13
Personal Protective Equipment

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13.1
Introduction

Personal protective equipment (PPE) has become ubiquitous at workplaces around the world, often the most visible aspect of a safety program. PPE is defined by the Council of the European Communities as '' . . . any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards'' (Council of the European Communities, 1989). As demonstrated in this chapter, this definition covers a large range of equipment designed to protect specific body parts or to protect multiple body parts from specific types of hazards.

A fundamental aspect of understanding and properly employing PPE is that it provides a barrier or means of isolating an individual from a hazard. PPE does not remove the hazard; rather it is used to reduce the impact of the hazard on an individual. As such, in the hierarchy of safety controls, PPE should only be employed after efforts to engineer out the hazard have been unsuccessful or determined to be ineffective or impractical.

In general, the most effective use of PPE comes when combined with a comprehensive hazard mitigation program that uses engineering controls to remove hazards and administrative controls to keep employees from encountering hazards. With these controls in place, PPE adds another independent layer of protection to prevent workers from coming into contact with a hazard. In many settings, there are situations where engineering and administrative controls are not possible or practical to implement, and PPE may therefore become the primary means of preventing an injury. In these cases, job hazard assessments or risk analyses need to include the use of PPE as a primary injury prevention method and take other precautions as appropriate for the task to minimize the risk of injury.

When included as a component of a comprehensive loss prevention program, effectively used by workers, and selected to match the hazards present, PPE can be very effective in protecting personnel from hazards that occur during a task or that are not identified in pre-task planning.

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13.2
General Selection

There are several resources available to consult when determining what type of PPE is applicable to a specific hazard. Governmental regulations should be consulted to determine whether regulatory requirements exist for the equipment or type of work being performed. In addition, there are a variety of consensus standards that may be incorporated by reference in regulations or may be used for guidance in the absence of or in addition to regulatory requirements. These include standards from the International Organization for Standardization (ISO), the American National Standards Institute (ANSI), ASTM International, formerly the American Society for Testing and Materials (ASTM), and others that are referenced in this chapter.

In the United States, the Occupational Health and Safety Administration (OSHA) sets general industry requirements for the selection and use of PPE in 29 CFR 1910 Subpart I (OSHA, 2011).

The European Union (EU) sets basic requirements that PPE must satisfy and conditions for its marketing throughout the EU in its Directive 89/686/EEC on PPE (Council of the European Communities, 1989). In addition, the EU has published Harmonized Standards which specify requirements for the design, manufacture, testing, and application of specific types of PPE to ensure provision of adequate levels of protection through conformance with 89/686/EEC and has adopted several ISO standards regarding PPE.

When selecting PPE to be used to protect against workplace hazards, the buyer must refer to national or local regulations to ensure that an adequate hazard assessment has been conducted and that the PPE will protect sufficiently against the hazards in question. The EU Directive 89/686/EEC and related Harmonized Standards will ensure that the selected PPE is adequately designed, constructed, and tested, but will not ensure that the PPE selected adequately protects against the specific hazards in question.

13.3
Types

13.3.1
Head Protection

Head protection is most commonly provided through the use of hard hats or industrial safety helmets (Figure 13.1). With some exceptions, these are designed to provide protection from impact or penetration due to falling objects or impact of the wearer’s head on protruding objects rather than to protect the wearer from impact with the ground or work surface due to a fall. Additionally, some models may provide flame, electrical, molten metal, and arc flash protection and some may be suitable for use in very high- or low-temperature environments. When

Figure 13.1 A worker wearing a standard industrial safety helmet or hard hat (OSHA, 1996).

selecting industrial safety helmets, it is necessary to review the specifications from the manufacturer or distributor to ensure that the helmet meets the requirements identified during the hazard assessment.

A key distinction needs to be made at this point between an industrial safety helmet and a bump cap, both of which may be offered for sale in the same category of head protection. While industrial safety helmets are designed and constructed to provide protection from impacts from above and potentially from the side as well as from bumps against protruding objects, bump caps are only designed to protect from the latter and provide no protection from impact or penetration of falling objects. Bump caps are not suitable for most industrial uses where there is potential for impact from a falling object.

Industrial safety helmets generally have two standard components, the outer shell and the interior suspension. The outer shell is commonly made of a thermoplastic such as ABS, high-density polyethylene, or polycarbonate; however, fiberglass, aluminum, and other materials may be found on the market. Although these non-thermoplastic materials may be commercially available, their characteristics need to be evaluated against the risk assessment to ensure that they do not pose a hazard to the wearer, such as the use of highly conductive aluminum helmets where electrical exposure is possible. In general, the current lines of thermoplastic industrial safety helmets provide a good balance between weight, heat retention, electrical insulation, and usability over a wide range of temperatures, making them an appropriate choice unless the hazard assessment indicates that a specific type of helmet is required. In addition to the material, there are several options for the shell, including cap style (front brim), full brim, accessory slots, vents, high-visibility, and size.

