefore they should be used immediately. Cartridges should be discarded after use but should not be used for longer than one shift or when breakthrough occurs, whichever comes first.

Where a canister or cartridge is being used against gases or vapors, the appropriate device shall be used only if the chemical(s) have "adequate warning properties" (30 CFR Part 11.150). NIOSH considers a substance to have adequate warning properties when its odor, taste, or irritant effects are detectable and persistent at concentrations below the recommended exposure limit (REL) (see Chapter 6). A substance is considered to have poor warning properties when its odor or irritation threshold is above the applicable exposure limit. Warning properties are essential to safe use of air-purifying respirators since they allow detection of contaminant breakthrough, should it occur. While warning properties are not foolproof, because they rely on human senses which vary widely among individuals and in the same individual under varying conditions (e.g., olfactory fatigue), they do provide some indication of possible sorbent exhaustion, poor facepiece fit, or other malfunctions. OSHA permits the use of air-purifying respirators for protection against specific chemicals with poor warning properties provided that (1) the service life of the sorbent is known and a safety factor has been applied or (2) the respirator has an approved end-of-service-life indicator.

Selection of Protective Clothing and Accessories

In this manual, personal protective clothing is considered to be any article offering skin and/or body protection. It includes:

- Fully-encapsulating suits.
- Non-encapsulating suits.
- Aprons, leggings, and sleeve protectors.
- Gloves.
- Firefighters' protective clothing.
- Proximity, or approach, garments.
- Blast and fragmentation suits.
- Cooling garments.
- Radiation-protective suits.

Each type of protective clothing has a specific purpose; many, but not all, are designed to protect against chemical exposure. Examples of protective clothing are shown in Figure 8-3.

Table 8-5 describes various types of protective clothing available, details the type of protection they offer, and lists the factors to consider in their selection and use. This table also describes a number of accessories that might be used in conjunction with a PPE ensemble, namely:

- Knife.
- Flashlight or lantern.
- Personal locator beacon.
- Personal dosimeters.
- Two-way radio.
- Safety belts and lines.

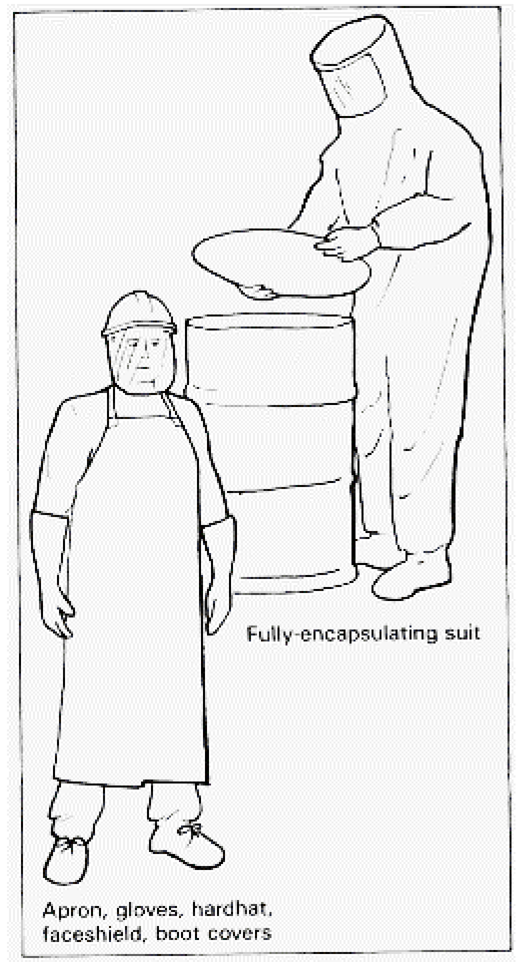


Figure 8-3. Examples of Protective Clothing.

Table 8-5. Protective Clothing and Accessories

BODY PART PROTECTED	TYPE OF CLOTHING OR ACCESSORY	DESCRIPTION	TYPE OF PROTECTION	USE CONSIDERATIONS
Full Body	Fully-encapsulating suit	One-piece garment. Boots and gloves may be integral, attached and replaceable, or separate.	Protects against splashes, dust, gases, and vapors.	Does not allow body heat to escape. May contribute to heat stress in wearer, particularly if worn in conjunction with a closed-circuit SCBA; a cooling garment may be needed. Impairs worker mobility, vision, and communication.
	Non-encapsulating suit	Jacket, hood, pants, or bib overalls, and one-piece coveralls.	Protects against splashes, dust, and other materials but not against gases and vapors. Does not protect parts of head or neck.	Do not use where gas-tight or pervasive splashing protection is required. May contribute to heat stress in wearer. Tape-seal connections between pant cuffs and boots and between gloves and sleeves.
	Aprons, leggings, and sleeve protectors	Fully sleeved and gloved apron. Separate coverings for arms and legs. Commonly worn over non-encapsulating suit.	Provides additional splash protection of chest, forearms, and legs.	Whenever possible, should be used over a non-encapsulating suite (instead of using a fully-encapsulating suite) to minimize potential for heat stress. Useful for sampling, labeling, and analysis operations. Should be used only when there is a low probability of total body contact with contaminants.

Table 8-5. (cont.)

BODY PART PROTECTED	TYPE OF CLOTHING OR ACCESSORY	DESCRIPTION	TYPE OF PROTECTION	USE CONSIDERATIONS
Full Body (cont.)	Firefighters' protective clothing	Gloves, helmet, running or bunker coat, running or bunker pants (NFPA No. 1971, 1972, 1973), and boots.	Protects against heat, hot water, and some particles. Does not protect against gases and vapors, or chemical permeation or degradation. NFPA Standard No. 1971 specified that a garment consist of an outer shell, an inner liner, and a vapor barrier with a minimum water penetration of 25 lbs/in^2 (1.8 kg/cm^2) to prevent the passage of hot water.	Decontamination is difficult. Should not be worn in areas where protection against gases, vapors, chemical splashes, or permeation is required.
	Proximity garment (approach suit)	One- or two-piece overgarment with boot covers, gloves and hood of aluminized nylon or cotton fabric. Normally worn over other protective clothing, such as chemical-protective clothing, firefighters' bunker gear, or flame-retardant coveralls.	Protects against brief exposure to radiant heat. Does not protect against chemical permeation or degradation. Can be custom-manufactured to protect against some chemical contaminants.	Auxiliary cooling and an SCBA should be used if the wearer may be exposed to a toxic atmosphere or needs more than 2 or 3 minutes of protection.
	Blast and fragmentation suit	Blast and fragmentation vests and clothing, bomb blankets, and bomb carriers.	Provides some protection against very small detonations. Bomb blankets and baskets can help redirect a blast.	Does not provide hearing protection.

Table 8-5. (cont.)

