Chapter 13

RESPIRATORY PROTECTION

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INTRODUCTION

The Occupational Safety and Health Administration (OSHA) has established requirements for worker respiratory protection. OSHA regulation requires employers to develop and put in place a respiratory protection program that includes engineering and administrative controls to prevent workplace hazards, and to use respirators only after all other means to reduce or eliminate occupational exposures to airborne contaminants have been exhausted. Respirators are only intended to be an interim measure to reduce workplace exposures when other controls are neither feasible nor effective at reducing exposures below the OSHA permissible exposure limit.[1]

When an employer develops a respiratory protection program, the first order of business is to define the hazardous exposures present in the workplace and establish their exposure levels. This usually involves arranging for an experienced, certified industrial hygienist to conduct an industrial hygiene survey. Once the workplace hazards and levels are identified, appropriate respiratory protection and other personal protective equipment is selected. The National Institute for Occupational Safety and Health (NIOSH) published 42 Code of Federal Regulations (CFR) Part 84, Approval of respiratory protective devices,[2] that factors in considerations for respirator selection such as hazard properties, concentration, and warning properties in terms of odor and color.[2,3] The local industrial hygienist assesses the program annually and recommends improvements to the installation safety and occupational health council or person in charge of the respiratory protection program.

Respirator use is the least desirable method of controlling workplace exposures because respirators must be properly selected, fit tested, maintained, and worn; and their use must be monitored.[2] Respirators can be hot and uncomfortable to wear, particularly for an 8- to 12-hour shift. Respirators can pose a safety hazard if they impair the ability to hear, see, or communicate effectively. Also, employees with cardiopulmonary health conditions may require a special screening, which is done as part of the medical clearance, to assess their suitability to wear a respirator.[1] If the respiratory protection program is not well executed, it can pose a health hazard to employees and give them a false sense of security.

Workers should only wear NIOSH-approved respirators.[1] The M40 military protective mask is a tight-fitting, full facepiece, air-purifying respirator developed to protect against chemical, biological, and radiological contaminants on the battlefield. These masks, however, are not approved by NIOSH for use in the industrial workplace for protection against toxic industrial chemicals.[3]

RESPIRATOR CLASSIFICATION

Respirators are designed to protect workers from inhaling harmful airborne substances and allow employees to work in oxygen-deficient spaces. There are two basic types of respirators: the *air-purifying* respirator removes contaminants from the air; and *atmosphere-supplying* respirators provide clean breathing air from an uncontaminated source.[2,3] There is a combination respirator which is a subset of each of the two categories. Respirators can also be categorized as tight- and loose-fitting. Respirators are designed to work properly with either a tight-fitting facepiece that forms an airtight seal or a loose-fitting facepiece that forms a partial seal.[2,3] Both air-purifying and atmosphere-supplying respirators can have facepieces that maintain either positive or negative pressure. There are some respirators that maintain positive pressure in the facepiece relative to the ambient air pressure outside the mask during the entire breathing cycle.[2,3] Some respirators maintain a negative pressure in the facepiece when the wearer inhales and often leak ambient air into the facepiece.

Air-Purifying Respirators

When someone wearing an air-purifying respirator inhales, contaminants such as gases, vapors, aerosols, particulates, or a combination of these are removed from the air as it passes over and is absorbed by filter elements.[2,3] There must be sufficient oxygen in the space to support life, and the hazard level has to be low enough that it does not overwhelm the respirator's filtering capacity too quickly. A filtering respirator's useful life span is calculated using the contaminant's concentration rate, the wearer's breathing rate, the workplace temperature and humidity levels, and the filter element's removal capacity. Wood wrote an article that addressed how to estimate the service life of organic vapor cartridges, and Cothran identified software that estimates the service life of respirator cartridges.[4,5]

Selecting an air-purifying respirator depends on the needed level of protection and the types of hazards in the working environment. Available styles are described below.

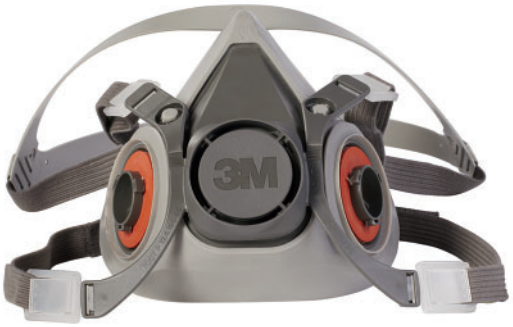

Figure 13-1. This 3M half-face filtering respirator (model 6200) is designed with two attached filtering cartridges and intended to be worn with safety goggles.
Photograph courtesy of 3M Corporation, used with permission.

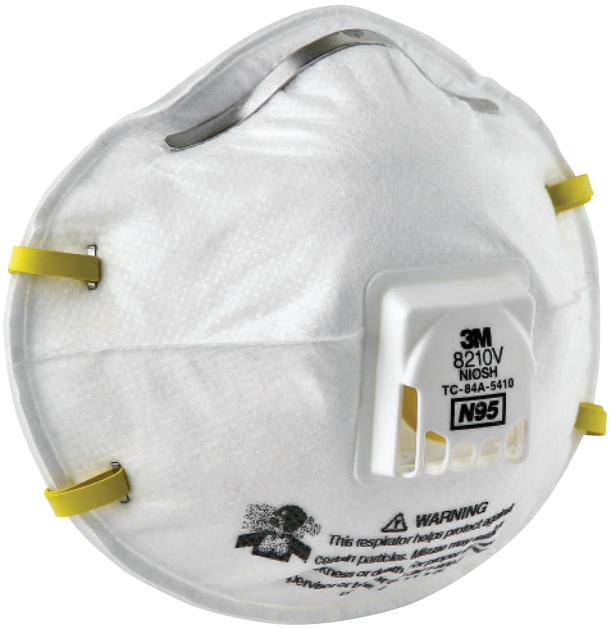

Figure 13-2. This 3M half-face N95 filtering respirator (model 8210V) is designed for wear in hospitals and intended to be worn with safety goggles.
Photograph courtesy of 3M Corporation, used with permission.

