CHAPTER 7.6

PERSONAL PROTECTIVE EQUIPMENT

JOHN B. MORAN
RICHARD M. RONK

National Institute for Occupational Safety and Health
Morgantown, West Virginia

7.6.1 INTRODUCTION

Personal protective equipment, such as respirators or hearing protectors, must be considered as the last line of defense for workers. Every attempt should be made to eliminate the potential of exposure to hazards to the individual worker through administrative and/or engineering control measures such as job rotation or ventilation, respectively. There are, of course, many tasks that are infrequent in nature and often associated with servicing, maintenance, or installation of equipment, where administrative or engineering controls are not practical or feasible. It is in those instances where personal protective equipment can play the key role of protecting the worker from exposures to hazardous substances or physical agents such as noise.

This chapter is devoted to a review of a broad range of personal protective measures available. Its aim is to provide a fundamental understanding of such devices when used in various industrial settings. As such, it is intended to serve as an introduction to the selection, use, and maintenance of personal protective devices. A fundamental assumption is that administrative and/or engineering control means of reducing or eliminating potentially hazardous exposures have been considered and applied where appropriate and feasible.

The reader is cautioned that there are many regulatory standards promulgated by regulatory agencies such as Occupational Safety and Health Administration (OSHA), Mine Safety and Health Administration (MSHA), and Nuclear Regulatory Commission (NRC), which establish specific requirements for the selection and application of personal protective devices. For example, many specific and general OSHA standards require personal protective equipment where forseeable hazards are present. These specific standards define the hazards present and establish the protective equipment required for workers exposed to such hazards. Further, both regulatory standards and consensus standards governing the performance of such devices have been established. These standards and requirements do change as new exposure standards, for instance, are promulgated. Therefore, the reader must ascertain the current applicable standard governing the specific situation. To serve as a reference point, this chapter refers to standards pertinent to specific devices as they presently exist.

7.6.2 PERSPECTIVE

Personal protective equipment includes a very broad range of devices produced and marketed by a large number of diverse suppliers. Such devices range from complex and expensive self-contained breathing apparatus (SCBA) to simple vinyl disposable gloves. Although there is little information available about the size of the protective equipment business, respirators alone were estimated to represent a $285 million market in 1980 and were used by 15% of workers engaged in mining, manufacturing, and construction (approximately 5 million persons) (NIOSH, 1982). Selection of personal protective equipment does not necessarily follow the usual stages of engineering decisions because information vital to making a rational choice is frequently lacking.

Personal protective equipment seldom provides complete protection against a significant stress; rather it serves to attenuate the stress to a level which is acceptable. For example, if protection from a falling pipe wrench is desired for a pipe fitter working 10 ft below his fellow workers, then it would seem desirable to express the stress in engineering terms, dividing by the allowable stress on the head/neck/shoulder system and selecting the hard hat providing the required attenuation. Unfortunately, neither the allowable stress nor the degree of attenuation is known for most applications of personal protective equipment.

Biomechanical research to establish allowable stress is extremely complex and costly and there is little, if any, economic incentive for protective equipment manufacturers or equipment purchasers to conduct inquiries. Government protective equipment research is also limited, with a majority being conducted for defense purposes, much of this having little transfer to nonmilitary applications.

One researcher in head protection has said "the injury criterion currently used to evaluate industrial safety helmets has no biomechanical justification" (Cook, 1980). Other researchers have called the criteria for respirator certification "technological anachronisms." Many of the criteria for "attenuation" or "performance" of personal protective equipment are based upon design failures that have been frozen into standards for equipment by consensus groups. These groups are chosen largely from manufacturers or distributors of safety equipment who have little, if any, access to research facilities in their organizations and access to only a limited amount of government or academic research. Therefore, it is not surprising that the standards reflect the "art of the profitable" or practical and not necessarily the most effective "state of the art."

Nearly all personal protective devices are manufactured to comply with a "standard." Such performance standards range from federal standards for respirators (30 Code of Federal Regulations Part

11) to consensus standards such as ANSI Z87.1 for eye and face protection devices. Most consensus performance standards for protective devices have, by reference, been adopted by regulatory agencies as establishing acceptable performance criteria. Devices that are stated as complying with such consensus standards are, in essence, self-certified by the individual manufacturer. Studies by the National Institute for Occupational Safety and Health (NIOSH) in the mid-1970s, however, showed that not all such devices in fact met the requirements of the applicable consensus standard. For example, 18 of 21 Class B helmets tested failed to meet the minimum requirements of the ANSI Z89.2 consensus standard (Cook and Groce, 1975). Publication of the results of the NIOSH tests and the recent creation of an independent private certification laboratory (SEI, Safety Equipment Institute) have likely resulted in improved performance standards compliance, however. All devices stated as meeting a consensus standards requirements are so labeled by the manufacturer. Similarly, devices certified by SEI carry the SEI label.

The most common personal protective devices tested and certified by the federal government are respirators. Regulatory agencies require that such approved devices be utilized where respiratory protection is required, and where an appropriate certified device is available. All approved respirators carry a label issued by NIOSH and MSHA which states the limitations of use.

Some protective devices, principally protective clothing such as gloves, splash aprons, and encapsulating suits, are not tested for compliance with standards because none exist to date.

Personal protective devices are largely marketed by safety equipment distributors. Such distributors often represent many manufacturers. Contrary to the fact that personal protective devices are frequently lifesaving equipment such as escape respirators, protective equipment is largely marketed as a commodity item and sold principally on price rather than performance. This is fostered by the fact that the performance standards are largely minimum acceptable performance standards; thus superior performance is not generally marketable for superior price. The selection of personal protective equipment, therefore, should be exercised with care and with preference being given to the supplier and/or manufacturer that can provide information specific to the intended use situation.

The subsequent sections of this chapter are devoted to specific protective devices. The concluding section examines aspects of human factors in personal protective equipment use. Additionally, each section also addresses the negative impact on the user as a consequence of the use of protective equipment. This is an essential consideration, because the use of nearly all protective devices reduces the effectiveness of one or more of the human systems. Respirators, for example, reduce peripheral vision and impede voice communications, increase respiratory and cardiac stress, and may impose psychological stress (Harber, 1984).

7.6.3 HEARING PROTECTION

OSHA standards (29 CFR 1910.95) establish maximum noise levels permitted and establish the requirement for hearing protection programs, including hearing protective devices, when the specified levels are exceeded. The basic philosophy behind the protective equipment component of the standard is that the hearing protection devices should reduce noise levels at the ear to a level at or below the stated standard. This is a common approach to the application of protective devices, which span a wide range of designs including combinations with other protective devices such as hard hats.

There are, however, two basic types of hearing protectors available: those that cover the ear (muffs) and those used in the ear canal, usually referred to as earplugs. The essential feature of relevance, however, is the noise attenuation characteristics.

Prior to 1974, hearing protectors were tested in accordance with ANSI Z24.22-1957. Subsequently, a new method was adopted as ANSI Z3.19-1974, which incorporated the substitution of third-octave bands of noise instead of the discrete tones used in the Z24.22 standard. In addition, reverberant test rooms replaced the earlier anechoic test rooms. Mean attenuation of hearing devices varies with frequency of noise to which exposure is occurring. For example, an earplug may exhibit 25 dB attenuation at a frequency of 250 Hz while exhibiting 35 dB attenuation at 8000 Hz. Earmuffs, on the other hand, may exhibit a 15 dB attenuation at 250 Hz and 37 dB at 8000 Hz.

The present OSHA standards require that no exposure to continuous sound over 115 dB(A) be permitted at any time. Additionally, the standard specifies methods of acceptable noise level measurement that can be achieved with either sound level meters for real time measurements or personal noise dosimeters for integrated work-shift exposure. Noise levels must first be determined before appropriate hearing protection can be selected.