BODY PART PROTECTED	TYPE OF CLOTHING OR ACCESSORY	DESCRIPTION	TYPE OF PROTECTION	USE CONSIDERATIONS
Full Body (cont.)	Radiation-contamination protective suit	Various types of protective clothing designed to prevent contamination of the body by radioactive particles.	Protects against alpha and beta particles. *Does NOT protect against gamma radiation.*	Designed to prevent skin contamination. If radiation is detected on site, consult an experienced radiation expert and evacuate personnel until the radiation hazard has been evaluated.
	Flame/fire retardant coveralls	Normally worn as an undergarment.	Provides protection from flash fires.	Adds bulk and may exacerbate heat stress problems and impair mobility.
	Flotation gear	Life jackets or work vests. (Commonly worn underneath chemical protective clothing to prevent flotation gear degradation by chemicals.)	Adds 15.5 to 25 lbs (7 to 11.3 kg) of buoyancy to personnel working in or around water	Adds bulk and restricts mobility. Must meet USCG standards (46 CFR Part 160).
	Cooling Garment	One of three methods: (1) A pump circulates cool dry air throughout the suit or portions of it via an air line. Cooling may be enhanced by use of a vortex cooler, refrigeration coils, or a heat exchanger. (2) A jacket or vest having pockets into which packets of ice are inserted. (3) A pump circulates chilled water from a water/ice reservoir and through circulating tubes, which cover part of the body (generally the upper torso only).	Removes excess heat generated by worker activity, the equipment, or the environment.	(1) Pumps circulating cool air require 10 to 20 ft^3 (0.3 to 0.6 m^3) of respirable air per minute, so they are often uneconomical for use at a waste site. (2) Jackets or vests pose ice storage and recharge problems. (3) Pumps circulating chilled water pose ice storage problems. The pump and battery add bulk and weight.

Table 8-5. (cont.)

BODY PART PROTECTED	TYPE OF CLOTHING OR ACCESSORY	DESCRIPTION	TYPE OF PROTECTION	USE CONSIDERATIONS
Head	Safety helmet (hard hat)	For example, a hard plastic or rubber helmet.	Protects the head from blows.	Helmet shall meet OSHA standard 29 CFR part 1910.135.
	Helmet liner		Insulates against cold. Does not protect against chemical splashes.	
	Hood	Commonly worn with a helmet.	Protects against chemical splashes, particulates, and rain.	
	Protective hair covering		Protects against chemical contamination of hair. Prevents the entanglement of hair in machinery or equipment. Prevents hair from interfering with vision and with the functioning of respiratory protective devices.	Particularly important for workers with long hair.
Eyes and Face[a]	Face shield	Full-face coverage, eight-inch minimum.	Protects against chemical splashes. Does not protect adequately against projectiles.	Face shields and splash hoods must be suitably supported to prevent them from shifting and exposing portions of the face or obscuring vision. Provides limited eye protection.
	Splash hood		Protects against chemical splashes. Does not protect adequately against projectiles.	
	Safety glasses		Protect eyes against large particles and projectiles.	If lasers are used to survey a site, workers should wear special protective lenses.

Table 8-5. (cont.)

BODY PART PROTECTED	TYPE OF CLOTHING OR ACCESSORY	DESCRIPTION	TYPE OF PROTECTION	USE CONSIDERATIONS
Eye and Face (cont.)	Goggles		Depending on their construction, goggles can protect against vaporized chemicals, splashes, large particles, and projectiles (if constructed with impact-resistant lenses).	
	Sweat bands		Prevents sweat-induced eye irritation and vision impairment.	
Ears	Ear plugs and muffs		Protect against physiological damage and psychological disturbance.	Must comply with OSHA regulation 29 CFR Part 1910.95. Can interfere with communication. Use of ear plugs should be carefully reviewed by a health and safety professional because chemical contaminants could be introduced into the ear.
	Headphones	Radio headset with throat microphone.	Provide some hearing protection while enabling communication.	Highly desirable, particularly if emergency conditions arise.
Hands and Arms	Gloves and sleeves	May be integral, attached, or separate from other protective clothing.	Protect hands and arms from chemical contact.	Wear jacket cuffs over glove cuffs to prevent liquid from entering the glove. Tape-seal gloves to sleeves to provide additional protection.
		Overgloves.	Provide supplemental protection to the wearer and protect more expensive undergarments from abrasions, tears, and contamination.	

Table 8-5. (cont.)

BODY PART PROTECTED	TYPE OF CLOTHING OR ACCESSORY	DESCRIPTION	TYPE OF PROTECTION	USE CONSIDERATIONS
Hands and Arms (cont.)		Disposable gloves.	Should be used whenever possible to reduce decontamination needs.	
Foot	Safety boots	Boots constructed of chemical-resistant material.	Protect feet from contact with chemicals.	
		Boots constructed with some steel materials (e.g., toes, shanks, insoles).	Protect feet from compression, crushing, or puncture by falling, moving, or sharp objects.	All boots must at least meet the specifications required under OSHA 29 CFR Part 1910.136 and should provide good traction.
		Boots constructed from nonconductive, spark-resistant materials or coatings.	Protect the wearer against electrical hazards and prevent ignition of combustible gases or vapors.	
	Disposable shoe or boot covers	Made of a variety of materials. Slip over the shoe or boot.	Protect safety boots from contamination. Protect feet from contact with chemicals.	Covers may be disposed of after use, facilitating decontamination.
General	Knife		Allows a person in a fully-encapsulating suit to cut his or her way out of the suit in the event of an emergency or equipment failure.	Should be carried and used with caution to avoid puncturing the suit.

Table 8-5. (cont.)

BODY PART PROTECTED	TYPE OF CLOTHING OR ACCESSORY	DESCRIPTION	TYPE OF PROTECTION	USE CONSIDERATIONS
General (cont.)	Flashlight or lantern		Enhances visibility in buildings, enclosed spaces, and the dark.	Must be intrinsically safe or explosion-proof for use in combustible atmospheres. Sealing the flashlight in a plastic bag facilitates decontamination. Only electrical equipment approved as intrinsically safe, or approved for the class and group of hazard as defined in Article 500 of the National Electrical Code, may be used.
	Personal dosimeter		Measures worker exposure to ionizing radiation and to certain chemicals.	To estimate actual body exposure, the dosimeter should be placed inside the fully-encapsulating suit.
	Personal locator beacon	Operated by sound, radio, or light	Enables emergency personnel to locate victim.	
	Two-way radio		Enables field workers to communicate with personnel in the Support Zone.	
	Safety belts, harnesses, and lifeline		Enable personnel to work in elevated areas or enter confined areas and prevent falls. Belts may be used to carry tools and equipment.	Must be constructed of spark-free hardware and chemical-resistant materials to provide proper protection. Must meet OSHA standards in 29 CFR Part 1926.104.

Selection of Chemical-Protective Clothing (CPC)

Chemical-protective clothing (CPC) is available in a variety of materials that offer a range of protection against different chemicals. The most appropriate clothing material will depend on the chemicals present and the task to be accomplished. Ideally, the chosen material resists permeation, degradation, and penetration. Permeation is the process by which a chemical dissolves in and/or moves through a protective clothing material on a molecular level. Degradation is the loss of or change in the fabric's chemical resistance or physical properties due to exposure to chemicals, use, or ambient conditions (e.g., sunlight). Penetration is the movement of chemicals through zippers, stitched seams or imperfections (e.g., pinholes) in a protective clothing material.

Selection of chemical-protective clothing is a complex task and should be performed by personnel with training and experience. Under all conditions, clothing is selected by evaluating the performance characteristics of the clothing against the requirements and limitations of the site- and task-specific conditions. If possible, representative garments should be inspected before purchase and their use and performance discussed with someone who has experience with the clothing under consideration. In all cases, the employer is responsible for ensuring that the personal protective clothing (and all PPE) necessary to protect employees from injury or illness that may result from exposure to hazards at the work site is adequate and of safe design and construction for the work to be performed (see OSHA standard 29 CFR Part 1910.132, 1910.137).