In addition to the shell, the suspension is an integral component of the industrial safety helmet. The suspension serves two primary functions: ensuring a good, stable fit, and stretching to lessen the force of an impact from above or, in some cases, from the side.

The specifications and testing requirements for industrial safety helmets are determined by the jurisdiction in which they are intended to be used or imported. In general, these provide requirements for impact and penetration capacity of the shell, stretch of the suspension, flame resistance, and other special circumstances which the helmet has been designed to protect against. For instance, both the EN 397 (European Committee for Standardization, 2012c) and ANSI Z89.1-2009 (American National Standards Institute, 2009) standards specify shock absorption testing that involves dropping a rounded impactor of specified weight (5 kg and 8 lb, respectively) from a specified height (1 m and height that results in impact speed of $18\,\mathrm{ft\,s^{-1}}$, respectively) to measure the amount of force transmitted by the helmet and suspension. In the absence of local specifications, buyers should refer to one of the standards referenced below to ensure that the industrial helmet has been certified to provide a given level of protection.

In the EU, all industrial PPE is required to have an EC Certificate to be eligible for free trade in the European market (Reckter, 2004), and in the case of industrial safety helmets, conformance is measured against EN 397 (European Committee for Standardization, 2012c).

In the United States, the OSHA requires that all hard hats purchased to be used for industrial head protection comply with ANSI Z89.1-1986 (OSHA, 2009a); however, this standard has been revised several times since the 1986 edition and employers would be prudent to ensure that any hard hats purchased meet the requirements included in ANSI Z89.1-2009 (American National Standards Institute, 2009), the latest update of the standard.

13.3.2
Hand Protection

PPE that protects the hands is most commonly implemented through gloves, either general work gloves or gloves matched to a specific hazard such as chemical exposure, puncture, or sharp objects. In addition to gloves, other forms of hand protection include items such as finger guards and barrier creams.

Like other forms of PPE, the critical factor in selecting hand protection is an accurate hazard assessment to identify the hazards that are expected in a given task or type of work. There is not one ‘‘perfect’’ glove that provides adequate protection against all hazards. Rather, some compromise must be made between the variety of hazards to protect against and the level of protection against each hazard that is provided. General work gloves provide limited protection from a wide variety of hazards, including lacerations, scrapes, punctures, insect/animal bites, and abnormal temperatures. Specialty or hazard-specific gloves provide a higher level of protection from the specified hazard, but may provide no or dramatically lower protection from other hazards. When the hazard is not mitigated to an acceptable level by the protection offered by a general work glove, specialty gloves need to be considered. Safety equipment suppliers typically stock a wide variety of gloves offering protection from various hazards; however, that diversity of supply also increases the difficulty of selecting the right glove.

13.3.3
General Hand Protection

General work gloves may be composed of leather, cotton, or a similar fabric, or synthetic materials. As mentioned above, they provide a minimal to moderate level of protection to various hazards and are a good choice for tasks where a specific or significant hazard is not identified. For tasks requiring increased dexterity and feel, fitted mechanic-style gloves should be considered, although they will have a significantly higher cost than common leather or cotton gloves. Additionally, work gloves are also available with different types of coatings on the palm and fingers to improve grip, are lined to provide limited thermal protection, and may have extended or sealable cuffs to prevent objects from entering the gloves.

13.3.4
Chemical Hand Protection

Gloves offering chemical protection are made from a variety of materials, each with varying resistance to different types of chemicals (Figures 13.2–13.5). Owing to the multitude of glove materials and potential chemical types, it is impossible to provide general recommendations for chemical-resistant gloves in this context. Rather, this section will provide best practices for use of chemical-resistant gloves

Figure 13.2 Laminate chemical-resistant gloves provide protection from a wide array of chemicals but little cut and abrasion resistance (OSHA, 1996).

Figure 13.3 Butyl chemical-protective gloves provide high permeation resistance to gas and water vapors (OSHA, 1996).

Figure 13.4 Chemical-resistant gloves made of Viton are highly resistant to chlorinated and aromatic solvents (OSHA, 1996).

and guidance for using manufacturer testing data in selecting gloves for a particular task or exposure.

Chemical-resistant materials used in gloves and protective suits are susceptible to failure in one of three ways: permeation, penetration, and degradation. Permeation involves chemical migration through the material on a molecular level, penetration involves chemical migration through pinholes or defects in the glove material, and degradation involves changes in the resistant material's properties due to chemical interaction (Forsberg, 2009).