All reputable hearing protector manufacturers provide noise attenuation curves for these protective devices. They should be consulted as an essential step in the process of hearing protector selection. Helpful general guidance with regard to the effectiveness of noise attenuation is available as a result of EPA regulations requiring hearing protector labeling. Key to this labeling is the noise reduction rating (NRR). The NRR rating is based upon noise attenuation tests for continuous noise. In most industrial cases, the attenuated noise exposure to the employee can be reasonably approximated by subtracting the NRR value from the A-weighted noise level. If, however, noise exposure is largely below 500 Hz or is impulse noise, the NRR value approach is less reliable. Typical NRR values for various types of hearing protectors are as follows:

Earmuffs	15 to 25 dB
Premolded and custom molded earplugs	10 to 25 dB
Foam earplugs	29 dB
Disposable earplugs	20 dB

Additional practical factors must be considered in regard to hearing protectors. Earmuff performance often varies depending on whether the headband is worn over the head, under the chin, or behind the head. For example, one such protector offered 26 dB attenuation at 2000 Hz when worn behind the head, and 39 dB attenuation when worn over the head. Earplug performance obviously varies as a function of conformity or fit to the ear canal.

Earmuffs are generally less comfortable than plugs if worn for extended periods such as a whole work shift. Improper fit is most often the result of attempts by the wearer to make this device more comfortable. The attenuation data provided by manufacturers are data obtained in a "perfect" environment, not a working environment. Therefore, care must be taken to provide a comfortable protector to the user, insofar as is possible, because the manufacturer's performance will rarely be realized in the real work setting. Durability, cost, sanitation-hygiene characteristics, and duration of required use both during a shift and during subsequent shifts are additional factors that should be considered in hearing protector selection.

Compensation costs associated with occupationally induced hearing loss are increasing significantly. Noise exposure should be reduced through administrative and/or engineering controls wherever possible. Where hearing protection is required, however, care should be taken to make an informed selection and to ensure an adequate continuing protection program including visitors to "noise" areas. The days of merely providing every employee a set of earplugs are over.

7.6.4 HEAD PROTECTION

Head protection, in the form of the common construction workers' hard hat, is well known. Such protection is often mandated as well by regulating agencies such as OSHA which, under provisions of 29 CFR 1910.135, requires that such head protection be worn where protection to the head from impact and penetration from falling or flying objects or from limited electrical shock and burn is necessary. Such head protective devices must comply with the ANSI Z89.1-1969 consensus standard. Subsequent to the promulgation of the OSHA regulations, an additional improved ANSI standard, ANSI Z89.2-1971 Class B, was issued. This standard relates only to helmets for electrical protection and is now widely used by helmet manufacturers.

There are four categories of industrial head protection devices based on the exposure that may be encountered:

Class A. General industrial head protection devices with limited dielectric protection

Class B. Industrial protective helmets for electrical workers (high-voltage protection)

Class C. Aluminum safety headwear with no dielectric protection

Class D. Fire fighters' helmets

These devices all have two basic elements in common: an outer shell and an inner suspension system. In order to function as designed, the suspension system must be adjusted so that the helmet shell does *not* rest on the head.

Selection must be based on the hazard for which protection is sought. A Class B helmet, for example, meets all the basic requirements of a Class A, yet possesses specific high-voltage dielectric properties to provide protection from electrical contacts. Clearly, a Class C aluminum helmet should never be used where electrical contact is possible. By far the most common helmet in use today is the class B helmet.

Head protection devices are available with a wide range of attachable accessories. Hearing protectors, face shields, welders' face shields, head lamps, and winter liners are the most common. Caution, however, must be exercised in the selection, attachment, and use of these accessories. For example, a winter liner may have a metal zipper that will void the Class B electrical helmet rating and render the helmet unsuitable for an electrical application. Earmuffs should be those specifically adopted for use with the helmet, usually with a swivel mounting on the helmet over each ear.

It is important to note that helmets meeting the noted standards are designed for protection from objects falling directly on the head. Moreover, industrial helmets do not provide protection appropriate for vehicular use. They therefore provide little protection from blows in the horizontal plane. Further, there are many additional helmets available that do not and are not intended to meet these standards. These are often referred to as skullcaps or bump caps. Such devices are intended to provide minimum abrasion or cutting protection to the head. They afford little or no protection from impact.

Helmets often become "personal" to workers and are adorned with names, logos, and so on. Helmets, however, require routine inspection for cracks, breaks, and failure of the suspension, for example. A cracked helmet or a suspension that has one of the four or six suspension attachment points broken offers little protection. Periodic inspection should be required, therefore. When the shell is not damaged, replacement suspensions are available and should be used where the individual has a personal attachment to his/her helmet.

Helmets do not, it must be noted, provide protection against all possible impacts. The ANSI standard requires, for example, that no substantial contact occur between the helmet shell and the suspension when an 8 lb steel ball is dropped on the top of the helmet mounted on a rigid head form from a height of 5 ft. Caution should be exercised with regard to such limitations.

7.6.5 RESPIRATORY PROTECTION

Of all the personal protective devices utilized in the workplace, respiratory protective devices are by far the most complex, diverse, and demanding with regard to proper selection and use. In many instances, such as the fire-fighting environment, these devices are literally life sustaining. In many other applications, however, the misuse or misapplication may not be apparent for several years. An example of this is when exposure to asbestos occurs because of improper respiratory protection and the long-term consequences of the disease manifest themselves 20 to 30 years later. There may also be disagreement among the regulatory agencies, respirator manufacturers, respirator users, and the testers and certifiers of respirators with regard to the degree of respiratory protection required or provided in a specific exposure situation. Sources of advice regarding proper respirator selection for specific exposure situations should be sought from the following:

Respirator manufacturers who market NIOSH/MSHA-approved respirators.

Suppliers of approved respirators if such suppliers have available data or direct supporting guidance from the manufacturers they represent.

NIOSH, through the annual *NIOSH Certified Equipment List,* or by calling the Chief, Certification Branch, Division of Safety Research, NIOSH in Morgantown, West Virginia.

OSHA area, regional, or headquarters offices. For organizations coming under other regulatory agencies, such as MSHA for mining or NRC for nuclear plants, call the appropriate agency office.

The *NIOSH/OSHA Pocket Guide to Chemical Hazards,* DHEW (NIOSH) Publication No. 78-210 or latest revision thereof.

Specific regulatory agency regulations such as OSHA's 29 CFR 1910.1001 standard for asbestos exposures. Substance-specific regulations by OSHA normally contain a respiratory requirements section. The OSHA general industry respirator requirements are contained within 29 CFR 1910.134, which lists the minimum requirements for an acceptable respirator program.

A Guide to Industrial Respiratory Protection, NIOSH publication 76-189, which contains very specific guidelines with regard to establishing an acceptable respirator program.

ANSI standards Z88.2 and Z86.1, available from most respirator manufacturers and suppliers or from American National Standards Institute, 1430 Broadway, New York, NY, 10018.

Respirators are of only two major types: air purifying and atmosphere supplying. *Air-purifying respirators* are those that remove specific contaminants from the atmosphere immediately surrounding the wearer. Examples would be removal of dust in the air by a filter and removal of an organic vapor by a sorbent cartridge. Cartridges may be designed for removal of dusts, mists, fumes, radionuclides, organic vapors, acid gases, alkali gases, or combinations thereof. The wearer, in essence, breathes through a filtering device that does not supply adequate oxygen in an oxygen-deficient atmosphere. *Atmosphere-supplying respirators* are those in which clean, breathing-quality air is delivered to the wearer from an external source. Air may be supplied from compressed air tanks, blowers, or air compressors, or be recirculated through appropriate scrubbers with oxygen recharging (referred to as closed-circuit SCBA). An example would be a fire fighter's SCBA.. Within each of these major categories there are many additional variations. Facepieces may be quarter masks (mouth and nose covered), half masks (nose, mouth, and chin covered), full facepieces (mouth, nose, chin, and eyes covered), helmets with face shields, and hoods, for example.