Permeation and Degradation

The selection of chemical-protective clothing depends greatly upon the type and physical state of the contaminants. This information is determined during site characterization (Chapter 6). Once the chemicals have been identified, available information sources should be consulted to identify materials that are resistant to permeation and degradation by the known chemicals. One excellent reference, *Guidelines for the Selection of Chemical-Protective Clothing* [4], provides a matrix of clothing material recommendations for approximately 300 chemicals based on an evaluation of permeation and degradation data from independent tests, vendor literature, and raw material suppliers. Charts indicating the resistance of various clothing materials to permeation and degradation are also available from manufacturers and other sources. It is important to note, however, that no material protects against all chemicals and combinations of chemicals, and that no currently available material is an effective barrier to any prolonged chemical exposure.

In reviewing vendor literature, it is important to be aware that the data provided are of limited value. For example, the quality of vendor test methods is inconsistent; vendors often rely on the raw material manufacturers for data rather than conducting their own tests; and the data may not be updated. In addition, vendor data cannot address the wide variety of uses and challenges to which CPC may be subjected. Most vendors strongly emphasize this point in the descriptive text that accompanies their data.

Another factor to bear in mind when selecting CPC is that the rate of permeation is a function of several factors, including clothing material type and thickness, manufacturing method, the concentration(s) of the hazardous substance(s), temperature, pressure, humidity, the solubility of the chemical in the clothing material, and the diffusion coefficient of the permeating chemical in the clothing material. Thus permeation rates and breakthrough time (the time from initial exposure until hazardous material is detectable on the inside of the CPC) may vary depending on these conditions.

Most hazardous wastes are mixtures, for which specific data with which to make a good CPC selection are not available. Due to a lack of testing, only limited permeation data for multi-component liquids are currently available.

Mixtures of chemicals can be significantly more aggressive towards CPC materials than can any single component alone. Even small amounts of a rapidly permeating chemical may provide a pathway that accelerates the permeation of other chemicals [4]. Formal research is being conducted on these effects. NIOSH is currently developing methods for evaluating CPC materials against mixtures of chemicals and unknowns in the field. For hazardous waste site operations, CPC should be selected that offers the widest range of protection against the chemicals expected on site. Vendors are now providing CPC material composed of two or even three different materials laminated together that is capable of providing the best features of each material.

Heat Transfer Characteristics

The heat transfer characteristics of CPC may be an important factor in selection. Since most chemical-protective clothing is virtually impermeable to moisture, evaporative cooling is limited. The "clo" value (thermal insulation value) of chemical-protective clothing is a measure of the capacity of CPC to dissipate heat loss through means other than evaporation. The larger the clo value, the greater the insulating properties of the garment and, consequently, the lower the heat transfer [5]. Given other equivalent protective properties, clothing with the lowest clo value should be selected in hot environments or for high work rates. Unfortunately, clo values for clothing are rarely available at present.

Other Considerations

In addition to permeation, degradation, penetration, and heat transfer, several other factors must be considered during clothing selection. These affect not only chemical resistance, but also the worker's ability to perform the required task. The following checklist summarizes these considerations.

- Durability:
  - Does the material have sufficient strength to withstand the physical stress of the task(s) at hand?
  - Will the material resist tears, punctures, and abrasions?
  - Will the material withstand repeated use after contamination/decontamination?
- Flexibility:
  - Will the CPC interfere with the workers' ability to perform their assigned tasks (this is particularly important to consider for gloves)?
- Temperature effects:
  - Will the material maintain its protective integrity and flexibility under hot and cold extremes?
- Ease of decontamination:
  - Are decontamination procedures available on site?
  - Will the material pose any decontamination problems?
  - Should disposable clothing be used?
- Compatibility with other equipment:
  - Does the clothing preclude the use of another, necessary piece of protective equipment (e.g., suits that preclude hardhat use in hardhat area)?
- Duration of use:

- Can the required task be accomplished before contaminant breakthrough occurs, or degradation of the CPC becomes significant?

Special Conditions

Fire, explosion, heat, and radiation are considered special conditions that require special-protective equipment. Unique problems are associated with radiation and it is beyond the scope of this manual to discuss them properly. A qualified health physicist should be consulted if a radiation hazard exists. Special-protective equipment is described in Table 8-5 (see Full Body section of the table). When using special-protective equipment, it is important to also provide protection against chemicals, since the specialized equipment may provide little or no protection against chemicals which may also be present.

Selection of Ensembles

Level of Protection

The individual components of clothing and equipment must be assembled into a full protective ensemble that both protects the worker from the site-specific hazards and minimizes the hazards and drawbacks of the PPE ensemble itself.

Table 8-6 lists ensemble components based on the widely used EPA Levels of Protection: Levels A, B, C, and D. These lists can be used as a starting point for ensemble creation; however, each ensemble must be tailored to the specific situation in order to provide the most appropriate level of protection. For example, if work is being conducted at a highly contaminated site or if the potential for contamination is high, it may be advisable to wear a disposable covering, such as Tyvek coveralls or PVC splash suits, over the protective ensemble. It may be necessary to slit the back of these disposable suits to fit around the bulge of an encapsulating suit and SCBA [6].

The type of equipment used and the overall level of protection should be reevaluated periodically as the amount of information about the site increases, and as workers are required to perform different tasks. Personnel should be able to upgrade or downgrade their level of protection with concurrence of the Site Safety Officer and approval of the Field Team Leader.

Reasons to upgrade:

- Known or suspected presence of dermal hazards.
- Occurrence or likely occurrence of gas or vapor emission.
- Change in work task that will increase contact or potential contact with hazardous materials.
- Request of the individual performing the task.

Reasons to downgrade:

- New information indicating that the situation is less hazardous than was originally thought.
- Change in site conditions that decreases the hazard.
- Change in work task that will reduce contact with hazardous materials.

PPE Use

PPE can offer a high degree of protection only if it is used properly. This section covers the following aspects of PPE use:

- Training.
- Work mission duration.
- Personal use factors.
- Fit testing.
- Donning.
- In-use monitoring.
- Doffing.
- Inspection.
- Storage.
- Maintenance.

Decontamination is covered in Chapter 10. Inadequate attention to any of these areas could compromise the protection provided by the PPE.

Training

Training in PPE use is recommended and, for respirators, required by federal regulation in the OSHA standards in 29 CFR Part 1910 Subparts I and Z. This training:

- Allows the user to become familiar with the equipment in a nonhazardous situation.
- Instills confidence of the user in his/her equipment.
- Makes the user aware of the limitations and capabilities of the equipment.
- Increases the efficiency of operations performed by workers wearing PPE.
- May increase the protective efficiency of PPE use.
- Reduces the expense of PPE maintenance.

Training should be completed prior to actual PPE use in a hazardous environment and should be repeated at least annually. At a minimum, the training portion of the PPE program should delineate the user's responsibilities and explain the following, utilizing both classroom and field training when necessary:

- OSHA requirements as delineated in 29 CFR Part 1910 Subparts I and Z.
- The proper use and maintenance of the selected PPE, including capabilities and limitations.
- The nature of the hazards and the consequences of not using the PPE.
- The human factors influencing PPE performance.
- Instruction in inspecting, donning, checking, fitting, and using PPE.
- Individualized respirator fit testing to ensure proper fit.
- Use of PPE in normal air for a long familiarity period and, finally, wearing PPE in a test atmosphere to evaluate its effectiveness.