- **Mouth bit**. This respirator is used for escape-only situations and regenerates breathable air for emergency escape from areas containing harmful gasses. It is tight fitting and has a short tube designed to fit in the mouth. The wearer must use a nose clip to seal the nostrils to prevent inhalation of ambient air during evacuation from the contaminated environment. The mouth seal and nose clips form the respirator's seal.[2]
- **Half-face**. This respirator is also tight fitting; it covers the facial area from the top of the nose to the bottom of the chin. Half-face respirators (Figure 13-1) generally have two filter cartridges, but a few have a single cartridge.[2]
- **Half-face filtering respirator**. Much like the half-face respirator, the half-face filtering respirator covers the area from above the nose to underneath the chin; however, the entire respirator is made of filtering material. While considered tight fitting, these devices do not have a good elastomeric sealing surface. Almost all filtering facepiece respirators are exclusively designed to protect against particulates and bioaerosols commonly present in the healthcare industry. Filtering facepiece respirators also protect against tuberculosis and similar sized pathogens.[2] The respirator wearer should never confuse a surgical mask with a half-face filtering respirator. A high efficiency particulate air (HEPA) respirator protects against tuberculosis and the transmission of small viruses and particles, while a surgical mask only reduces the amount of aerosol droplets when the wearer sneezes. Figure 13-2 is an example of a half-face N95 filtering HEPA respirator.[2,3]
- **Full-face**. This respirator is unique because it covers the whole face from the scalp to underneath the chin. It fully covers the eyes and protects against splashes from irritating chemical vapors, aerosols, dusts, fumes, and particulates. Figure 13-3 shows an example of a full-face filtering respirator with canisters.[2,3]
- **Powered air-purifying respirator (PAPR).** This respirator (Figure 13-4) is ideal for people who have difficulties wearing a respirator, including those with a respiratory impairment. PAPRs use a blower to force air through the filter and reduce the labor of breathing through a respirator. PAPRs can have either tight- or loose-fitting facepieces, hoods, or helmets. NIOSH requires PAPR blower units to provide at least 4 cubic feet per minute of air to a tight-fitting facepiece and at least 6 cubic feet per minute of air to a loose-fitting facepiece, helmet, or hood.[2,3] PAPRs with hoods and helmets are well suited for wearers who have facial hair and are unable to get a good facial seal. PAPRs that maintain positive pressure inside the mask have loose-fitting facepieces with partial sealing surfaces at the temple, cheek, or chin. In

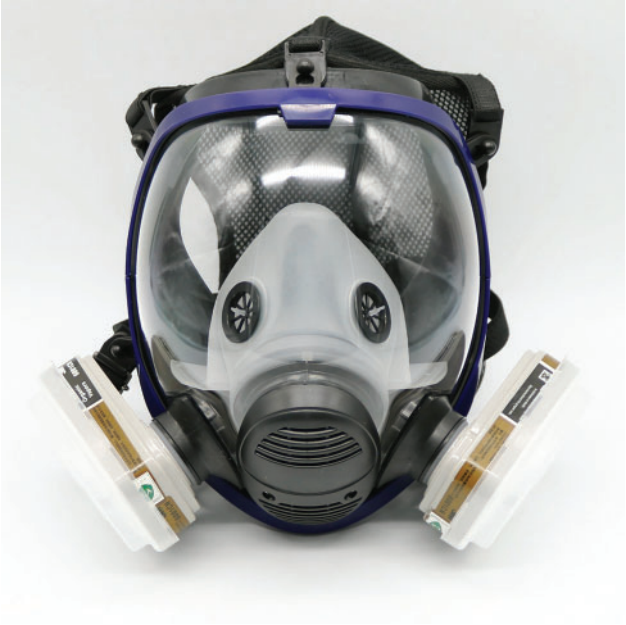

Figure 13-3. This 3M full-face filtering respirator (model 6800) is designed for wear with filtering cartridges attached. Prescription glass inserts may be added to improve worker wearability.
Photograph courtesy of 3M Corporation, used with permission.

order to obtain a tight seal, respirator wearers should remove any facial hair that contacts the respirator's sealing surface.[2,3] NIOSH requires PAPRs to have HEPA filters. The HEPA and P100 filters for negative pressure, air-purifying respirators are magenta or purple in color.[2]

- **Particulate**. Particulate respirators capture air particles such as dusts, mists, and fumes. They are more effective when particles accumulate on the filter and plug spaces between the fibers. Particulate respirators do not protect against gases or vapors. The filters should be replaced when the user finds it difficult to breathe through them.
- **Gas and vapor removing**.
  - Air-purifying respirators that remove gases and vapors tend to remove specific chemicals or a combination of contaminants via cartridges or canisters containing sorbents. Sorbents are often granular, porous materials that remove contaminants by a variety of mechanisms including adsorption, absorption, and catalytic reaction. The cartridges must be replaced when the sorbents lose effectiveness.[2,3] These respirators are not designed to protect against airborne particles.
  - Air-purifying aerosol respirators have filters that protect the wearer against gases and vapors.[2,3] The filtering facepiece respirator may have either a replaceable or permanent cartridge. There are a number of filter cartridge configurations, including randomly laid nonwoven fiber materials, compressed natural wool, and synthetic felt or glass fibers loosely packed into a filter container. Alternatively, any of the above materials may be compressed into a flat sheet that is then pleated and placed into a filter canister. Expanding the filter's surface area by pleating the filter material increases its capacity and efficiency and decreases its resistence.[2,3]
- **Combination.** Combination respirators are used in atmospheres that contain both particulate and gas hazards. They use both particulate filters and gas or vapor filters, and tend to be heavier than other respirators.

Filtration Mechanisms and Classification

A number of mechanisms provide the respirator wearer with clean air. The four commonly used mechanisms in fibrous filters are interception, sedimentation, impaction, and diffusion. Some filters employ a

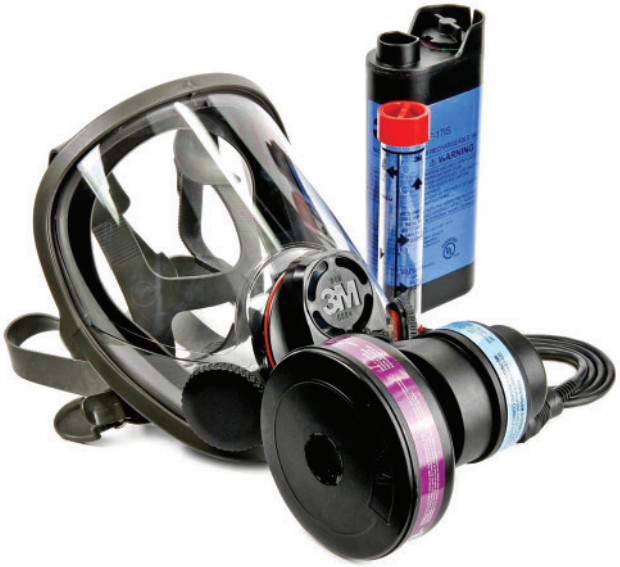

Figure 13-4. The 3M powered air-purifying respirator (model 6884) is designed for wear in settings where neither a tight-fitting facepiece nor a negative pressure respirator can be worn.
Photograph courtesy of 3M Corporation, used with permission.

combination of mechanical means to remove particles; the contribution of each depends on flow rate, particle size, and aerodynamic diameter. In addition to mechanical methods, some respirators use an electrostatic attraction to remove particles.