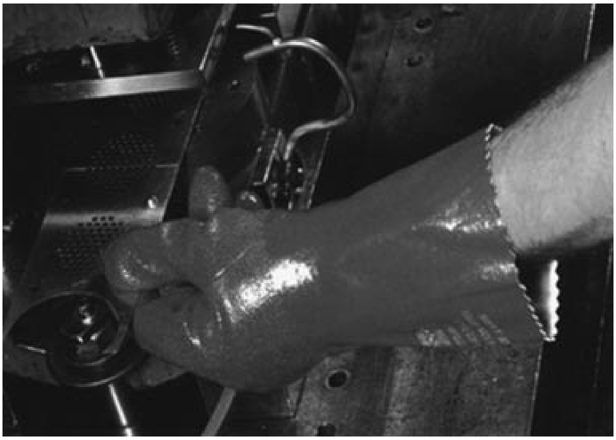

Figure 13.5 Chemical-resistant gloves made of nitrile protect against a wide range of solvents, chemicals, fats, and hydrocarbons while providing good cut, abrasion, and puncture resistance (OSHA, 1996).

Testing for penetration resistance is more aligned with quality control testing and less with resistance to specific chemicals. According to ASTM F903-10 (ASTM International, 2010) and EN 374-2:2003 (European Committee for Standardization, 2003a) test materials are subjected to an air and/or water leak test to check for pinholes, faulty seams, or other defects that would allow chemical to flow freely through the glove. Gloves that fail the penetration testing are generally not tested further for chemical resistance as they are considered unsuitable for chemical use if the penetration routes are inherent to the material or construction of the glove (leather gloves, stitched materials, etc.) or of inadequate quality if the penetration routes are due to defects such as pinholes or other defects.

Once the material's penetration resistance has been established, it is generally tested for degradation where samples of the glove material are immersed in a test chemical for 30 min and changes in size, weight, and appearance are evaluated. Ansell, a leading chemical-resistant glove manufacturer, stops the chemical resistance testing at this point as significant physical changes to the material will generally degrade the permeation resistance (Ansell Healthcare, 2008).

While some manufacturers may utilize the penetration and degradation tests described above to limit the number of materials that are tested for permeability, this is the definitive test method prescribed by the EU in EN 374-3:2003 (European Committee for Standardization, 2003b) and the United States in ASTM Method F739-07 (ASTM International, 2007). To test for permeation, a test chamber is set up with a sample of the test material separating the chemical in question from fresh gas. The fresh gas is tested at intervals to determine the time to breakthrough and corresponding rate of chemical moving through the glove material (Ansell Healthcare, 2008).

Although the various combinations of glove material and chemical resistances make it difficult to provide general recommendations for selection, there are general practices that can be employed to minimize exposure to personnel. Without specific guidance otherwise from the manufacturer, chemical-resistant gloves should be considered temporary barriers that will break down over time, regardless of the tested resistance. As such, they should be worn for no longer than the manufacturer recommends, or no more than 2 h in the absence of manufacturer recommendations. Because of this assumption of degradation over time and the inability to determine the impact on permeability, gloves labeled as disposable should not be reused. When chemical-resistant gloves are employed, good occupational hygiene practices need to be implemented, including thoroughly washing the gloves prior to removal and also the hands following removal. Additionally, gloves and other chemical protective clothing that become completely immersed or covered with chemicals should be removed and replaced as often as is necessary to ensure that the material maintains its chemical resistance integrity.

Finally, and arguably most important, is selecting a manufacturer that produces gloves proven to resist the chemicals used in the specific task or setting where they will be used. The leading glove manufacturers provide information on the chemical resistance of the various materials and glove types against a range of commonly used chemicals. Employers can also contact many of the leading glove manufacturers for guidance on resistance to chemicals not listed in their use guides. Global manufacturers such as Ansell publish guides specific to the standards used in various jurisdictions such as the *Chemical Resistance Guide* (Ansell Healthcare, 2008) for the United States and other ASTM F379 users and the *EN Chemical Recommendation Guide* (2012) for employers subject to EN 374-3:2003.

13.3.5
Hand Protection from Cuts and Punctures

Like chemical-resistant gloves, cut, and puncture-resistant gloves are made from a variety of materials. Kevlar, leather, and metals are common materials that prevent an object from cutting or penetrating the glove (Figure 13.6). It must be noted, however, that although these materials prevent cuts and penetration, they do not prevent the force of impact with the object from being transmitted to the underlying body part or tissue. As such, it is still very possible to suffer an impact-type injury. In the EU, cut resistance is measured according to the EN 388:2003 standard (European Committee for Standardization, 2003c), which results in a four-digit rating of resistance to material failure for resistance to abrasion, cut, tear, and puncture. Each digit in the rating ranges on a scale from 0 to 5, with higher numbers representing greater resistance to failure. In the United States, the ANSI/ISEA 105-2011 standard (American National Standards Institute, 2011) is used to determine resistance to mechanical failure, utilizing a similar five-point scale although the rating is only one digit with a higher number indicating greater resistance to mechanical failure. Additionally, EN 1082-1:1996 (European Committee for Standardization, 1996) provides testing requirements for chainmail gloves that are intended to protect against cuts from hand knives (Figure 13.7).