Table 8-6. Sample Protective Ensembles[a]

LEVEL OF PROTECTION	EQUIPMENT	PROTECTION PROVIDED	SHOULD BE USED WHEN:	LIMITING CRITERIA
A	RECOMMENDED: • Pressure-demand, full-facepiece SCBA or pressure-demand supplied air respirator with escape SCBA. • Fully-encapsulating, chemical-resistant suit. • Inner chemical-resistant gloves. • Chemical-resistant safety boots/shoes. • Two-way radio communications. OPTIONAL: • Cooling unit. • Coveralls. • Long Cotton underwear. • Hard hat. • Disposable gloves and boot covers.	The highest available level of respiratory, skin and eye protection.	• The chemical substance has been identified and requires the highest level of protection for skin, eyes, and the respiratory system based on either: - Measured (or potential for) high concentration of atmospheric vapors, gases, or particulates or - site operations and work functions involving a high potential for splash, immersion, or exposure to unexpected vapors, gases, or particulates of materials that are harmful to skin or capable of being absorbed through the intact skin. • Substances with a high degree of hazard to the skin are known or suspected to be present, and skin contact is possible. • Operations must be conducted in confined, poorly ventilated areas until the absence of conditions requiring Level A protection is determined.	• Fully-encapsulating suit material must be compatible with the substances involved.
B	RECOMMENDED: • Pressure-demand, full-facepiece SCBA or pressure-demand supplied-air respirator with escape SCBA. • Chemical-resistant clothing (overalls and long-sleeved jacket; hooded, one- or two-piece chemical splash suit; disposable chemical-resistant one-piece suit).	The same level of respiratory protection but less skin protection than Level A.	• The type and atmospheric concentration of substances have been identified and require a high level of respiratory protection, but less skin protection. This involves atmospheres: -with IDLH concentrations of specific substances that do not represent a severe skin hazard; or • -that do not meet the criteria for use of air-purifying respirators.	• Use only when the vapor or gases present are not suspected of containing high concentrations of chemicals that are harmful to skin or capable of being absorbed through the intact skin. • Use only when it is highly unlikely that the work being done will generate either high concentrations of vapors, gases, or particulates, or splashes of material that will affect exposed skin.

Table 8-6. (cont.)

LEVEL OF PROTECTION	EQUIPMENT	PROTECTION PROVIDED	SHOULD BE USED WHEN:	LIMITING CRITERIA
B (cont.)	• Inner and outer chemical-resistant gloves. • Chemical-resistant safety boots/shoes.. • Hard hat. • Two-way radio communications. OPTIONAL: • Coveralls. • Disposable boot covers. • Face shield. • Long cotton underwear.	It is the minimum level recommended for initial site entries until the hazards have been further identified.	• Atmosphere contains less than 19.5 percent oxygen. • Presence of incompletely identified vapors or gases is indicated by direct-reading organic vapor detection instrument, but vapors and gases are not suspected of containing high levels of chemicals harmful to skim or capable of being absorbed through the intact skin.	
C	RECOMMENDED: • Full-facepiece, air-purifying, canister-equipped respirator. • Chemical-resistant clothing (overalls and long-sleeved jacket; hooded, one- or two-piece chemical splash suit; disposable chemical-resistant one-piece suit). • Inner and outer chemical-resistant gloves. • Chemical-resistant safety boots/shoes.. • Hard hat. • Two-way radio communications. OPTIONAL: • Coveralls. • Disposable boot covers. • Face shield. • Escape mask. • Long cotton underwear.	The same level of skin protection as level B, but a lower level of respiratory protection.	• The atmospheric contaminants, liquid splashes, or other direct contact will not adversely affect any exposed skin. • The types of air contaminants have been identified, concentrations measured, and a canister is available that can remove the contaminant. • All criteria for the use of air-purifying respirators are met.	• Atmospheric concentration of chemicals must not exceed IDLH levels. • The atmosphere must contain at least 19.5 percent oxygen.

Table 8-6. (cont.)

LEVEL OF PROTECTION	EQUIPMENT	PROTECTION PROVIDED	SHOULD BE USED WHEN:	LIMITING CRITERIA
D	RECOMMENDED: • Coveralls. • Safety boots/shoes. • Safety glasses or chemical splash goggles. • Hard hat. OPTIONAL: • Gloves. • Escape mask. • Face shield.	No respiratory protection. Minimal skin protection.	• The atmosphere contains no known hazard. • Work functions preclude splashes, immersion, or the potential for unexpected inhalation of or contact with hazardous levels of any chemicals.	• This level should not be worn in the Exclusion Zone. • The atmosphere must contain at least 19.5 percent oxygen.

[a]**Based on EPA protective ensembles.**

- The user's responsibility (if any) for decontamination, cleaning, maintenance, and repair of PPE.
- Emergency procedures and self-rescue in the event of PPE failure.
- The buddy system (see Chapter 9, *Site Control*).
- The Site Safety Plan and the individual's responsibilities and duties in an emergency.

The discomfort and inconvenience of wearing PPE can create a resistance to the conscientious use of PPE. One essential aspect of training is to make the user aware of the need for PPE and to instill motivation for the proper use and maintenance of PPE.

Work Mission Duration

Before the workers actually begin work in their PPE ensembles, the anticipated duration of the work mission should be established. Several factors limit mission length. These include:

- Air supply consumption.
- Suit/ensemble permeation and penetration by chemical contaminants.
- Ambient temperature.
- Coolant supply.

Air Supply Consumption

The duration of the air supply must be considered before planning any SCBA-assisted work activity. The anticipated operating time of an SCBA is clearly indicated on the breathing apparatus. This designated operating time is based on a moderate work rate, e.g., some lifting, carrying, and/or heavy equipment operation.

In actual operation, however, several factors can reduce the rated operating time when planning an SCBA-assisted work mission, the following variables should be considered and work actions and operating time adjusted accordingly:

- Work rate. The actual in-use duration of SCBAs may be reduced by one-third to one-half during strenuous work, e.g., drum handling, major lifting, or any task requiring repetitive speed of motion [7].
- Fitness. Well-conditioned individuals generally utilize oxygen more efficiently and can extract more oxygen from a given volume of air (particularly when performing strenuous tasks) than unfit individuals, thereby slightly increasing the SCBA operating time [8].
- Body size. Larger individuals generally consume air at a higher rate than smaller individuals [8], thereby decreasing the SCBA operating time.
- Breathing patterns. Quick, shallow or irregular breaths use air more rapidly than deep, regularly spaced breaths. Heat-induced anxiety and lack of acclimatization (see Heat Stress and Other Physiological Factors in this chapter) may induce hyperventilation, resulting in decreased SCBA operating time [8].

Suit/Ensemble Permeation and Penetration

The possibility of chemical permeation or penetration of CPC ensembles during the work mission is always a matter of concern and may limit mission duration. Possible causes of ensemble penetration are:

- Suit valve leakage, particularly under excessively hot or cold temperatures.
- Suit fastener leakage if the suit is not properly maintained or if the fasteners become brittle at cold temperatures.

- Exhalation valve leakage at excessively hot or cold temperatures.