NIOSH classifies air-purifying respirators based on how well they resist oil. Those that are not resistant to oil are labeled "N"; those that are resistant to oil are labeled "R"; and those that are oil proof are labeled "P."[2] Each of these classifications has three filter efficiency ratings: 95%, 99%, and 99.97% (essentially 100%).[2,3] Particles that are between 0.1 and 0.4 μ in size are the most difficult to filter because they are too small for large particle removal mechanisms and too large for the diffusion filtering mechanism to remove effectively. Tuberculosis bacilli are 1 to 4 μ long and 0.3 to 0.6 μ in diameter. Anthrax bacilli are 1 to 8 μ long and 1 to 1.5 μ in diameter, while the spores are 1 μ in diameter. Filters rated at 95% efficiency remove more than 99.5% of tuberculosis- and anthrax-sized bacilli and spores.

Oil aerosols, including cutting oils, hydraulic oil, lubricating oil, engine oil, dioctyl phthalate, corn oil, and transformer oil, tend to degrade filter efficiency. Refer to the *Guide to the Selection and Use of Particulate Respirators Certified Under 42 CFR Part 84* for a list of respirators that may resist oil saturation.[3] OSHA now requires employers to estimate the cartridge life for particulate respirators.[1] Wood described the process and Cothran identified a computer software program that calculates service life for cartridges.[4,5]

Atmosphere-Supplying Respirators

Atmosphere-supplying respirators provide an air source independent of the ambient environment.[2,3] These respirators are used when: (*a*) a cartridge change-out schedule cannot be established, (*b*) an end-of-service-life indicator is not feasible because of the hazard's properties, or (*c*) the contaminant concentrations are at or near the immediately dangerous to life or health (IDLH) levels, which make an air-purifying respirator inadequate. There are three types of atmosphere-supplying respirators: air-line or supplied-air respirators, self-contained breathing apparatus (SCBA), and combination air-line SCBA.[2,3]

- **Full-face air-line**. Full-face air-line respirators use compressors to supply breathing air pressures no more than 125 psi and restricted to 300 ft of hose.[2,3] Figure 13-5 shows a full-face air-line respirator. The manufacturer must specify the operating pressure and maximum hose length. Air-line respirators are not permitted for use in IDLH atmospheres where the wearer is unable to escape when the air supply fails. Air-line respirators have a variety of facepieces including half-face, full-face, and loose-fitting hood, and they operate in continuous, demand, or pressure-demand modes.
- **Self-contained breathing apparatus**. An SCBA has an independent air supply that permits the wearer freedom of movement. Pressure-demand SCBAs are approved for IDLH and oxygen-deficient atmospheres. SCBAs are designed to be either closed- or open-circuit devices.
  - **Closed-circuit**. These respirators recirculate the wearer's exhaled breath within the respirator after carbon dioxide (CO_2) is removed and oxygen is replaced.[2,3] Closed-circuit SCBAs are smaller and more lightweight (weighing less than 35 lb) than open-circuit SCBAs and have a longer service life (up to 4 hours). Reoxygenation can be performed through a tank of compressed gas or through oxygen generation.
  - **Open-circuit**. An open-circuit respirator (Figure 13-6) discharges exhaled air into the atmosphere. Contaminants in the facepiece are purged instead of recirculated. The SCBA uses a large air tank carried on the wearer's back, making it heavier than the closed-circuit model and limiting the use to one hour. Open-circuit SCBAs are demand or pressure-demand devices.[2,3] NIOSH

Figure 13-5. The full-face air-line respirator provides the wearer breathing air in hazardous environments. The respirator can be worn for a full work shift.
Photograph courtesy of Brandon Gardner, Major, Medical Corps, US Army; US Army Medical Department Center and School, Fort Sam Houston, TX.

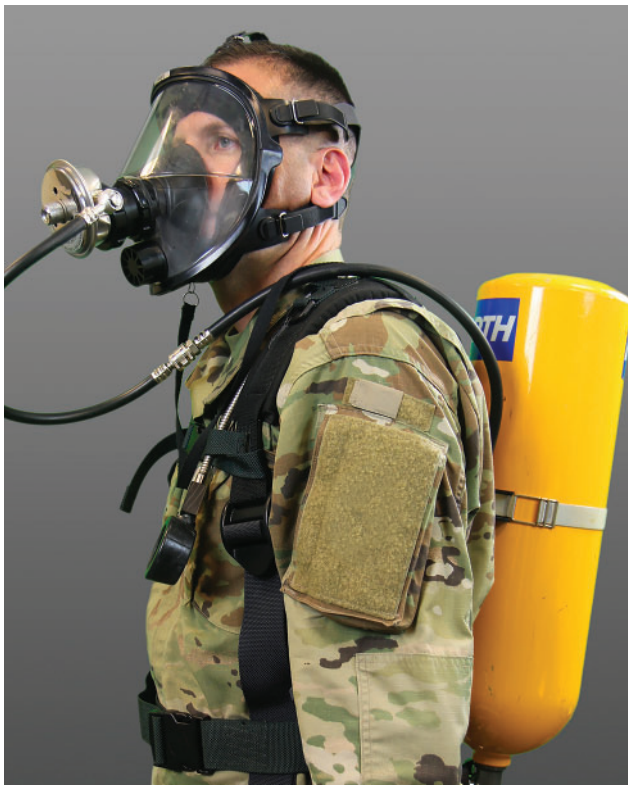

Figure 13-6. The full-face open circuit self-contained breathing apparatus is designed for wear in extremely hazardous environments for short periods up to 30 minutes.
Photograph courtesy of Brandon Gardner, Major, Medical Corps, US Army; US Army Medical Department Center and School, Fort Sam Houston, TX.

approves SCBA for firefighting using guidelines that generally require full-face, pressure-demand SCBAs equipped with 30-minute cylinders that meet National Fire Protection Association requirements.[6,7]

- **Escape-only.** These respirators are intended for emergency use only. NIOSH guidelines call for mouthpiece respirators to be equipped with nose clips to prevent inhalation of hazardous atmospheres.[2]