Respirators range in cost from less than $1 for a disposable dust mask to over $2000 for a long-duration self-contained rebreather. No one respirator is suitable for all possible applications, so selection of a single type does not assure universal application.

Fundamental to the proper selection of a respirator is that the following be known:

The toxic agent to which exposure is expected to occur.

The levels of expected exposure to the toxic agent.

The expected duration of exposure to the toxic agent.

The level of oxygen present in the atmosphere to be entered. Principal interest here is a determination as to whether oxygen depletion *or* enrichment is possible.

The permissible exposure limit to the agent. Sources include OSHA, MSHA, and NRC standards and other knowledgeable sources such as EPA, NIOSH, the ACGIH TLV tables (issued annually), Material Safety Data Sheets (MSDS's) provided by the material supplier, and so on. Where no standard per se exists, it is not safe to assume that the agent is nontoxic. Many new agents have been marketed since the OSHA standards were promulgated in 1971. Do *not* assume an agent is harmless unless a knowledgeable source so states.

The following additional information should also be sought although data sources available may vary with regard to the extent of such information.

If the agent is a gas or vapor, does it exhibit human sensory warning properties at levels at or below the exposure limit? For example, the human can easily smell hydrogen sulfide at very low concentrations. However, at very high concentrations, the olfactory senses are quickly defeated and death can occur.

Does the agent possess an eye irritation potential?

Is the agent absorbed through the skin?

What is the lower flammability limit for the agent?

What is the IDLH concentration of the agent? IDLH refers to the immediately dangerous to life or health concentration. IDLH is defined by NIOSH to include both acute (short-term) and chronic (long-term) consequences of exposure. Thus NIOSH would consider exposure to a known or suspect carcinogen to be an IDLH situation.

Regulatory agency definitions of IDLH may be different and may not include the chronic consequences component.

Is there the possibility of poor respirator cartridge sorbent efficiency at IDLH levels or below? (This information may be difficult to obtain.)

Armed with the above information, one can begin the respirator selection process. The discussion that follows is directed toward development of a fundamental understanding of the selection process and the relevance of the information previously noted. It does not, however, constitute a fully adequate basis for respirator selection, for such would require more space than available here. Knowledgeable manufacturers, suppliers, and other sources previously noted can provide such specific guidance.

The fundamental principle behind the use of any respirator is that the wearer shall not breathe the toxic agent *at levels exceeding* established standards or safe levels. In the simplest of examples, the respirator simply filters toxic dust present in the workers' environment so that the air inhaled by the wearer, inside the respirator facepiece, is at or below the exposure limit for that toxic dust. The ratio of the toxic agent concentration in the atmosphere and the concentration inside the respirator facepiece after filtering is referred to as the respirator protection factor (PF).

Protection factors have been assigned to classes of respirators for use in the workplace.

Various sources give varying protection factors based on laboratory studies of test panels or worker populations. The published values should be considered guidelines because no fully acceptable test method has been developed and therefore no fully valid body of test data exists.

Recent studies by NIOSH suggest that the high protection factor for powered air-purifying respirators demonstrated in the laboratory is not achieved in the field and that much lower values may be more appropriate to the workplace. These lower values are suggested as a guide until performance of these respirators is significantly improved. Escape respirators do not have assigned protection factors, because their use is appropriate only in an emergency situation and exposures are expected to be for very short durations during the egress activity. An example is the belt-worn, chlorine-escape, mouth-bit respirator.

The application of protection factors to the selection process is evident. If the exposure limit to substance X is 10 parts per million and the work atmosphere concentration is 100 parts per million, a suitable respirator with a protection factor of 10× is required.

Based on the substance data collected, the following factors can be included in the respirator selection decision-making process.

The IDLH concentration has as its purpose the establishment of an exposure concentration below which a worker could escape within 30 min without injury or irreversible health consequences in the event the respirator fails. If expected exposure concentrations are at or above the IDLH concentration, only SCBA operating such that a positive pressure is always present inside the facepiece is recommended. Air-purifying or supplied-air respirators are not permitted where exposures are at or above the IDLH concentration.

Oxygen concentration in the exposure environment is clearly of importance where an air-purifying respirator may be considered. These respirators, which merely purify the atmosphere surrounding the wearer, cannot be used where oxygen depletion has occurred or may occur. Only SCBA or supplied air respirators combined with SCBA emergency egress devices may be used in such atmospheres because the source of breathing air is external to the immediate exposure environment.

Warning properties of the agent are important with regard to respirator selection. For example, if a worker is wearing an air-purifying respirator for protection against a gas or vapor with poor warning properties, failure of the respirator or saturation of the sorbent cartridge would not be detectable. Therefore, air-purifying respirators are not appropriate in atmospheres containing toxic substances with warning thresholds above the exposure standard limits. Equally important, as in the hydrogen sulfide case, materials that cause very rapid olfactory fatigue should be approached with caution with regard to the use of air-purifying respirators. If releases of the substance may result in high exposure, air-purifying respirators should not be used.

Eye irritation characteristics are important in respirator selection as well. Clearly, for a substance with eye irritancy potential a respirator with a full facepiece should be used.

Agents that are absorbed through the skin pose potential for serious and often fatal consequences on exposure primarily to liquid substances but, on occasion, to vapor as well. In such instances, air-supplied, fully encapsulating garments provide the maximum protection, although such are not certified as respirators. Material selection is important as well, however, and is addressed in a subsequent section of this chapter.

Exposures to concentrations of a substance above the lower flammable limit are considered IDLH environments. In addition to other protective measures such as nonsparking tools, only positive pressure SCBA or positive pressure supplied-air respirators combined with positive pressure SCBA emergency egress devices are allowed.

Sorbent efficiency is an important consideration in respirator selection. For example, an air-purifying respirator with sorbent cartridge may not be the respirator of choice if sorbent breakthrough may be expected to occur in less than the time required to perform a necessary task at exposure concentrations at or below the IDLH concentration. In such instances, air-purifying respirators are not permitted for escape use either. Sorbent efficiency data is often difficult to obtain. Most reliable respirator manufacturers can provide guidance, however, and their input should be solicited.

Upon selection of the appropriate respirator class and type, air-purifying organic vapor, for example, consideration of additional factors is appropriate and necessary. Under the OSHA regulations, if a respirator is used in the workplace, a respirator program conforming to the requirements specified in 29 CFR 1910.134 is required. Briefly, the requirements are as follows:

1. Written operating procedures governing selection and use shall be established.
2. Selection shall be on the basis of the hazard to which the worker is exposed.
3. The respirator user shall be trained regarding use and limitations of respirators.
4. Respirators shall be regularly cleaned and disinfected.
5. Respirators shall be stored in a convenient, clean, and sanitary location.
6. Respirators shall be inspected and maintained.
7. Work area surveillance is required to assure that the basis for selection remains valid. Where operational or process changes occur, reevaluate the respirator selection logic.
8. Regular inspections and evaluations are required to ascertain program effectiveness.
9. Persons required to use respirators must be medically certified as being capable of doing so.
10. Respirators shall be approved by NIOSH–MSHA.

Many OSHA regulations of specific substances require quantitative respirator fit testing as well. This is a dynamic process where a small room or closed portable envelope is filled with a test aerosol and the actual protection factor of a respirator worn by the individual to whom the respirator will be assigned is determined by comparing chamber concentration to the in-mask concentration. The intent is to permit assignment of the best fitting respirator to an individual.

Qualitative fit testing is required for all respirator programs. This involves exposing a respirator wearer to banana oil or irritant smoke and noting a subjective response in the wearer. Because this test usually does not include a measurement of the challenge concentration and the subjective response threshold is quite variable, the test does not lead to a quantitative determination of fit. Again, selection of the best fitting respirator and recognition of proper fitting adjustments are the objectives.