Also, when considering mission duration, it should be remembered that no single clothing material is an effective barrier to all chemicals or all combinations of chemicals, and no material is an effective barrier to prolonged chemical exposure.

Ambient Temperature

The ambient temperature has a major influence on work mission duration as it affects both the worker and the protective integrity of the ensemble. Heat stress, which can occur even in relatively moderate temperatures, is the greatest immediate danger to an ensemble-encapsulated worker. Methods to monitor for and prevent heat stress are discussed in the final section of this chapter, *Heat Stress and Other Physiological Factors*. Hot and cold ambient temperatures also affect:

- Valve operation on suits and/or respirators.
- The durability and flexibility of suit materials.
- The integrity of suit fasteners.
- The breakthrough time and permeation rates of chemicals.
- The concentration of airborne contaminants.

All these factors may decrease the duration of protection provided by a given piece of clothing or respiratory equipment.

Coolant Supply

Under warm or strenuous work conditions, adequate coolant (ice or chilled air, see Table 8-5) should be provided to keep the wearer's body at a comfortable temperature and to reduce the potential for heat stress (see *Heat Stress and Other Physiological Factors* at the end of this chapter). If coolant is necessary, the duration of the coolant supply will directly affect mission duration.

Personal Use Factors

As described below, certain personal features of workers may jeopardize safety during equipment use Prohibitive or precautionary measures should be taken as necessary.

Facial hair and long hair interfere with respirator fit and wearer vision. Any facial hair that passes between the face and the sealing surface of the respirator should be prohibited. Even a few days' growth of facial hair will allow excessive contaminant penetration. Long hair must be effectively contained within protective hair coverings. Eyeglasses with conventional temple pieces (earpiece bars) will interfere with the respirator-to-face seal of a full facepiece. A spectacle kit should be installed in the face masks of workers requiring vision correction.

When a worker must wear corrective lenses as part of the facepiece, the lenses shall be fitted by qualified individuals to provide good vision, comfort, and a gastight seal. Contact lenses may trap contaminants and/or particulates between the lens and the eye, causing irritation, damage, absorption, and an urge to remove the respirator. Wearing contact lenses with a respirator in a contaminated atmosphere is prohibited (29 CFR Part 1910.134[e][51][ii]).

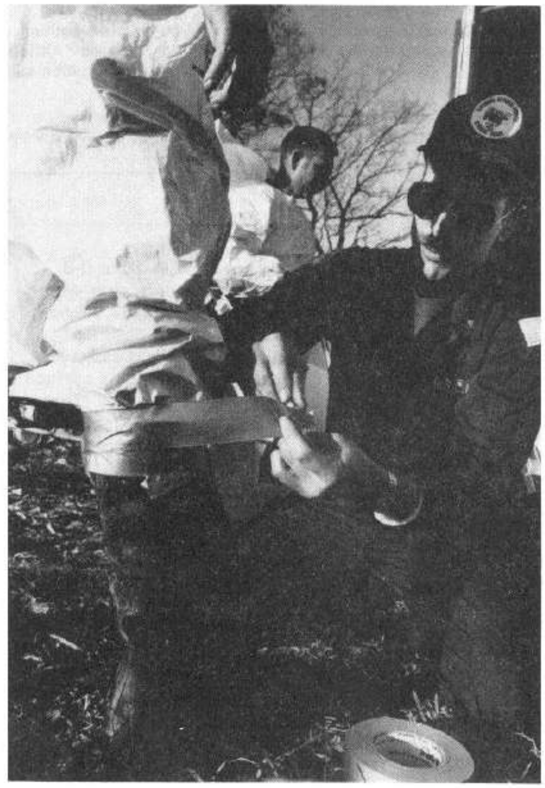
Gum and tobacco chewing should be prohibited during respirator use since they may cause ingestion of contaminants and may compromise the respirator fit.

Donning an Ensemble

A routine should be established and practiced periodically for donning a fully-encapsulating suit/SCBA ensemble. Assistance should be provided for donning and doffing since these operations are difficult to perform alone, and solo efforts may increase the possibility of suit damage.

Table 8-7 lists sample procedures for donning a fully encapsulating suit/SCBA ensemble. These procedures should be modified depending on the particular type of suit and/or when extra gloves and/or boots are used. These procedures assume that the wearer has previous training in SCBA use and decontamination procedures.

Once the equipment has been donned, its fit should be evaluated. If the clothing is too small, it will restrict movement, thereby increasing the likelihood of tearing the suit material and accelerating worker fatigue. If the clothing is too large, the possibility of snagging the material is increased, and the dexterity and coordination of the worker may be compromised. In either case, the worker should be recalled and better fitting clothing provided.



As part of donning operations, and assistant tape seals boots to protective clothing to eliminate routes of entry for chemicals.

Respirator Fit Testing

The "fit" or integrity of the facepiece-to-face seal of a respirator affects its performance. A secure fit is important with positive-pressure equipment, and is essential to the safe functioning of negative-pressure equipment, such as most air-purifying respirators. Most facepieces fit only a certain percentage of the population; thus each facepiece must be tested on the potential wearer in order to ensure a tight seal. Facial features such as scars, hollow temples, very prominent cheekbones, deep skin creases, dentures or missing teeth, and the chewing of gum and tobacco may interfere with the respirator-to-face seal. A respirator shall not be worn when such conditions prevent a good seal. The workers' diligence in observing these factors shall be evaluated by periodic checks.

For a qualitative respirator fit testing protocol, see Appendix D of the OSHA lead standard (29 CFR Part 1910.1025). For quantitative fit testing, see the NIOSH publication *A Guide to Industrial Respiratory Protection* [10]. For specific quantitative testing protocols, literature supplied by manufacturers of quantitative fit test equipment should be consulted. Note that certain OSHA standards require quantitative fit testing under specific circumstances (e.g., 29 CFR Parts 1910.1018[h][3][iii], 1910.1025[f][3][ii], and 1910.1045[h][3][iii][B]).

Table 8-7. Sample Donning Procedures[a,b,c]

1. Inspect the clothing and respiratory equipment before donning (see *Inspection*).
2. Adjust hard hat or headpiece if worn, to fit user's head.
3. Open back closure used to change air tank (if suit has one) before donning suit.
4. Standing or sitting, step into the legs of the suit; ensure proper placement of the feet within the suit; then gather the suit around the waist.
5. Put on chemical-resistant safety boots over the feet of the suit. Tape the leg cuff over the tops of the boots.
   - If additional chemical-resistant boots are required, put these on now.
   - Some one-piece suits have heavy-soled protective feet. With these suits, wear short, chemical-resistant safety boots inside the suit.
6. Put on air tanks and harness assembly of the SCBA. Don the facepiece and adjust it to be secure, but comfortable. Do *not* connect the breathing hose. Open valve on air tank.
7. Perform negative and positive respirator facepiece seal test procedures.
   - To conduct a negative-pressure test, close the inlet part with the palm of the hand or squeeze the breathing tube so it does not pass air, and gently inhale for about 10 seconds. Any inward rushing of air indicates a poor fit. Note that a leaking facepiece may be drawn tightly to the face to form a good seal, giving a false indication of adequate fit.
   - To conduct a positive-pressure test, gently exhale while covering the exhalation valve to ensure that a positive pressure can be built up. Failure to build a positive pressure indicates a poor fit.
8. Depending on type of suit:
   - Put on long-sleeved inner gloves (similar to surgical gloves).
   - Secure gloves to sleeves, for suits with detachable gloves (if not done prior to entering the suit).
   - Additional overgloves, worn over attached suit gloves, may be donned later.
9. Put sleeves of suit over arms as assistant pulls suit up and over the SCBA. Have assistant adjust suit around SCBA and shoulders to ensure unrestricted motion.
10. Put on hard hat, if needed.
11. Raise hood over head carefully so as not to disrupt face seal of SCBA mask. Adjust hood to give satisfactory comfort.
12. Begin to secure the suit by closing all fasteners on opening until there is only adequate room to connect the breathing hose. Secure all belts and/or adjustable leg, head, and waistbands.
13. Connect the breathing hose while opening the main valve.
14. Have assistant first ensure that wearer is breathing properly and then make final closure of the suit.
15. Have assistant check all closures.
16. Have assistant observe the wearer for a period of time to ensure that the wearer is comfortable, psychologically stable, and that the equipment is functioning properly.