- **Combination air-line/self-contained breathing apparatus**. Figure 13-7 is an example of a supplied-air respirator and an SCBA cylinder that serves as an auxiliary air supply.[2,3] Pressure demand combination air-line/SCBAs are approved for IDLH atmospheres.[2]

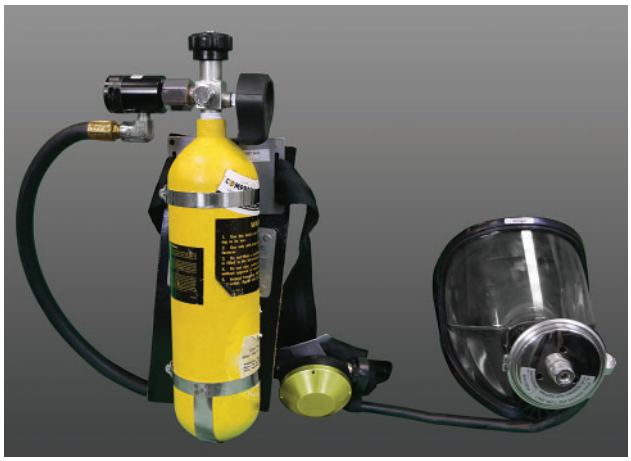

Figure 13-7. The air-line filtering respirator with emergency escape canister permits the wearer to work a full shift and escape the area if there is a release of immediately dangerous to life hazards.
Photograph courtesy of Brandon Gardner, Major, Medical Corps, US Army; US Army Medical Department Center and School, Fort Sam Houston, TX.

After the September 11, 2001 terror attacks, NIOSH established certification standards for SCBAs worn by firefighters and other first responders.[6] SCBAs must protect the wearer from harmful chemicals, pathogens, and radioactive materials. Respirators approved for chemical, biological, radiological, and nuclear (also known as CBRN) environments are rigorously tested and certified to protect against both toxic industrial chemicals and chemical and biological warfare agents. The list of approved respirators is maintained on the NIOSH website.[8]

Respirator Service Life

OSHA respirator regulations eliminated odor thresholds to determine when a respirator has reached the end of its service life. Regulations now require that chemical canisters and cartridges are changed before their end-of-service-life based on a color change.[3] This data, along with the logic for the change-out schedule, must be described in the employer's written respirator protection program. Some cartridges have a colorimetric end-of-service-life indicator that changes color when the filter sorbent is saturated.

RESPIRATORY PROTECTION PROGRAMS

Major requirements of OSHA's respiratory protection standard, 29 CFR 1910.134, requires that employers develop and implement a written respiratory protection program with worksite-specific procedures for respirator use.[1] Each military installation commander must appoint an installation respirator program director and an

installation respirator specialist.[9] The program director is responsible for preparing local regulations in conjunction with the local medical authority. Elements of the OSHA respiratory protection program include the following:[10]

- procedures for respirator selection;
- medical evaluation of employees prior to respirator wear;
- fit testing procedures;
- procedures for routine and emergency use;
- procedures and schedules for cleaning storing, inspecting, and maintaining respirators;
- procedures to ensure air quality, quantity, and flow for atmosphere-supplying respirators;
- employee training about the respiratory hazards at work;
- employee training in all aspects of the program; and
- regular evaluation of program effectiveness.

All work areas where respirators are worn should have specific written standard operating procedures that identify which respirator to wear and under what conditions, and address emergency situations. OSHA regulations also permit workers to voluntarily wear respirators to control nuisance odors or dust. NIOSH-approved respirators are not required for voluntary use, nor do the devices have to be fit tested. The filtering facepiece dust masks and air-purifying respirators are the most commonly worn. The employer does not need a written respiratory protection program if only filtering facepiece dust masks are worn. The employer should ensure the dust masks are clean and do not pose a safety hazard. Each user must be given a copy of Appendix D of 29 CFR 1910.134, (Mandatory) information for employees using respirators when not required under standard,[1] which addresses voluntary respirator use.

RESPIRATOR SELECTION GUIDELINES

OSHA requires wearers to use NIOSH-approved respirators. There are several factors to consider when selecting the correct respirator for a given circumstance.[2]

- **Nature of the hazard.** Includes physical and chemical properties of the contaminants.
  - **Oxygen deficiency.** NIOSH approves air-purifying respirators only for use in atmospheres containing 19.5% oxygen or greater at sea level.[2] OSHA defines oxygen-deficient atmospheres (less than 19.5% oxygen by volume) as IDLH and requires personnel entering these atmospheres to wear either a pressure-demand SCBA or combination pressure-demand air-line/SCBA.[1]
  - **Physical properties.** Physical properties include physical state (gas, vapor, dust, fume, mist, etc), particle size, molecular weight, boiling point, and vapor pressure.
  - **Chemical properties.** The hazard solubility in water, reactivity with other chemicals, and sorbent materials in respirator cartridges or canisters must be considered when selecting a respirator filter. The hazardous decomposition products and oil content in the aerosol are important because these materials will degrade filter efficiency.
  - **Physiological effects.** Physiological effects on the body include skin absorption, eye and mucus membrane irritation, simple or chemical asphyxiation, anesthesia, sensitization, carcinogenicity, and hazards to reproductive systems.
  - **Warning properties.** Warning properties include odor, taste, and irritant effects. The odor properties are least important because OSHA regulations now require that air-purifying respirators be equipped with approved end-of-service-life indicators.[2]
- **Concentration and relevant exposure limit.** The concentration of a compound is an important factor in determining the appropriate respiratory protection. OSHA established the permissible exposure level, and the American Conference of Governmental Industrial Hygienists established the threshold limit value. The DoD requires the services to use the most protective exposure limit choosing between the permissible exposure limit and the threshold limit value. For military chemical warfare agents (nerve and blister agents), the Army has published airborne exposure limits.[11] If concentrations are unknown, the atmosphere should be considered IDLH, and a full-face pressure-demand SCBA or full-face pressure-demand combination air-line/SCBA should be worn. This is similar to the maximum use concentration above which filtering respirators should not be worn.
- **Nature and location of the work operation or process.** The work area, materials, workers' duties, and actions that must be taken in

an emergency all factor into the selection of a respirator. Other considerations include exertion level and climate because workers must be monitored for either heat or cold stress.