The single most important testing aspect when using air-purifying respirators is the positive–negative pressure test, which should be performed at every respirator donning. This test involves blocking the exhalation port with the hand and subsequently exhaling into the facepiece, creating a pressure. Missing inhalation valves, ineffective inhalation valves, improperly seated cartridges, and headband fit can all be quickly checked. Next, the cartridges are covered with the hand(s) and the wearer inhales, creating a negative pressure inside the facepiece. In this test, the exhalation valve conditions and facepiece condition including fit can be quickly determined.

Where supplied-air respirators are used, the quality of air delivered to the wearer is important. Requirements are established for both the air quality and the routine monitoring of air compressors which supply the breathing air. These, again, are in the OSHA standards under 29 CFR 1910.134. Manufacturers of air-supplied respirators can also provide comprehensive advice on this issue.

Common problems associated with the use of respirators include costs, discomfort, increased respiratory and cardiac stress, psychological stress, reduction of certain sensory inputs, communication difficulties, proper cartridge or filter change frequencies, corrective eye wear, and beards or long sideburns.

Cost issues should be examined not solely on the basis of the respirator cost. The actual respirator is likely the least expensive part of a respiratory protection *program*. Inspections, cleaning, maintenance, repairs, and so on are normally the major cost factors.

Discomfort and communication difficulties will normally increase the task time for workers wearing respirators. Owing to communication difficulties and 85 dB(A) noise levels in most supplied air hoods and helmets, the wearer is at increased risk of injury from other potential hazards present in the workplace. A related issue, of course, is reduced sensory perception levels, such as reduced peripheral visual fields. These factors should be recognized and measures taken to mitigate the potential consequences.

Cartridge or filter change intervals are difficult to predetermine, because life of these components is related to exposure concentration. If they are used for protection against materials with good warning properties, the wearer is usually aware that the sorbent cartridge is saturated and breakthrough has occurred. High breathing resistance is the change indicator for particulate filters. As a general rule, filters or cartridges should be targeted for change at the end of the normal work shift. More frequent changing of single-use disposable dust masks may be desirable and even required.

Workers who require corrective eye wear and who must use a respirator with a full facepiece can obtain special temples adaptable to the facepiece interior from the respirator manufacturer. A full facepiece respirator may not be worn over standard spectacles because the facepiece fit is compromised. Many authorities also recommend that contact lenses not be worn in full facepiece respirators because they may become difficult to retain. Special attention to workers who wear corrective eye wear is required where use of emergency escape breathing apparatus may be necessary.

For fit compromise reasons, the same logic applies to the use of respirators by individuals with beards or long sideburns as in the case of spectacles. Beards and long sideburns that interfere with respirator fit are not permitted.

Respirators may be but one component of a multiple protection ensemble such as chemical splash goggles, hearing protectors, head protection, gloves, and so forth. In such instances, it is essential that the respirator be carefully evaluated to assure that its purpose is not defeated by another protective device. Of particular concern is the use of a respirator and a welding helmet. Specifically, modified respirators have helped reduce this interface problem. Special combinations that eliminate this potential problem and optimize personal protection do exist in the marketplace. An example is the abrasive blasting hood that provides respiratory protection and protection to the eyes, face, head, and upper torso.

Although respirators may be required for special tasks such as cleaning of pressure vessels or for emergency escape, it should be evident that a comprehensive and adequate respiratory program for routine use of respirators is complex, demanding, and costly and presents a number of disadvantages to the worker that can affect morale and productivity. These issues alone should serve to reinforce the preference for administrative and/or engineering controls as a priority above respirators.

7.6.6 EYE AND FACE PROTECTION

Eye and face protective devices cover a broad range of products including safety glasses, welding goggles, and face shields, all relatively simple devices, to laser goggles, which are extremely complex. Eye and face protection is required where potential for injury can be foreseen by regulatory agencies. OSHA standards are contained within 29 CFR 1910.133, which contains many specific requirements such as being durable, capable of being disinfected, and appropriate for the protection required. Devices manufactured in compliance with the ANSI 87.1 standard are required.

It is of interest to note that current NIOSH studies suggest that over 900,000 serious eye injuries occur annually in the occupational setting and that well over 50% of eye injuries occur to individuals who are not wearing eye protection devices (Cook and Fletcher, 1977). It is evident that a majority of those suffering eye injuries did not perceive that a risk was present. Organizations with mandatory eye protection programs evidence a reduced incidence of such injuries. In addition, new eye wear technology has begun to emerge, polycarbonate safety lenses standing out as a unique example as the impact properties of polycarbonate are vastly superior to glass, yet the spectacles are substantially lighter than glass spectacles.

However, the introduction of this new technology has not been without problems. When first introduced, polycarbonate lenses were available only as plano lenses (no correction). Thus workers who required corrective lenses could not be provided with this superior protection technology. Recent advances have largely resolved this particular problem, however.

Eye and face protection should be chosen based upon the hazard. The ANSI Z87.1 standard provides an excellent guideline for such selection, as do most of the protective eye and face device manufacturers and their suppliers. Proper initial selection requires an analysis of the potential hazards present at the work site and consultation with the manufacturer or supplier. For routine exposures, the process is fairly straightforward, with the major issues of concern being cost and delivery times for prescription lenses. Proper fitting is necessary, of course, as is well known to anyone who wears corrective street eye wear.

There are a number of more complex situations, however. Welders require special protective "welders' lenses and plates." These vary in optical density, depending upon the welding or cutting process. Plate and lens densities are classified by shade number. An excellent guideline is presented in table form in the OSHA standard contained within 29 CFR 1910.252, Welding, Cutting, and Brazing. Welders' plates and lenses, as with spectacles, must also meet other requirements such as impact resistance.

Protective eye wear is available in a wide range of colors ranging from clear to yellow to rose. Each possesses special light transmission characteristics tailored to specific applications. Extreme care should be exercised in selecting the special colored lenses because the visible light transmission spectra and more importantly the IR and UV transmission spectra are not the same as for glass. Glass has a rather high visible light transmittance and low UV and IR transmittance. Thus a special lens that might be used to enhance the yellow spectrum may result in much greater UV exposure to the eye from welding arcs, even at a distance. Reputable eye wear manufacturers can provide transmission spectra and discuss these issues to aid in proper selection.

Polycarbonate has a much greater transmittance of UV and IR than does glass, which it is replacing. UV inhibitors have been developed to improve the UV performance but the IR spectrum remains difficult to resolve. In addition, glass lenses, often referred to as welders' glasses, are commonly used in the welding environment by welders' helpers to reduce eye exposures to indirect or peripheral welding arc emissions. These glass lenses are a distinct green color. Polycarbonate lenses have been marketed in the past in the same green color. Despite the warnings on the packages that they were not suitable for welding arc exposures, many individuals have used them for such.

Protection of the eyes from exposure to laser sources is complex. Laser goggles lenses are designed to be highly absorptive in very narrow frequency bands. Reductions in allowable transmission for very powerful lasers vastly exceed the reductions required in the most intense welding operation. Selection of proper eye protection from lasers requires specific knowledge of the laser type, emission wavelength, and power output, at a minimum. Those manufacturers who provide laser protective eye wear and the laser manufacturer are the only sources that should be relied on to recommend such eye wear. The calculation of the required optical density at one or more frequencies is not simple, nor straightforward. Requests for appropriate protective eye wear requirements should be requested from the laser manufacturer in writing. Recommendations by NIOSH have been developed for more specific spectral exposure selection limits that would assist in these situations. In addition, ANSI Z136.1 provides additional insight.

As is the case with protective devices, eye and face protective devices affect the wearer. Although some limited decrease in the visual field occurs with simple spectacles, such is usually minimal. However, as the degree of protection increases, such as with the addition of side shields or with chippers' goggles, loss of peripheral vision begins to occur and the discomfort index increases. Lens density required for protection against welding flash, lasers, or IR transmittance may also reduce visible light required for task performance or emergency actions to unacceptable levels. The work station layout and job design should consider the imposition of such limiting factors on the worker.