[a]Source: Based on reference [9].

[b]Perform the procedures in the order indicated.

[c]When donning a suit, use a moderate amount of a powder to prevent chafing and to increase comfort. Powder will also reduce rubber binding.

In-Use Monitoring

The wearer must understand all aspects of the clothing operation and its limitations; this is especially important for fully-encapsulating ensembles where misuse could potentially result in suffocation.

During equipment use, workers should be encouraged to report any perceived problems or difficulties to their supervisors). These malfunctions include, but are not limited to:

- Degradation of the protective ensemble.
- Perception of odors.
- Skin irritation.
- Unusual residues on PPE.
- Discomfort.
- Resistance to breathing.
- Fatigue due to respirator use.
- Interference with vision or communication.
- Restriction of movement.
- Personal responses such as rapid pulse, nausea, and chest pain.

If a supplied-air respirator is being used, all hazards that might endanger the integrity of the air line should be removed from the working area prior to use. During use, air lines should be kept as short as possible and other workers and vehicles should be excluded from the area.

Doffing an Ensemble

Exact procedures for removing fully-encapsulating suit/SCBA ensembles must be established and followed in order to prevent contaminant migration from the work area and transfer of contaminants to the wearer's body, the doffing assistant, and others.

Sample doffing procedures are provided in Table 8-8. These procedures should be performed only after decontamination of the suited worker (see Chapter 10, *Decontamination*). They require a suitably attired assistant. Throughout the procedures, both worker and assistant should avoid any direct contact with the outside surface of the suit.

Clothing Reuse

Chemicals that have begun to permeate clothing during use may not be removed during decontamination and may continue to diffuse through the material towards the inside surface, presenting the hazard of direct skin contact to the next person who uses the clothing.

Where such potential hazards may develop, clothing should be checked inside and out for discoloration or other evidence of contamination (see next section, *Inspection*). This is particularly important for fully encapsulating suits, which are generally subject to reuse due to their cost. Note, however, that negative (i.e., no chemical found) test results do not necessarily preclude the possibility that some absorbed chemical will reach the suit's interior.

At present, little documentation exists regarding clothing reuse. Reuse decisions must consider the known factors of permeation rates as well as the toxicity of the contaminant(s). In fact, unless extreme care is taken to ensure that clothing is properly decontaminated and that the decontamination does not degrade the material, the reuse of chemical protective clothing that has been contaminated with toxic chemicals is not advisable [4].

Table 8-8. Sample Doffing Procedures[a]

If sufficient air supply is available to allow appropriate decontamination before removal:

1. Remove any extraneous or disposable clothing, boot covers, outer gloves, and tape.
2. Have assistant lossen and remove the wearer's safety shoes or boots.
3. Have assistant open the suit completely and lift the hood over the head of the wearer and rest it on top of the SCBA tank.
4. Remove arms, one at a time, from suit. Once arms are free, have assistant lift the suit up and away from the SCBA backpack–avoiding any contact between the outside surface of the suit and the wearer's body–and lay the suit out flat behind the wearer. Leave internal gloves on, if any.
5. Sitting, if possible, remove both legs from the suit.
6. Follow procedure for doffing SCBA.
7. After suit is removed, remove internal gloves by rolling them off the hand, inside out.
8. Remove internal clothing and thorooughly cleanse the body.

If the low-pressure warning alarm has sounded, signifying that approximately 5 minutes of air remain:

1. Remove disposable clothing.
2. Quickly scrub and hose off, especially around the entrance/exit zipper.
3. Open the zipper enough to allow access to the regulator and breathing hose.
4. Immediately attach an appropriate canister to the breathing hose (the type and fittings should be predetermined). Although this provides some protection against any contamination still present, it voids the certification of the unit.

Follow Steps 1 through 8 of the regular doffing procedure above. Take extra care to avoid containinating the assistant and wearer.

[a]Source = Based on reference [9].

Inspection

An effective PPE inspection program will probably feature five different inspections:

- Inspection and operational testing of equipment received from the factory or distributor.
- Inspection of equipment as it is issued to workers.
- Inspection after use or training and prior to maintenance.
- Periodic inspection of stored equipment.
- Periodic inspection when a question arises concerning the appropriateness of the selected equipment, or when problems with similar equipment arise.

Each inspection will cover somewhat different areas in varying degrees of depth. Detailed inspection procedures, where appropriate, are usually available from the manufacturer. The inspection checklists provided in Table 8-9 may also be an aid.

Records must be kept of all inspection procedures. Individual identification numbers should be assigned to all reusable pieces of equipment (respirators may already have ID numbers) and records should be maintained by that number. At a minimum, each inspection should record the ID number, date, inspector, and any unusual conditions or findings. Periodic review of these records may indicate an item or type of item with excessive maintenance costs or a particularly high level of "down-time."

Table 8-9. Sample PPE Inspection Checklists

CLOTHING

Before use:

- Determine that the clothing material is correct for the specified task at hand.
- Visually inspect for:
  - Imperfect seams
  - non-uniform coatings
  - tears
  - malfunctioning closures
- Hold up to light and check for pinholes.
- Flex product:
  - observe for cracks
  - observe for other signs of shelf deterioration
- If the product has been used previously, inspect inside and out for signs of chemical attack:
  - discoloration
  - swelling
  - stiffness

During the work task, periodically inspect for:

- Evidence of chemical attack such as discoloration, swelling, stiffening, and softening. Keep in mind, however, that chemical permeation can occur without any visible effects.
- Closure failure.
- Tears.
- Puncture.
- Seam discontinuities.

GLOVES

- **BEFORE USE**, pressurize glove to check for pinholds. Either blow into glove, then roll gauntlet towards fingers or inflate glove and hold under water. In either case, no air should escape.