- **Time period the respirator is to be worn.** Many factors affect respirator wear time. Air-purifying respirators have different breakthrough (the penetration of contaminant through an air-purifying element) times, which can vary depending on the hazard air concentrations, temperature, and humidity. If workers use SCBAs, the fixed air supply and cylinder weight can increase the wearer's breathing labor and thus shorten the wear time.
- **Fit testing and employee's health.** Individuals must wear respirators that are properly fit tested and, because respirators increase the work of breathing and stress the heart and lungs, should only wear them after being medically cleared to do so.
- **Employee acceptance.** Many factors influence whether an employee will accept and properly wear a respirator; chief among these is the influence of a supervisor who adheres to OSHA regulations and advocates for employee health and safety. Further, the respirators should fit well and comfortably, provide little resistance to breathing, allow adequate visibility (including prescription inserts, when necessary), afford good communication with others, and allow the worker to perform tasks safely.
- **Respirator characteristics, capabilities, and limitations.** Respirator wear is required to protect the worker from workplace hazards and must not impair the workers' vision, hearing, or communication, or restrict movement. Peripheral vision can be impaired during full-face respirator wear. Workers with vision impairments may obtain prescription glass inserts that can be fitted to the facepiece of the full-face respirator. Full-face respirator wear can also impair mobility in confined areas; working in pairs can minimize difficulties when one worker directs the movements of the second worker. Workers who have hearing difficulty may struggle to hear speech in noisy conditions and should be tested for hearing capability. Further, respirator wearers can demonstrate hearing capability during trial use by wearing the respirator while performing job tasks.

MEDICAL CONSIDERATIONS AND EVALUATION

Respirator wear is a burden to the human body. It presents medical considerations including psychological and physiological issues that can interfere with task performance and reduce work efficiency. Left undetected or untreated, some issues may even be life threatening.

Physiological Effects of Respirator Wear

Respirator wear increases air flow resistance and breathing labor. Filtering respirators increase breathing labor by 20% to 30%, and SCBA units increase it by 100%. The body must work harder to breathe because it takes effort to overcome the inhalation and exhalation valves and to pull air through the respirator dead space and into the lungs. A normal breath measures about 500 mL of air. At rest, humans normally take 12 breaths per minute, which equals 6 L of air inhaled per minute. The normal anatomical dead space is about 150 mL. Respirator wear increases the anatomical dead space because some exhaled air remains inside the respirator; half masks retain 250 mL while full-facepiece respirators retain 750 mL. An increased amount of dead space reduces the volume of fresh air and oxygen moving into the alveoli. As a result, CO_2 levels increase inside the respirator by 2% to 5%. The alveolar partial pressure of CO_2 (P_{CO_2}) increases, and alveolar partial pressure of oxygen (P_{AO_2}) decreases. Some diseases impair the body's response to increased CO_2 concentrations; these must be detected during the baseline medical examination.

Medical surveillance should detect conditions that restrict or constrict the lungs and increase cardiac demand, such as asbestosis, silicosis, chronic bronchitis, or emphysema. Table 13-1 lists the specific disqualifying conditions for respirator wearers in accordance with National Fire Protection Association Standard 1582.[1,7] Wearing a respirator also increases heat production because air inside the respirator is heated from sorption chemical reactions in the filter cartridge during breathing. The body's ability to dissipate heat decreases and the skin is covered by a respirator and protective coveralls, thus hampering the evaporative cooling process.

Psychological and Physiological Problems

Many respirator wearers report they feel like they are suffocating in the facepiece, even though they have air. Some workers also get anxious or feel

claustrophobic while wearing a respirator. Wearers may also report a feeling of increased pressure on the face. Wearing a respirator involves carrying additional weight, increased breathing labor due to increased pulmonary resistance, decreased hearing and vision, and heat stress. Bulk weight is the single most important work factor for those using an SCBA; the extra weight increases the work and

TABLE 13-1

SPECIFIC DISQUALIFYING CONDITIONS FOR RESPIRATOR USE

Medical Condition	Problem	Solution
Eye glasses	Eye glasses worn inside the full-face negative pressure respirator prevent a good seal around the mask because outside air leaks in around the temple-bars on the glasses.	Inserts must be provided by the employer for myopic employees who use a respirator.
Contact lenses	Not allowed by federal regulation with any full-face respirator due to their possible contamination and dislocation, which could lead to injury.	Inserts must be provided if the employer cannot obtain full-face mask allowing wear of glasses.
Facial hair	Facial hair that extends between the face and facepiece border does not permit a proper seal.	Shaving or wear of a powered air-purifying respirator with loose-fitting hood.
Facial deformity	Marked facial furrowing or deformity due to the loss of teeth, surgery, or scarring may make a proper facial seal impossible.	Wear of a powered air-purifying respirator.
Respiratory conditions	Employees with emphysema may not be able to overcome the increased resistance to breathing caused by the negative pressure respirator. People with chronic bronchitis who take inhaled medication or have a sputum-producing cough may find constant respirator wear difficult.	Wear of a powered air-purifying respirator.
Cardiovascular	Employees with angina, significant arrhythmias, or myocardial infarction during last 12 months are not qualified to wear a respirator.	Perform a cardiovascular assessment and risk factor modification.
Hearing	Employees' hearing must be adequate to ensure communications and response to instructions/ alarms.	Perform a hearing check while the respirator is worn.
Ruptured ear drum	Perforations in the tympanic membrane allow toxic vapors to enter and be absorbed in the respiratory system.	A hooded respirator may provide protection.
Neurological	Inability to coordinate movements and conditions affecting consciousness will disqualify the employee.	Epilepsy controlled with medications for 1 year is not disqualifying.
Endocrine	Medical conditions where the employee may suffer sudden loss of consciousness (eg, hypoglycemia from too much insulin) may be disqualifying.	Perform assessment of hypoglycemic episodes.
Medications	Prescription drugs may affect judgment, performance, or reliability or alter state of consciousness.	Determine if medication is safe for respirator use.
Psychological	A psychological condition that results in poor judgment or reliability should be disqualifying.	History of claustrophobia or anxiety and respirator intolerance may require a trial of wear for 30 minutes.
Heat stroke	May require work restrictions depending on the environment and protective equipment.	Risk factor modification.
Dermatitis	Dermatitis aggravated by using occlusive materials may be disqualifying.	A loose-fitting powered air-purifying respirator may permit the wearer to use the respirator with dermatitis.

Data sources: (1) 29 CFR Part 1910.134. Respiratory protection. (2) National Fire Protection Association. *NFPA 1582: Standard on Comprehensive Occupational Medical Protection for Fire Departments*. Quincy, MA: NFPA; 2013.

physiological demands on the cardiopulmonary system. As a minimum, respirator wearers must have the physiologic capacity to perform at 10 METS (metabolic equivalents) when testing is conducted on a treadmill, particularly if the worker has any cardiovascular (CV) conditions.