Overall, the selection of suitable and appropriate eye and face protection can be readily accomplished through job analysis surveys and discussion with competent suppliers and manufacturers. Unique protective circumstances, such as eye wear to protect workers from lasers or unusual emission sources, can usually be satisfactorily resolved by the technical experts of the major manufacturers. Most importantly, the majority of industrial eye injuries occurring today are as a consequence of the failure to wear protective eye wear. Review of the noted ANSI standard is strongly encouraged as an important asset in the selection process as well. It will be noted therein, for example, that face shields are to be utilized only over safety spectacles, an important protective measure not commonly recognized.

7.6.7 HAND PROTECTION

There are a vast array of hand protective devices available, most of which are tailored to specify exposure hazards such as chemicals, cold, heat, fire, abrasion, cuts, punctures, and electricity. Standards exist only for electrical linesmen's rubber insulating gloves, which are embodied within ANSI J6.6 covering five voltage classes, designated 0, 1, 2, 3, and 4, with proof test voltages ranging from 5000

V (rms) for the 0 designation to 30,000 V (rms) for 4. Tests conducted by NIOSH of available linesman gloves indicated general compliance with the ANSI standard (Cook and Fletcher, 1977). OSHA requires compliance with this standard for linesmen's electrical insulating gloves. Selection of a designation class suitable to the expected electrical exposure is of course necessary in order to ensure adequate protection to the wearer. Frequent inspection for wear and tear is necessary as well. Such gloves are frequently worn with leather working over-gloves to reduce wear and tear to the insulating glove.

Fire fighters are exposed to a unique range of hand exposures ranging from cold to flame, yet their protective handwear must not unduly encumber the fire fighter in the diverse tasks that are involved in life-threatening environments. The National Fire Protection Association (NFPA) has recently published a standard for gloves for structural fire fighting (NFPA 1973–1983). The recommended standard covers a broad spectrum of exposure situations, many of which may be applicable to other hand protection devices. These include the following:

Resistance to cut
Resistance to puncture
Resistance to conductive heat penetration
Resistance to wet penetration
Flame resistance
Resistance to radiant heat penetration
Heat resistance

In addition, the following human factors were addressed:

Dexterity
Grip

Other types of gloves should also consider the following selection factors:

Comfort
Electrical resistance
Durability
Visibility
Chemical permeation
Chemical degradation
Decontamination
Wrist construction

These criteria encompass many criteria that might be considered in the selection of protective handwear for specific applications and serve as a useful checklist in reviewing the job task and making hand protection selections. This is not to suggest that the specific fire fighters' glove dexterity criterion would be appropriate to the selection of a latex glove used in a semiconductor operation to protect the semiconductor from the worker. The point is, of course, that dexterity must be a consideration in any selection process for protective hand wear for a specific work task.

Fortunately, hand injuries are rarely, if ever, fatal as a consequence of exposures of the hands to hazards associated with cuts, abrasions, cold, punctures, heat, or flame. In applications where such hazards may exist, a wide range of protective gloves is available and the individual worker can usually reach a satisfactory compromise between the type of glove and the work task.

Serious or fatal injury can occur, however, upon exposure to electricity. The recommended electrical criteria in NIOSH fire fighter's glove standard (NIOSH, 1976) and the ANSI J6.6 standard are clearly of major significance where such exposures may occur. Fortunately, based upon earlier NIOSH tests (Cook and Fletcher, 1977), linesmen's electrical insulating gloves appear to comply with the ANSI standard and thus represent a safe choice once the exposure voltage potential has been determined.

Potentially serious injury can also occur upon exposure of the skin to chemicals, Chemical burns, dermatitis, or absorption with subsequent toxic response consequences are possible. Unfortunately, no standards now exist governing the performance of gloves intended to provide protection against chemicals. Most suppliers provide subjective data referred to as chemical degradation characteristics with rating ranges from "excellent" to "not recommended." The degradation test merely subjectively assesses the response of the glove material to the chemical of interest when the glove material is immersed in the chemical. This test provides no information about the ability of the chemical to permeate the material, data that are relevant to the exposure environment. Fortunately, a new test method has been developed to determine the relevant information: ASTM F739-81. This is a permeation test method, which is now being utilized by the major glove and glove material manufacturers. Where exposure to chemicals occurs, the purchaser should also request data on glove performance based upon the ASTM permeation test method rather than relying only upon the degradation performance data.

User problems with hand protection devices are largely obvious and include affects on dexterity, comfort, and so on. The principal comfort problem involves sweating, particularly in chemical barrier gloves. Such gloves are often lined or used with cotton undergloves, several pairs of which may be required for a complete work shift. Recent studies in NIOSH's Division of Safety Research (DSR) have indicated that use of chemical protective gloves can increase errors and assembly time for mechanical assembly work. Time was increased from 15 to 37% over ungloved times, depending upon glove selection. Therefore, the use of gloves may prove to be an economic disincentive for workers on piecework.

7.6.8 FOOT PROTECTION

"Safety shoes" must be worn in the workplace where the potential for foot injury is foreseeable. Such devices must comply with the requirements of ANSI Z41.1, which is a standard established for safety-toe footwear (OSHA regulation 29 CFR 1910.136). The level of protection provided is determined by classifications of 30, 50, and 75, which refer to the weight dropped on the toe from a specified height while deforming the safety cap in the toe less than a specified amount. Tests by NIOSH (Cook, 1976) indicated that at that time only about 57% of the shoes tested met the requirements of the standard and that the principal failures appeared to be associated with overrating, that is, Class 75 select shoes were more likely to perform as Class 50 shoes.

The OSHA regulations do not specify the class required but place the burden on the employer to provide that which is appropriate to protect against the hazards present. In addition, safety-toe shoes principally protect only the toe from impact and compression insults. As in the case of eye injuries, the majority of foot injuries occur to individuals who are not wearing safety footwear. Further, more than half of these injuries result from an object falling on the foot, suggesting that the use of safety-toe shoes could result in a significant reduction in foot injuries while potentially reducing the severity of injuries as well.

In the mid-1970s, when the NIOSH tests were conducted, there were at least 25 manufacturers of safety shoes who marketed at least 703 styles of safety-toe footwear. Clearly, the selection available is large. There is also a large variety of additional foot protective devices, in addition to the basic safety-toe shoe, available for specific applications.

Metatarsal guards are devices that attach over the shoe to provide additional toe protection and, in addition, cover the top of the foot and the lower part of the ankle. ANSI Z41.2 recommends impact and compression standards for these devices. The wearer of metatarsal guards, however, has increased potential for tripping and for falls, particularly when using stairs and ladders. Extensions of the basic metatarsal device include skin-knee-instep, foot-shin guards with side shields and so on.

Flexible safety insoles or special outer sole devices are available as a means of providing protection against sole punctures where such hazards may be encountered. There are presently no recommended standards for these devices, however. Care should be exercised with many of the outer over-sole devices because they often are made of materials, such as wood, that possess very different frictional characteristics from those of the shoe sole.

ANSI Z41.3 recommends standards for a special class of electrical conductive footwear. Two types of conductive footwear are specified (Type I and Type II), each of which is intended for specific electrical hazard applications. Type I is appropriate for use by linesmen working with high voltages. ANSI Z41.4 recommends standards for electrical-hazard safety-toe footwear designed to provide protection against direct open electrical circuit contacts up to 600 V.

Although no specific additional ANSI standards exist beyond the basic ANSI Z41.1, there are additional types of safety footwear tailored to special environments. These include insulated, heat-resistant, nonsparking (for use in explosive atmospheres), water-repellent, chemical-resistant, and foundry/welders' footwear. Foundry/welders' boots serve as an excellent example of tailoring to solve a problem unique to a job task, for they are designed for quick removal should hot metal fall inside the boot top. Additional job-tailoring is evident in the wide range of sole materials and patterns available.

Sole pattern selection presents little selection problem and is largely based upon experience. Sole material, however, is generally categorized by exposure (oil) and/or slip resistance in the anticipated work environment. However, attempts to develop a dynamic floor surface friction measuring device, let alone a means of evaluating or quantifying frictional characteristics between a sole material and a floor, have not met with success. At this time, sole material selection must be based largely upon experience.