FULLY-ENCAPSULATING SUITS

Before use:

- Check the operation of pressure relief valves.
- Inspect the fitting of wrists, ankles, and neck
- Check faceshield, if so equipped, for:
  - cracks
  - crazing
  - fogginess

RESPIRATORS

SCBA

- Inspect SCBAs:
  - before and after each use
  - at least monthly when in storage
  - every time they are cleaned
- Check all connections for tightness.
- Check material conditions for:
  - signs of pliability
  - signs of deterioration
  - signs of distortion
- Check for proper setting and operation of regulators and valves (according to manufacturers' recommendations).
- Check operation of alarm(s).
- Check faceshields and lenses for:
  - cracks
  - crazing
  - fogginess

Supplied-Air Respirators

- Inspect SARs:
  - daily when in use
  - at least monthly when in storage
  - every time they are cleaned
- Inspect air lines prior to each use for cracks, kinks, cuts, frays, and weak areas.
- Check for proper setting and operation of regulators and valves (according to manufacturers' recommendations).
- Check all connections for tightness.
- Check material conditions for:
  - signs of pliability
  - signs of deterioration
  - signs of distortion
- Check faceshields and lenses for:
  - cracks
  - crazing
  - fogginess

Air-Purifying Respirators

- Inspect air-purifying respirators:
  - before each use to be sure they have been adequately cleaned
  - after each use
  - during cleaning
  - monthly if in storage for emergency use
- Check material conditions for:
  - signs of pliability
  - signs of deterioration
  - signs of distortion
- Examine cartridges or canisters to ensure that:
  - they are the proper type for the intended use
  - the expiration date has not been passed
  - they have not been opened or used previously
- Check faceshields and lenses for:
  - cracks
  - crazing and fogginess

Storage

Clothing and respirators must be stored properly to prevent damage or malfunction due to exposure to dust, moisture, sunlight, damaging chemicals, extreme temperatures, and impact. Procedures must be specified for both pre-issuance warehousing and, more importantly, postissuance (in-use) storage. Many equipment failures can be directly attributed to improper storage.

Clothing:

- Potentially contaminated clothing should be stored in an area separate from street clothing.
- Potentially contaminated clothing should be stored in a well-ventilated area, with good air flow around each item, if possible.
- Different types and materials of clothing and gloves should be stored separately to prevent issuing the wrong material by mistake.
- Protective clothing should be folded or hung in accordance with manufacturers' recommendations.

Respirators:

- SCBAs, supplied-air respirators, and air-purifying respirators should be dismantled, washed, and disinfected after each use.
- SCBAs should be stored in storage chests supplied by the manufacturer. Air-purifying respirators should be stored individually in their original cartons or carrying cases, or in heat-sealed or resealable plastic bags.

Maintenance

The technical depth of maintenance procedures vary. Manufacturers frequently restrict the sale of certain PPE parts to individuals or groups who are specially trained, equipped, and "authorized" by the manufacturer to purchase them.

Explicit procedures should be adopted to ensure that the appropriate level of maintenance is performed only by individuals having this specialized training and equipment. The following classification scheme is often used to divide maintenance into three levels:

- Level 1: User or wearer maintenance, requiring a few common tools or no tools at all.
- Level 2: Shop maintenance that can be performed by the employer's maintenance shop.
- Level 3: Specialized maintenance that can be performed only by the factory or an authorized repair person.

Heat Stress and Other Physiological Factors

Wearing PPE puts a hazardous waste worker at considerable risk of developing heat stress. This can result in health effects ranging from transient heat fatigue to serious illness or death. Heat stress is caused by a number of interacting factors, including environmental conditions, clothing, workload, and the individual characteristics of the worker. Because heat stress is probably one of the most common (and potentially serious) illnesses at hazardous waste sites, regular monitoring and other preventive precautions are vital.

Individuals vary in their susceptibility to heat stress. Factors that may predispose someone to heat stress include:

- Lack of physical fitness.
- Lack of acclimatization.
- Age.
- Dehydration.
- Obesity.
- Alcohol and drug use.
- Infection.
- Sunburn.
- Diarrhea.
- Chronic disease.

Reduced work tolerance and the increased risk of excessive heat stress is directly influenced by the amount and type of PPE worn. PPE adds weight and bulk, severely reduces the body's access to normal heat exchange mechanisms (evaporation, convection, and radiation), and increases energy expenditure. Therefore, when selecting PPE, each item's benefit should be carefully evaluated in relation to its potential for increasing the risk of heat stress. Once PPE is selected, the safe duration of work/rest periods should be determined based on the:

- Anticipated work rate.
- Ambient temperature and other environmental factors.
- Type of protective ensemble.
- Individual worker characteristics and fitness.

Monitoring

Because the incidence of heat stress depends on a variety of factors, all workers, even those not wearing protective equipment, should be monitored.

- For workers wearing permeable clothing (e.g., standard cotton or synthetic work clothes), follow recommendations for monitoring requirements and suggested work/rest schedules in the current American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values for Heat Stress [11]. If the actual clothing worn differs from the ACGIH standard ensemble in insulation value and/or wind and vapor permeability, change the monitoring requirements and work/rest schedules accordingly [12].
- For workers wearing semi-permeable or impermeable[1] encapsulating ensembles, the ACGIH standard cannot be used. For these situations, workers should be monitored when the temperature in the work area is above 70°F (21°C) [6].

To monitor the worker, measure:

- Heart rate. Count the radial pulse during a 30-second period as early as possible in the rest period.
  - If the heart rate exceeds 110 beats per minute at the beginning of the rest period, shorten the next work cycle by one-third and keep the rest period the same.
  - If the heart rate still exceeds 110 beats per minute at the next rest period, shorten the following work cycle by one-third [12].
- Oral temperature. Use a clinical thermometer (3 minutes under the tongue) or similar device to measure the oral temperature at the end of the work period (before drinking).

[1] Although no protective ensemble is "completely" impermeable, for practical purposes an outfit may be considered impermeable when calculating heat stress risk

- If oral temperature exceeds 99.6°F (37.6°C), shorten the next work cycle by one-third without changing the rest period.
- If oral temperature still exceeds 99.6°F (37.6°C) at the beginning of the next rest period, shorten the following work cycle by one-third [12].
- Do *not* permit a worker to wear a semi-permeable or impermeable garment when his/her oral temperature exceeds 100.6 °F (38.1 °C)[12].

- Body water loss, if possible. Measure weight on a scale accurate to ±0.25 lb at the beginning and end of each work day to see if enough fluids are being taken to prevent dehydration. Weights should be taken while the employee wears similar clothing or, ideally, is nude. The body water loss should not exceed 1.5 percent total body weight loss in a work day [12].

Initially, the frequency of physiological monitoring depends on the air temperature adjusted for solar radiation and the level of physical work (see Table 8-10). The length of the work cycle will be governed by the frequency of the required physiological monitoring.

Table 8-10. Suggested Frequency of Physiological Monitoring for Fit and Acclimatized Workers[a]

ADJUSTED TEMPERATURE[b]	NORMAL WORK ENSEMBLE[c]	IMPERMEABLE ENSEMBLE
90°F (32.2°C) or above	After each 45 minutes of work	After each 15 minutes of work
87.5°-90°F (30.8°-32.2°C)	After each 60 minutes of work	After each 30 minutes of work
82.5°-87.5°F (28.1°-30.8°C)	After each 90 minutes of work	After each 60 minutes of work
77.5°-82.5°F (25.3°-28.1°C)	After each 120 minutes of work	After each 90 minutes of work
72.5°-77.5°F (22.5°-25.3°)	After each 150 minutes of work	After each 120 minutes of work

Source: Reference [13].

[a]For work levels of 250 kilocalories/hour.