Purpose of the Medical Evaluation

OSHA[1] and US Army regulations[9] require that employees are medically qualified or cleared to wear a respirator, and that they are fit tested and trained. Employees are medically evaluated to ensure they can safely wear a respirator and they have no medical conditions that would put themselves or others at risk.[1] The medical clearance must be done prior to issuing the respirator to the employee. The baseline assessment is a comprehensive history and physical examination that includes a pulmonary function test, physical examination, baseline laboratory work, and a completed OSHA respirator questionnaire. The medical evaluator can perform a use test to ensure personnel who wear respirators in the workplace are safely able to do so while performing their jobs.

The medical evaluation is designed to identify serious conditions including heart problems such as hypertension or prior myocardial infarction, stroke, or angina; respiratory diseases such as asthma, bronchitis, emphysema, or chronic obstructive pulmonary disease; restrictive lung diseases such as asbestosis; neurological conditions that impair sensory function or involve psychological disorders; and musculoskeletal disorders. Personnel who wear a respirator for escape-only purposes do not require medical clearance. However, they must be briefed on the use of the escape respirator and escorted by personnel who can assist them in an emergency.

Who Should Perform the Medical Evaluation?

The medical evaluation must be performed by a physician or other licensed healthcare professional.[1] OSHA defines licensed healthcare professionals as physicians, occupational health nurses, nurse practitioners, and physician assistants who are licensed to perform the respirator assessment in the state in which they practice. OSHA requires the medical examiner to use its mandated medical questionnaire, which is published in Appendix C of 29 CFR 1910.134, OSHA respirator medical evaluation questionnaire (mandatory).[1] If the employee gives a positive response to any of the specific questions, a more thorough medical evaluation is required. OSHA regulations require the healthcare provider's written opinion regarding the employee's fitness and a list of any limitations to respirator wear. If medical follow-up is warranted, the licensed healthcare provider must indicate what is needed to assist the examiner in making a recommendation. Some medical conditions prohibit the wear of a negative pressure air-purifying respirator, and in these situations the powered air-purifying respirator may be a suitable alternative.

Frequency of Medical Evaluations

OSHA[1] and US Army regulations[9] require employers to medically reevaluate respirator wearers at least annually using the OSHA respirator questionnaire. The American National Standards Institute (ANSI) recommends a more comprehensive history and physical examination every 5 years for individuals below age 35, every 2 years for those age 35 to 45, and annually thereafter. Special evaluations should be performed after prolonged absences from work for medical reasons or whenever a functional disability is identified. A health assessment may be required more frequently than annually for changes in the health status of the employee when:

- medical signs or symptoms are present that interfere with the ability to use a respirator;
- a supervisor, healthcare professional, or safety/industrial hygiene professional observes that the worker has problems using a respirator;
- difficulties observed during employee fit testing suggest the need for reevaluation; or
- a change in work conditions increases the employee's physiological burden, such as increased work effort, a change in protective clothing, respirator type, or temperature/humidity changes.

Military personnel who have completed an annual periodic health assessment are deemed fit for full duty and medically qualified to use all respirator types. Civilian employees must complete the questionnaire in Appendix C of 29 CFR 1910.134. Then the examiner reviews the questionnaire responses. The employer must provide the examiner with a copy of the written respiratory protection program, a copy of regulation 29 CFR 134.10, Respiratory protection, and the following information about the job:

- type and weight of the respirator;
- duration and frequency of respirator use (including use for rescue and escape);
- expected physical work effort;
- other protective clothing and equipment; and
- temperature and humidity extremes.

Cardiovascular Risk Assessment and Evaluation Procedures

The healthcare provider must perform a CV risk assessment for respirator wearers in high risk positions (eg, firefighters, police, security guards, and other first responders). The CV evaluation consists of a level A and B screening. Level A screening determines if workers have any CV risk factors. If the CV risk factors are significant, such as a Framingham Risk Score (a risk assessment tool that estimates a patient's 10-year risk of developing CV disease) greater than 15%, then level B screening is required. Individuals who have coronary heart disease, or a coronary heart disease-risk equivalent, must undergo a level B screening evaluation. The level B CV evaluation consists of a noninvasive treadmill stress test that includes myocardial perfusion scintigraphy (thallium or sestamibi) or stress echocardiography.

Workers with an intermediate Framingham Risk Score (between 10% and 15%) should be referred to their primary care provider for chronic disease management to include dietary counseling, exercise prescription, and reduction of other risk factors. Workers with a Framingham Risk Score greater than 15% should be temporarily restricted from wearing a respirator until the level B screening is completed. Workers with a score above 15% but below 20% may be given a temporary medical clearance for 3 months to use an air-purifying respirator. Individuals should be reevaluated every 3 to 5 years, or sooner if they develop new symptoms or their cardiac risk increases. Individuals who fail level B screening should not use a respirator except for escape purposes.

Pulmonary Function Testing Basics

Spirometry has long been used to screen respirator wearers by measuring lung function, specifically the volume and speed of inhaled and exhaled air. Spirometry is readily available in doctors' offices because it is inexpensive, compact, and portable. Acute illness, smoking or bronchodilator use, upper or lower respiratory tract infection, operator experience, and individual motivation can affect spirometry results and require additional testing.

Testing Procedures

For each spirometry trial, the patient inhales maximally and then exhales completely. A minimum of three trials are needed to ensure reproducibility. Unreproducible results should be repeated. The volume-time tracing plots volume on the y-axis and time on the x-axis. The flow volume loops plot inspiratory and expiratory flow on the y-axis and time on the x-axis. Normal tracings are available for comparison with the flow and volume loops generated during testing. The results are adjusted for gender, height, age, and race, then compared to norms and presented as a percent of the predicted value. The normal range of the forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1) is any value greater than or equal to 80% of the predicted value. The normal FEV_1/FVC ratio (Tiffeneau-Pinelli index) is between 80% and 85%. Spirometry results may suggest that workers need further testing. If the FVC is less than 80%, or the FEV_1 is less than 70% of the predicted value, the individual should be restricted from respirator use for further evaluation. Any patient who complains of a persistent cough, wheezing, or shortness of breath should get a chest radiograph and pulmonary function test.

Abnormal pulmonary function test results can have an obstructive, restrictive, or mixed pattern. The obstructive pattern is altered because there is some pathology that restricts air movement out of the lungs. This causes the volume-time curve to look flatter than normal: the FEV_1 decreases, the FVC is normal, and the FEV_1/FVC ratio is less than 80%. When individuals have a restrictive pattern, interstitial lung disease causes reduced lung volumes and both the FEV_1 and FVC are reduced, but the FEV_1/FVC ratio is normal or slightly increased. The volume-time curve appears normal but is decreased in size. Workers may also have a mixed pattern, where features of both obstructive and restrictive disease are present. A mixed pattern pulmonary function test will show a decreased FEV_1 and FVC; the FEV/FVC or FEV_1% will be reduced as well.