As in every case involving selection of personal protective equipment for workers, the job task must be analyzed so that the obvious and perhaps less-than-obvious hazards, such as the need for nonsparking footwear, are identified. As in the case of chemical protective handwear, few data beyond simple degradation data are available to aid in the selection of chemical protective footwear. However, in the footwear instance, the degradation data are perhaps more useful because such devices are usually thick compared to a glove. Nonetheless, permeation data should be sought as an aid in the selection process. Frequent inspection of such devices during use is of course necessary. An additional issue, not addressed as yet by any recognized organization, is decontamination. Chemical boots tend to be used for much longer periods of time than chemical gloves, owing to their cost. Exposure to some chemicals may result in the chemical being retained in the outer boot material, washing the boot after exposure may not remove the chemical, or the washing agent may degrade the boot material. When exposure to toxic chemicals occurs, special care should be exercised in this regard. If off-gassing from a chemical or chemical reaction is occurring, the chemical is clearly adhering to the boot surface, or the washing agent is deteriorating the boot surface, the boot should be properly disposed. Disposable latex booties are frequently worn over chemical resistant boots to allow ease of gross decontamination.

7.6.9 FALL PROTECTION

Fall protection devices include a wide range of products generally categorized as safety belts, lifelines, lanyards, safety nets, and harnesses. No *general* OSHA standard exists for such devices in the General Industry Standards (29 CFR Part 1910). Specific sections of the General Industry Standards, such as Roof Lifelines (29 CFR 1910.28), are addressed, however. The Construction Industry Standards (29 CFR Part 1926) does address certain requirements related to such devices, although details vary with regard to specific application requirements. Therefore, specific applications must be evaluated with regard to regulatory requirements on a case-by-case basis.

The principal consensus standard covering performance requirements of belts, harnesses, and securing lines is ANSI A10-14, which bases performance largely upon weight-drop tests. Safety belts, harnesses, lifelines, nets, and lanyards deserve special attention by those selecting and using such devices, for they are literally, in many cases, the last line of defense for the worker who must rely upon them. It is essential to recognize that such devices are systems composed of a body harness, lanyard, and securing point. *All* elements of the system must function properly and must be mutually compatible. A 100 lb or more lanyard is of little value should a fall occur, regardless of the fact that the harness meets ANSI A10-14 performance requirements.

There are a number of specific use recommendations which must be observed for any effective fall protection program:

Inspection/maintenance
Replacement
Operation

All fall protection devices should be inspected and the warning labels on the devices carefully read to assure that the devices are suitable for the intended application. Each element of protection must be viewed as part of the fall protection *system*. This requires that all elements of the system be appropriately compatible. Prior to every use, the complete system should be inspected. The fall protection system is most often a backup emergency lifesaving device. Its relationship to the work area must be determined. As an example, lifelines are used when workers utilize scaffolds at elevation. Should the scaffold fall, the lifeline is of little value if it gets entangled in the falling scaffold, as has been the case in fatalities investigated by NIOSH. Maintenance per se should not be performed on fall protection devices if it involves repair of a system component. For example, if the snap hook on a securing level requires repair, the line should be replaced or returned to the manufacturer for repair.

The fall protection system—all components—should be replaced regardless of appearance if it has been subjected to impact loads such as occurs in arresting a fall. In addition, most manufacturers require that only their components be used in the fall protection system. This ensures integrated system performance and proper attachment of various elements of the system.

In operation, there are a number of precautions that must be observed. As noted above, the work site should be inspected with regard to potential entanglement of the fall protection system. The wearer must be continually alerted to changes in the work task which might similarly degrade or eliminate the value of the fall protection system. Manufacturers' instructions must be closely adhered to with regard to attachment methods, methods of safe operation, and so on. Fall protection systems are life or death devices. Expert assistance and guidance is necessary in the selection of appropriate systems and to assure compliance with the appropriate regulatory standard that applies. Special and diligent attention to such systems through inspections, maintenance, and operational procedures are required as a defective component can result in a fatality.

7.6.10 BODY PROTECTION

OSHA has established general regulations regarding body protection under 29 CFR 1910.132 which require that protective devices shall be used to protect workers from foreseeable hazards. In addition, many specific OSHA standards exist, such as 29 CFR 1910.261(g)5, Pulp, Paper, and Paperboard Mills, which requires that protective aprons and other appropriate protective equipment must be worn during lime slaking. Such specific requirements are far too numerous to outline here. Specific standards applicable to operations for which protective equipment is required must be reviewed to determine what is mandated by the cognizant regulatory agency.

Body protection exclusive of that covered above under separate headings in the chapter encompasses a wide range of devices including, but not limited to, the following:

- Aprons
- Disposable garments
  - Caps
  - Jackets
  - Pants
  - Shoe booties
  - Full coveralls
- Fire fighters' turnout gear
- Fire-approach suits
- Fully encapsulating suits
- Life jackets
- Splash/rain gear
  - Jackets
  - Pants
  - Hoods
- Liquid-cooling garments
- Air-cooling devices
- Cold weather suits
- Knee pads

There are essentially no performance standards with which these types of protective equipment need comply. Experience, recommendations from major suppliers and manufacturers, and a thorough job task hazard analysis are the principal components of proper selection.

There are, however, a number of important issues to consider that may be easily overlooked in the selection process. Aprons, garments, and so on intended to provide protection against metal splashes or chemical splashes must clearly be suitable for protection against those specific hazards. Particular care with regard to chemical splash protection is important. In the latter instance, chemical material degradation data are a suitable frame of reference because continuous contact, which is expected with gloves, is not intended. An apron material that is destroyed by sulfuric acid is, for example, clearly not an appropriate protective device where such protection is required.

Disposable clothing is becoming more widespread in industrial applications. Several fabrics are available and several fabrics that are coated with liquid barrier films are also available. The coated fabrics, however, generally increase the potential for heat stress because they do not "breathe." The purpose served by the disposables is to provide a reasonable degree of protection from dirt, oil, grease, and liquid splashes. They should be discarded daily or whenever tears, punctures, and so forth develop.

Fire fighters' turnout gear continues to improve in quality and performance. Currently, available gear is able to withstand exposures to higher heat levels and direct flame exposures more effectively than older equipment. As a consequence, fire fighters are being exposed to higher temperature extremes that have resulted in heat damage to their other supporting equipment, principally the respirator and helmets. Improved helmets are becoming available and respirator manufacturers are beginning to examine the respirator problem. Additionally, NIOSH and other organizations are working toward the development of high-performance SCBA standards for specific application to the fire service.

Fully encapsulating impermeable suits, and fire-approach suits to a degree, represent a major potential heat stress threat to the wearer. NIOSH has published a personal protective equipment selection guideline for hazardous materials exposures. Encapsulating garments are included in this document. Should work be required while wearing such garments, extreme care must be exercised to avoid excessive heat stress. In addition, appropriate medical facilities should be available to heat stress victims. Most heat stress fatalities result from the failure to apply appropriate medical measures quickly. Additionally, workers often are overcome by heat stress without being aware that their situation is becoming critical. Auxiliary cooling is frequently used with such garments to reduce the heat stress potential. Two approaches are utilized: air cooling and liquid cooling. Air cooling involves passing breathing quality air through a vortex tube and subsequently passing the cold air from the tube into the garment, thus providing both breathing air and some cooling. Liquid cooling is achieved by wearing a vest that contains small tubes throughout. Within the tubes, cold water is circulated by a battery-powered pump after circulation through a heat exchange containing ice or cold blocks. The cool vest, pump, battery, and heat exchange are carried by the individual. For optimal effectiveness, the vest must be directly in contact with the skin and the cold blocks or ice must be changed hourly. Current data suggest that liquid-cooling garments offer little advantage when the individual is working at high metabolic rates because the cooling provided is nearly offset by the added work associated with carrying the device.