[b]Calculate the adjusted air temperature (ta adj) by using this equation: ta adj °F = ta °F + (13 x % sunshine). Measure the air temperature (ta) with a standard mercury-in-glass thermometer, with the bulb shielded from radiant heat. Estimate the percent sunshine by judging what percent time the sun is not covered by clouds that are thick enough to produce a shadow. (100 percent sunshine = no cloud cover and a sharp, distinct shadow; 0 percent sunshine = no shadows.)

[c]A normal work ensemble consists of cotton coveralls or other cotton clothing with long sleeves and pants.

Prevention

Proper training and preventive measures will help avert serious illness and loss of work productivity. Preventing heat stress is particularly important because once someone suffers from heat stroke or heat exhaustion, that person may be predisposed to additional heat injuries. To avoid heat stress, management should take the following steps:

- Adjust work schedules:
  - Modify work/rest schedules according to monitoring requirements.
  - Mandate work slowdowns as needed.

- Rotate personnel: alternate job functions to minimize overstress or overexertion at one task.
- Add additional personnel to work teams.
- Perform work during cooler hours of the day if possible or at night if adequate lighting can be provided.

• Provide shelter (air-conditioned, if possible) or shaded areas to protect personnel during rest periods.
• Maintain workers' body fluids at normal levels. This is necessary to ensure that the cardiovascular system functions adequately. Daily fluid intake must approximately equal the amount of water lost in sweat, i.e., 8 fluid ounces (0.23 liters) of water must be ingested for approximately every 8 ounces (0.23 kg) of weight lost. The normal thirst mechanism is not sensitive enough to ensure that enough water will be drunk to replace lost sweat [141. When heavy sweating occurs, encourage the worker to drink more. The following strategies may be useful:
    - Maintain water temperature at 50° to 60 °F (10° to 15.6°C).
    - Provide small disposable cups that hold about 4 ounces (0.1 liter).
    - Have workers drink 16 ounces (0.5 liters) of fluid (preferably water or dilute drinks) before beginning work.
    - Urge workers to drink a cup or two every 15 to 20 minutes, or at each monitoring break. A total of 1 to 1.6 gallons (4 to 6 liters) of fluid per day are recommended, but more may be necessary to maintain body weight.
    - Weigh workers before and after work to determine if fluid replacement is adequate.
• Encourage workers to maintain an optimal level of physical fitness:
    - Where indicated, acclimatize workers to site work conditions: temperature, protective clothing, and workload (see Level of Acclimatization at the end of this chapter).
    - Urge workers to maintain normal weight levels.
• Provide cooling devices to aid natural body heat exchange during prolonged work or severe heat exposure. Cooling devices include:
    - Field showers or hose-down areas to reduce body temperature and/or to cool off protective clothing.
    - Cooling jackets, vests, or suits (see Table 8-5 for details).
• Train workers to recognize and treat heat stress. As part of training, identify the signs and symptoms of heat stress (see Table 8-11).

Other Factors

PPE decreases worker performance as compared to an unequipped individual. The magnitude of this effect varies considerably, depending on both the individual and the PPE ensemble used. This section discusses the demonstrated physiological responses to PPE, the individual human characteristics that play a factor in these responses, and some of the precautionary and training measures that need to be taken to avoid PPE-induced injury.

The physiological factors may affect worker ability to function using PPE include:

• Physical condition.
• Level of acclimatization.
• Age.
• Gender.
• Weight.

Table 8-11. Signs and Symptoms of Heat Stress[a]

- **Heat rash** may result from continuous exposure to heat or humid air.
- **Heat cramps** are caused by heavy sweating with inadequate electrolyte replacement. Signs and symptoms include:
  - Muscle spasms
  - pain in the hands, feet, and abdomen
- **Heat exhaustion** occurs from increased stress on various body organs including inadequate blood circulation due to cardiovascular insufficiency or dehydration. Signs and symptoms include:
  - Pale, cool, moist skin
  - Heavy sweating
  - Dizziness
  - Nausea
  - Fainting
- **Heat stroke** is the most serious form of heat stress. Temperature regulation fails and the body temperature rises to critical levels. Immediate action must be taken to cool the body before serious injury and death occur. Competent medical help must be obtained. Signs and symptoms are:
  - Red, hot, usually dry skin
  - Lack of or reduced perspiration
  - Nausea, dizziness and confusion
  - Strong, rapid pulse, and coma

[a]Source: Reference [6].

Physical Condition

Physical fitness is a major factor influencing a person's ability to perform work under heat stress. The more fit someone is, the more work they can safely perform. At a given level of work, a fit person, relative to an unfit person, will have [5,8,15,16]:

- Less physiological strain.
- A lower heart rate.
- A lower body temperature, which indicates less retained body heat (a rise in internal temperature precipitates heat injury).
- A more efficient sweating mechanism.
- Slightly lower oxygen consumption.
- Slightly lower carbon dioxide production.

Level of Acclimatization

The degree to which a worker's body has physiologically adjusted or acclimatized to working under hot conditions affects his or her ability to do work. Acclimatized individuals generally have lower heart rates and body temperatures than unacclimatized individuals [17], and sweat sooner and more profusely. This enables them to maintain lower skin and body temperatures at a given level of environmental heat and work loads than unacclimatized workers [18]. Sweat composition also becomes more dilute with acclimatization, which reduces salt loss [8].

Acclimatization can occur after just a few days of exposure to a hot environment [15,16]. NIOSH recommends a progressive 6-day acclimatization period for the unacclimatized worker before allowing him/her to do full work on a hot job [16]. Under this regimen, the first day of work on site is begun using only 50 percent of the anticipated workload and exposure time, and 10 percent is added each day through day 6 [16]. With fit or trained individuals, the acclimatization period may be shortened 2 or 3 days. However, workers can lose acclimatization in a matter of days, and work regimens should be adjusted to account for this.

When enclosed in an impermeable suit, fit acclimatized individuals sweat more profusely than unfit or unacclimatized individuals and may therefore actually face a greater danger of heat exhaustion due to rapid dehydration. This can be prevented by consuming adequate quantities of water. See previous section on *Prevention* for additional information.

Age

Generally, maximum work capacity declines with increasing age, but this is not always the case. Active, well-conditioned seniors often have performance capabilities equal to or greater than young sedentary individuals. However, there is some evidence, indicated by lower sweat rates and higher body core temperatures, that older individuals are less effective in compensating for a given level of environmental heat and work loads [19]. At moderate thermal loads, however, the physiological responses of "young" and "old" are similar and performance is not affected [19].

Age should not be the sole criterion for judging whether or not an individual should be subjected to moderate heat stress. Fitness level is a more important factor.

Gender

The literature indicates that females tolerate heat stress at least as well as their male counterparts [20]. Generally, a female's work capacity averages 10 to 30 percent less than that of a male [8]. The primary reasons for this are the greater oxygen-carrying capacity and the stronger heart in the male [15]. However, a similar situation exists as with aging: not all males have greater work capacities than all females.

Weight

The ability of a body to dissipate heat depends on the ratio of its surface area to its mass (surface area/weight). Heat loss (dissipation) is a function of surface area and heat production is dependent on mass. Therefore, heat balance is described by the ratio of the two.

Since overweight individuals (those with a low ratio) produce more heat per unit of surface area than thin individuals (those with a high ratio), overweight individuals should be given special consideration in heat stress situations. However, when wearing impermeable clothing, the weight of an individual is not a critical factor in determining the ability to dissipate excess heat.

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