Causes of Obstructive and Restrictive Patterns

Obstructive lung disease is associated with decreased airflow, which results from bronchoconstriction, inflammation of bronchial linings and increased mucus secretion, and loss of lung elasticity. Asthma and smoking are associated with an obstructive pattern. Restrictive lung disease is associated with decreased lung volumes but normal rates of airflow. A restrictive pattern may be seen with diseases that may affect specific parts of the lungs. For example, pleural diseases decrease lung volumes by restricting the expansion of the lungs. Alveolar diseases such as pneumonia and pulmonary embolism decrease lung volume by displacing air or preventing air from filling the alveolar spaces. Interstitial lung diseases such as sarcoidosis, pulmonary fibrosis, silicosis, and asbestosis decrease lung volume by filling the interstitium of the lung.

RESPIRATOR TESTS AND CHECKS

Fit Testing

Respirators are sometimes classified as tight-fitting or loose-fitting. Tight-fitting respirators need a tight seal between the respirator and the user's face or neck in order to work properly and provide optimal protection. To ensure a tight seal, the employer performs a fit test on a worker using the same make, model, and type of respirator as those used on the job. Tight-fitting respirators shall not be worn when conditions prevent a good seal. OSHA and Army regulations require tight-fitting respirators to be fit tested prior to initial use, when there are changes in facial features, and annually. Facial hair, temple bars on eyeglasses, missing dentures, facial deformities, and jewelry may interfere with the seal. Personnel with beards or eyeglasses may wear devices that are not tight-fitting, such as air-line respirators and PAPRs. Loose-fitting devices do not need to be fit tested. Personnel who perform fit testing must follow ANSI Z88.10 Section 5, *Respirator Fit Testing Methods*.[12] OSHA regulations require respirator wearers to be fit tested initially before wearing the respirator and at least annually thereafter. If there has been a change in the facial conformation, then personnel should be tested sooner.

Quantitative and Qualitative Fit Tests

Quantitative fit testing determines the leakage around the wearer's face and sealing surfaces; the results do not rely on a subjective response from the worker. Quantitative fit testing requires expensive equipment, trained personnel, and probed respirators or special filter adapters. Figure 13-8 shows quantitative fit testing equipment attached to a respirator. Qualitative fit testing uses a test chemical to elicit a response from the wearer. These tests are fast, easy to perform, inexpensive, and usually involve an odor test, taste test, or irritant smoke. All respirator wearers are screened to ensure they can detect the fit test agent. Figure 13-9 shows qualitative fit testing equipment.

Negative and Positive Pressure Respirators

Negative pressure respirators include a safety factor of 10 per ANSI Z88.2 para. 9.1.1-2015, *American National Standard Practices for Respiratory Protection*.[13] Negative pressure respirators must pass the fit test with a fit factor at least 10 times greater than the assigned protection factor.[8] The respirator fit factor is measured during fit testing and expressed as a ratio of the test agent's concentration level outside the respirator to the test agent's concentration level inside the respirator facepiece.[2] Respirators with higher fit factors provide greater protection against contaminants. Positive pressure respirators, including PAPRs, must be fit tested in the negative pressure mode by temporarily converting the facepiece into a negative pressure air-purifying respirator or by using a "surrogate" negative pressure facepiece. OSHA allows positive pressure respirators to be fit tested either qualitatively or quantitatively.[1]

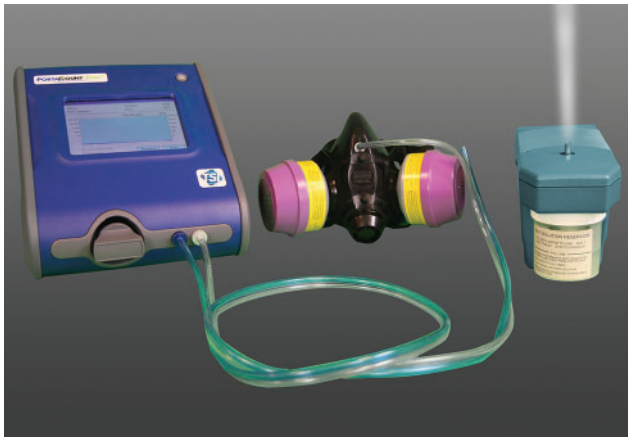

Figure 13-8. Quantitative fit testing will measure the concentration of particulates outside the mask and compare it with the concentration inside the mask to assure mask seal quality.
Photograph courtesy of Brandon Gardner, Major, Medical Corps, US Army; US Army Medical Department Center and School, Fort Sam Houston, TX.

Figure 13-9. Qualitative fit testing is done by releasing a chemical with a recognizable odor into the hood space surrounding the respirator and determining whether the odor is detectable in the respirator's facepiece.
Photograph courtesy of Brandon Gardner, Major, Medical Corps, US Army; US Army Medical Department Center and School, Fort Sam Houston, TX.

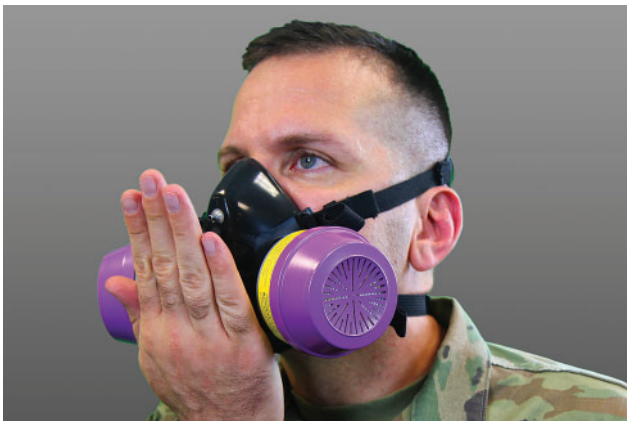

Figure 13-10. A positive seal check is a function check of the respirator performed by the wearer who exhales forcefully while covering the exhaust port of the respirator.
Photograph courtesy of Brandon Gardner, Major, Medical Corps, US Army; US Army Medical Department Center and School, Fort Sam Houston, TX.

Figure 13-11. A negative seal check is a function check of the respirator performed by the wearer who inhales forcefully while covering the intake ports of the respirator.
Photograph courtesy of Brandon Gardner, Major, Medical Corps, US Army; US Army Medical Department Center and School, Fort Sam Houston, TX.