Applications involving the use of impermeable encapsulating garments frequently involve exposure to chemicals. In such instances where the chemicals are known, permeation data is a necessity for proper selection. It should be recognized that such data are also necessary with regard to the gloves and boots, which are usually of different materials from the garment. Where the chemicals may be unknown, such as at hazardous waste sites, every effort should be made to determine the probable materials present with subsequent decisions made based upon permeation data. In every instance where such garments must be utilized, training and emergency preparedness are vital.

The use of much of the body protective equipment previously noted places additional physical and sensory burdens on the wearer. While an impermeable encapsulating garment is worn, a simple job task may be difficult and time consuming. A thorough job task analysis is necessary in order to assess the potential for adverse consequences associated with the use of such equipment. For example, mechanical power transmission equipment oilers are not permitted to wear loose-fitting clothing.

7.6.11 COMBINATION PROTECTION

The preceding sections of this chapter have discussed specific body protection keyed to a body part, such as the head. In practical reality, many workers utilize more than one protective device at the same time. Wearing a hard hat, safety glasses, safety-toe boots, and work gloves, for example, would not be uncommon for a construction worker. In this instance, the devices do not interfere with the respective function of each. There are instances where combinations of protective devices do interfere. Earmuffs over safety glasses are one simple example. A vastly more complex example is that of using a SCBA with an impermeable encapsulating garment. Such factors must be considered when utilizing protective equipment. For the simple muff-safety glasses example, earplugs might be substituted where the individual finds the muff uncomfortable. The complex cases, those involving potentially serious consequences, demand much more attention.

Proper selection and utilization of personal protective equipment requires thoughtful job task analysis, knowledge about the limitations of protective equipment, and the commitment of the individual who must use such equipment. Improper selection, improper use, and improper maintenance, for example, will quickly defeat the purpose for which protective equipment is used, that is, to protect the worker when administrative or engineering control measures are not available or feasible.

7.6.12 HUMAN FACTORS IN PERSONAL PROTECTIVE EQUIPMENT USE

Recommendations for medical surveillance of employees using personal protective equipment, particularly respirators, are frequently found in regulations or guidelines. There is no general agreement on what constitutes an adequate surveillance program nor on the criteria desirable in selecting users of personal protective equipment. The American National Standards Institute has developed a consensus standard, "Respirator Use—Physical Qualifications for Personnel," ANSI Z88.6-1984, in an attempt to fill this void.

Harber (1984) has suggested an interim three-level protocol of medical examination and qualification for selection of respirator users based on physical examination and job evaluation. He points out that a basic program component should include a period of observation of the worker using the respirator, preferably at the exercise level required by the job (Harber, 1984).

Suggestions of a single spirometric test as a screening device have been made by Raven, Moss, Garmon, and Skjaggs (1981). They recommend the 15 sec maximum voluntary ventilation ($MVV_{.25}$) without a respirator. The results of this test along with clinical evaluation and a knowledge of respirator resistances and job ventilatory requirements could then serve as the basis for selection. Harber (1984) points out the limitations of simple spirometry:

1. Sensitivity to restrictive lung disease, respiratory control disorders, and endurance is limited.
2. There is extreme variability in $MVV_{.25}$.
3. No direct relationship exists between the $MVV_{.25}$ and ability to breathe effectively for a prolonged period.
4. $MVV_{.25}$ is difficult to perform with a respirator.
5. The respiratory pattern during an $MVV_{.25}$ test differs from that during normal work.

The ANSI standard mentions spirometry as an addition to the clinical examination. ANSI further states that the employer should consider restriction of respirator use by any employee exhibiting an FVC (forced vital capacity) of less than 80% of the predicted volume or an FEV-1 (forced expiratory

Volume, 1 sec) of less than 70% of the predicted volume. Microprocessor-controlled spirometers are available which give instant readouts of such data as well as the predicted capacities; these can be utilized by trained personnel as a quick screening technique.

Similar discussions of the medical implications of other items of personal protective equipment use are virtually nonexistent in the literature.

Physiological studies of the effects of personal protective equipment have been largely restricted to respirators and specialized protective clothing, particularly fully encapsulating chemical suits and items of military use such as body armor.

Atterbom and Mossman (1978), Raven, Dodson, and Davis (1979a, b), Goldman and Breckenridge (undated), Myhre, Holden, Baumgardner, and Tucker (1979), Ronk et al. (1983), and Ronk, White, and Linn (1984) have published useful reviews of the literature on the physiological consequences of using various respirators and clothing combinations.

Performance decrements and imposed stress when using personal protective equipment are severe. The magnitude of the effect varies considerably between individuals and depends on the type of personal protective equipment worn, environmental conditions, and the work rate of the task to be performed.

Morgan (1980) has suggested that as many as 10% of the work force may be psychologically precluded from the effective use of respirators. He has found that 75% of his test subjects who experienced anxiety attacks while wearing respirators had elevated scores on the trait anxiety scale (STAI) of Spielberger, Gorsuch, and Lushene (1969).

This led him to the conclusion that certain "types" of individuals are more likely to experience anxiety attacks while wearing SCBA than others and that these individuals can be identified in advance with acceptable precision. As of yet, no extension of Morgan's work has been seen to other stressful personal protective equipment such as fully encapsulating suits.

Implementation of personal protective equipment as a control mechanism imposes significant risks of increased physiological and psychological stress. The stressor mechanisms are not well identified and predictive instruments are undeveloped. Caution is urged so that the use of personal protective equipment does not create more problems than it can solve.

Sizing of personal protective equipment that is similar to ordinary clothing is usually based upon commercial practice. That is, a size 12D safety-toe shoe is approximately the same size as a 12D dress shoe. More specialized protective equipment, such as respirator facepieces, may be single sized or of multiple sizes designed to fit a wide range of face geometries.

Fitting to size, especially in respirator facepieces, where the face seal is critically important to minimize inboard leakage, has been addressed in several studies.

McConville and Churchill (1972, 1974), using anthropometric data collected on armed forces personnel, concluded that these data could be used for design and sizing of respirators for civilian respirator users with a considerable degree of confidence. They pointed out, however, that both racial and sex characteristics were variables to be considered. Intraracial variation, they felt, was accommodated by the overall size variation within the sample. Sex differences may not necessarily equate small male facial sizes and female facial characteristics.

In applying McConville's work to the selection of respirator face fit test panels, Hack et al. (1974) used panels consisting of 40% Spanish-Americans and found that the mean values were within 2 mm of the base data. The assumption was made that male and female faces within the same two key dimensions (face length and width) were equivalent.

Respirator face-fit testing using the panel concept was conducted at several laboratories but, owing to problems of sample size and selection, the basic premises of racial and sexual equivalency have not been adequately resolved.

Individual fitting using either a subjective response to a challenge aerosol or vapor (qualitative fitting) or the measurement of both in-mask and ambient (challenge) concentrations (quantitative fitting) is frequently practiced to ensure adequate protection. Studies by Myers and Peach (1983), Myers and Peach (1984), and Lenhart and Campbell (1984), indicate that for at least two types of respirators, the powered air-purifying helmet for particulate protection and the half facepiece powered air-purifying respirator for particulate protection, these levels of protection assigned by laboratory studies are too high by a factor of some 10 to 40. This is in line with common practice in nuclear materials handling, whereby the employee is required to pass a quantitative facepiece fit test with a protection factor 10 times higher than that expected to be used in practice. Therefore, a full facepiece respirator would have to provide a protection factor of 500 in the fitting test but only could be used at concentrations of 50 times the permissible exposure (protection factor of 50).

Other protection that varies with sizing or fitting, such as shoes, hard hats, or muff hearing protectors and safety spectacles, has not been addressed in any meaningful manner.

Training in the use of personal protective equipment, which includes practice in nonhostile environments, has proved beneficial in increasing protection afforded by personal protective equipment, enhancing utilization of personal protective equipment, and reducing physiological and psychological stress. The American Occupational Medical Association (1982) has taken the position that training is a "very important" aspect of a hearing conservation program.

OSHA requires training in use of respirators [29 CFR 1910.134(e)(5)] and hearing protectors [29

CFR 1910.95(K)]. Yet few objective studies have been published to document the value of training. McDonagh (1982) has demonstrated decreased air consumption (hence physiological stress) in fire fighters who completed a 40 hr "smoke divers" course in the use of SCBA in comparison to the air consumption of the same students prior to their training.

The design of certain complex personal protective equipment makes safe use and maintenance unnecessarily difficult. Specific examples noted below illustrate these two points.

One fully encapsulating chemical protective suit has a zippered front opening that is extremely difficult to put on. However, after several complaints, and at least one overexertion injury, the zipper was extended to increase the opening length.

Investigation of several deaths involving the use of SCBA indicated that maintenance of the units was difficult and that users performing the maintenance were not fully informed as to critical variables such as screw torques (NIOSH, 1979). The units were redesigned and parts retrofitted in the field.

Use of SCBA under fully encapsulating chemical protective suits renders the essential bypass and main-line valves inaccessible in an emergency caused by the failure of the air regulator. No full solution to this problem has surfaced.

A sophisticated SCBA designed for escape from shipboard fires failed by releasing a highly caustic aerosol into the hood. The unit had to be redesigned before it could be marketed.

Another SCBA designed for emergency escape from underground coal mines was contained in a case that repeatedly could not be opened. The case required redesign before acceptance.

Interference between items of protective equipment such as hard hats and hearing protectors or respirators, hard hats and chemical protective clothing, or spectacles and respirators are common.

No area of a personal protective equipment program is more critical to its effectiveness than the factors affecting whether or not such equipment is actually used. Yet little research has been done on factors that provide incentives or disincentives for wearing personal protective equipment.

These factors may take several forms and can, for our purposes, be categorized as physical, psychological, social, and economic.

Physical factors that may influence the wearing of personal protective equipment include respiratory or cardiovascular disorders that are magnified when using personal protective equipment. Individuals may be sensitive to changes in oxygen, carbon dioxide, inhalation/exhalation resistance, relative humidity or temperature of inhaled air or oxygen, and/or weight of the personal protective equipment. Similar factors such as preexisting skin disorders, hypohydrosis, or previous heat disorders, may also adversely affect the user's ability to wear protective clothing or equipment. Individuals with low work capacities may be particularly reluctant to use personal protective equipment because of the added metabolic work load required with the additional weight and burden of the equipment.

Social factors, or how the work group perceives the wearing of personal protective equipment, may also influence an individual decision as to personal use. Training and educational techniques can be used to enhance peer acceptance of personal protective equipment use. Direct incentives, such as premium pay or tokens redeemable for merchandise, have been shown in some studies to be effective in increasing utilization of personal protective equipment (Zohar, Cohen, and Azar, 1980; Zohar, 1980).

Economic disincentives such as piecework, in which the worker perceives a decrease in his productivity, and hence pay, through the wearing of personal protective equipment, or the requirement that the worker pay all or part of the cost of purchases or maintenance of his personal protective equipment inhibit personal protective equipment use.

Whatever mechanism is used to motivate workers to wear personal protective equipment must ensure a very high degree of utilization if it is to be successful. For example, given a hazardous atmosphere at 100 times the permissible exposure limit (PEL) for an 8 hr workday, an employee using a protective ensemble having a protection factor of 10,000 will be overexposed if utilization of the ensemble is less than 99%, that is, if he or she removes it for 5 min during the 8 hr of exposure. Figure 7.6.1 illustrates how severely protection decreases with minimal periods of nonwear.

Worker input into the personal protective equipment program is vital if it is to gain acceptance. One national union has stated six general concerns regarding respirator programs which offer goal guidance for any personal protection (O'Brien, 1981):

1. *Greater emphasis must be given to the proper selection of respirators (PPE);*
2. *The fitting of respirators (personal protective equipment) must be more controlled than hit or miss, positive and negative fit tests. This problem includes the availability of facepieces of different sizes and fit-testing procedures that are more quantitative than qualitative;*
3. *An element of employee choice in the selection of the type of respirator (personal protective equipment);*

4. *Provisions for limiting time for respirators (personal protective equipment) wear either by designating certain areas as break areas and providing time for using them or by averaging time of use based on the exposure level and protection factor of the respirator;*
5. *Determining whether an employee is able to wear respiratory (personal protective equipment) protection and economic protection for those workers whose health has already been damaged to such an extent that they cannot wear currently available respirators;*
6. *Concern for the actual development and enforcement of a respirator (personal protective equipment) program in the workplace where such questions as discipline and discharge for failure to wear a respirator or the unilateral imposition of a policy on facial hair can strain even the best of labor–management relations.*

Studies by Plummer et al. (1985) and Poppelsdorf and Cramer (1982) have shown significant increase in time required to assemble small parts while wearing protective gloves over the time required bare-handed. This could directly translate into loss of productivity, wages, and social position for affected workers.

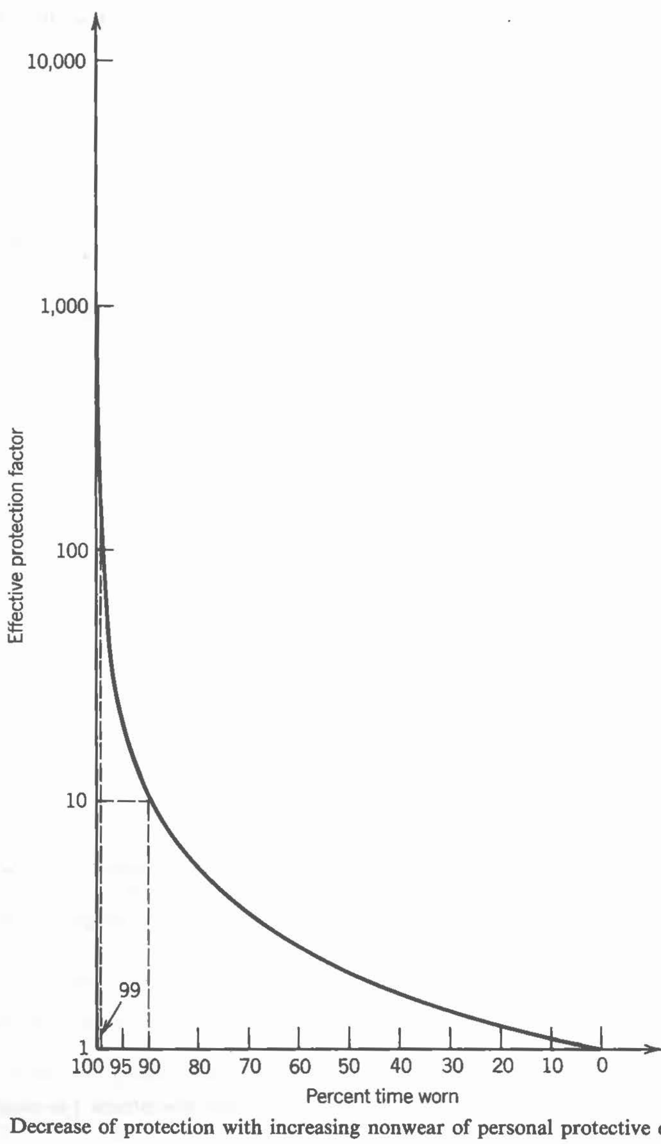

Fig. 7.6.1 Decrease of protection with increasing nonwear of personal protective equipment.

7.6.13 SUMMARY

In summary, personal protective equipment, by establishing an artificial microenvironment for the user, may seriously impact virtually any human–machine–environment interface.

The decision to prescribe the use of personal protective equipment in lieu of, or as a supplement to, effective administrative or engineering controls is not to be made lightly. At best, effective personal protective equipment programs are not inexpensive; at worst, ineffective ones may stifle productivity and increase occupational injuries and disease.

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