User Seal Checks

Users of tight-fitting respirators must be trained to perform user seal checks, which is a function test done before each use. To perform the check, a worker generates positive pressure in the mask by exhaling with force while covering the exhaust port, as shown in Figure 13-10. For a negative pressure seal check, the wearer covers the inlet valves of the filter cartridge and inhales deeply, as shown in Figure 13-11. Seal checks are not substitutes for quantitative or qualitative fit tests and should be done per the manufacturer's recommendations.

MAINTENANCE

Cleaning and Storage

OSHA regulations require proper respirator maintenance and cleaning, which help prevent skin irritation and encourage worker acceptance of respirator wear. Some contaminants, such as particulates and aerosols, build up on the sealing surface and may enter the breathing zone. In addition, the contaminant buildup on the respirator will cause it to deteriorate. Lastly, a dirty facepiece may obscure vision.

Respirators must be stored in an area free of dust, harmful chemicals and biological agents, sunlight, vibration, shock, extreme heat or cold, insects, and excessive moisture. Plastic reclosable storage bags make great storage devices. Respirators should be packed and stored so the facepiece and exhalation valves rest in a normal position. Respirators must be stored properly without using straps or deforming the facepiece, which can cause facepiece failure. Respirators designated for emergency use should be stored in clearly marked compartments dedicated to emergency equipment and must be accessible at all times.

Inspection and Function Checks

All respirators, even new ones, should be inspected to make sure they are free from defects and not damaged in shipment. All respirators must be inspected before each use and after each cleaning. Emergency use respirators must be inspected before each use, at least monthly in accordance with the manufacturer's instructions, and before being carried into the workplace. Each employee must inspect and maintain their own respirator. This includes a functional check of respirator connections, and a check of the condition of all parts, including the facepiece, lenses, head straps, valves, connecting tubes/hoses, filters/cartridges/canisters, and air cylinders.

Color Coding

Air-purifying respirator canisters, cartridges, and filters are color coded for rapid identification and to ensure consistency among respirator manufacturers. The standards in ANSI Z88.7-2010, *Color Coding of Air Purifying Respirator Canisters, Cartridges, and Filters*, permit rapid selection of respirator cartridges.[14]

Breathing Air for Supplied-Air Respirators

OSHA requires that all compressed air meets the specification for Grade D breathing air per 29 CFR 1910.143(i)(1), Nonwater carriage disposal systems.[15] Breathing air stored in cylinders or produced by compressors must be tested, and vendors must have a certificate stating the air meets Grade D breathing air requirements. Organizations that generate their own breathing air, such as fire departments, should sample and analyze air quarterly. The Compressed Gas Association G-7. 1-1997 technical bulletin, *Commodity Specification for Air*,[16] requires the collection and testing of breathing air. Compressed oxygen must never be used in supplied-air respirators because it poses an explosion risk if oil or grease were previously introduced during compressed-air operations.

TRAINING

Prior to respirator use, OSHA requires employers to train their employees, including personnel who issue respirators and supervisors of respirator wearers, on all aspects of the respiratory protection program. The training goal is to further assure proper respirator selection, use, and maintenance. OSHA regulations require training programs tailored to the educational level and language skills of the employee. Each person who wears respiratory protection in the workplace must be given instruction that includes:

- an explanation for respirator use including hazard identification, the extent of employee exposures to those hazards, and potential health effects if the respirator is not properly worn;
- a discussion about what engineering and administrative controls are being used (if any) and why respirators are still needed for protection in the workplace;
- an explanation of why a particular type of respirator has been selected, along with the function, capabilities, and limitations of that device (especially with regard to IDLH environments);
- instruction on how to inspect, check, don, wear, and remove the respirator, and what to do if a problem is discovered;
- instruction on how to use the respirator in an emergency situation, such as during a malfunction or if the environment becomes IDLH;
- training on proper respirator cleaning, maintenance, and storage procedures;
- information on adverse health conditions (such as asthma) that may limit or prevent the effective use of respirators; and
- a review of the OSHA Respiratory Protection Standard so that employees understand their employer's obligations with respect to employee protection.

Employees who are trained in respirator donning and wear must physically handle the respirator and practice donning, adjusting the straps, performing seal checks, and determining a proper fit.

PROGRAM EVALUATION

Under the OSHA respirator rule, employers must ensure that the written respiratory protection program is properly implemented in their workplaces and that employees are properly using respirators.[1] Employers must ask respirator users about program quality and identify any program problems. This assessment must include all program elements including proper fit testing, safe respirator wear, respirator suitability for the hazards present, situational use, and maintenance. Problems identified through this assessment process must be corrected immediately.

RECORD KEEPING

The OSHA Respirator Standard requires employers to keep a copy of the written respiratory protection program on hand. Employers must record and retain written information regarding medical evaluations, fit testing, training, and the respirator program in general.[1] Employers can use this information to promote employee involvement in the respirator program, to audit program adequacy, and to provide a record for compliance purposes. Employees can use this information to assess their own health risks.

Medical Evaluation Records

The healthcare provider must keep a medical evaluation record on file for each employee who is required to wear a respirator. This record must include a copy

of the OSHA medical questionnaire and the licensed healthcare provider's written opinion and recommendations regarding the employee's ability to wear the respirator. These records must be retained and made available per OSHA regulations at 29 CFR 1910.1020, Access to employee exposure and medical records.[17]

Fit Test Records

OSHA requires the employer to keep fit test records on file until the next fit test is administered. If an employee no longer needs to wear a respirator because of reassignment or change of duties, a record must contain annual fit test results and the respirator type used for the employment period.

Training Records

The minimum training documentation includes training dates and the names of the trainees and training administrator. Training records are maintained by the installation respirator specialist.

SUMMARY

This chapter reviewed OSHA requirements for employers to have a respiratory protection program in place when they require employees to wear a respirator. OSHA standards place primary emphasis on utilizing engineering, administrative, and work practice controls to reduce or eliminate occupational exposures to airborne contaminants. However, respirators are often required as an interim measure in those instances where workplace controls are not feasible in reducing exposures. Respirators are the least desirable method of exposure control, and they only provide effective protection if properly selected, fit tested, maintained, and worn. Factors to consider when selecting a respirator include the hazard, hazard properties, hazard concentration, and hazard warning properties (color, odor, etc). Workers require medical clearance prior to use of a respirator, and respirators must be approved by NIOSH. The local industrial hygienist should document any apparent deficiencies in a respiratory protection program and bring them to the attention of the unit commander, site supervisor, or person in charge.

ACKNOWLEDGMENTS

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