Figure 13.6 Cut-resistant gloves made of materials such as Kevlar are highly resistant to cuts and abrasion (OSHA, 1996).

Figure 13.7 Metal chainmail gloves made from stainless steel or other metals provide excellent resistance to cut and abrasion and are commonly used in food service where knife and other cutting hazards are present (OSHA, 1996).

13.3.6
Thermal and Flame Hand Protection

Other gloves are available to provide protection against elevated temperatures and flame at more effective levels than general work gloves. When working with equipment, materials, or work processes that involve elevated temperatures or open flame that a worker may be exposed to, these thermal protection gloves should be considered. The EN 407 (European Committee for Standardization, 2004b) standard provides specification and testing requirements for the EU and the ANSI

105 (American National Standards Institute, 2011) standard provides equivalent requirements for the US.

13.3.7
Eye and Face Protection

Eye protection is most commonly provided by safety glasses and goggles meant to protect the wearer from flying particles and dust from entering the eyes. Safety glasses are also available to protect against non-ionizing radiation from lasers, welding, burning, and glare. Safety goggles are typically used to prevent chemical splashes from entering the eyes and in situations where there is a high concentration of particulate matter in the air, such as sand or dust. Potential exposure to moderate to major chemical splashes, hazardous chemicals, and significant flying particles (such as when grinding) require additional face protection provided in the form of face shields, welding shields, and other similar shields. Notable in any discussion of face shields is that they are designed to complement, not replace, safety glasses or goggles and, as such, should be worn in conjunction with suitable safety glasses or goggles at all times (OSHA, 2009b).

13.3.8
General Eye and Face Protection

Safety glasses (Figure 13.8) and goggles (Figure 13.9) are comprised of two basic components – the frame and the lens(es). Some glasses may have a single lens that covers both eyes, whereas others may looks more like traditional glasses with two distinct lenses. For general protection against impacts from flying objects, both the lens(es) and frame need to be tested and certified for impact resistance. In the United States, ANSI Z87.1 (American National Standards Institute, 2010)

Figure 13.8 General safety glasses (OSHA, 1996).

Figure 13.9 Safety goggles (OSHA, 1996).

defines the testing protocols for impact resistance in safety glasses, and a marking should be evident on both the frame and lens(es) showing conformance with this standard. For frames and lens(es) that meet specifications for high-speed impacts, the marking is shown as ANSI Z87.1 + . In the EU, EN 166 (European Committee for Standardization, 2001) provides a similar set of testing requirements; however, the scope is far narrower than ANSI Z87 with additional EN standards discussed below providing guidance for welding applications.

There are two primary types of safety eyewear for those who require corrective lenses, over the glass (OTG) and prescription safety glasses. Both of these solutions need to conform to the impact resistance standards mentioned above; however, both also offer unique issues that need to be considered when evaluating their use.

OTG-type safety glasses are typically larger than standard safety glasses as they need to fit over other types of corrective glasses, and as such they can be unwieldy and uncomfortable to wear. As they introduce a second surface which the eyes must view through, they can also introduce some distortion and eye discomfort if they are scratched or do not fit well, so some additional instruction may be necessary to ensure that the OTG safety glasses fit well, providing the expected level of protection and increasing the likelihood that they will be worn. Even with this additional instruction, these drawbacks decrease the likelihood of use if OTG-type glasses are required on a constant basis. The benefits of OTG-type glasses is that like the general safety glasses discussed above, they are not specific to the wearer, are relatively inexpensive, can be readily available for visitors, and, if needed, can be worn without corrective glasses underneath. Given the benefits and drawbacks of OTG-type glasses, they should primarily be used for personnel who do not regularly require safety glasses, such as visitors and office personnel.

Prescription safety glasses come in many styles, ranging from traditional corrective glasses styles to those that look identical with current styles only with corrective lenses installed in the frame. Prescription safety glasses can be significantly more expensive than non-prescription versions, costing perhaps 10 times more when the costs of frames and lenses are combined; however, they equal the comfort of both non-prescription safety glasses and non-safety rated prescription glasses and do not require the wearer to look through multiple layers of lenses. Based on the comfort and visual quality, they are more likely than the OTG type to be worn as a part of standard safety equipment. Many types of prescription eyewear include detachable side shields, and the employer needs to set clearly the expectation that these always be worn as an integral part of the eyewear to protect the wearer from particles entering the eyes from the side. When prescription safety eyewear that requires side shields is worn without them, the eyewear needs to be considered ineffective and replacement side shields provided prior to the wearer engaging in further work. Employers also need to inspect the prescription eyewear worn by workers to ensure that the ANSI Z87.1 or EN 166 marking is evident on both the frame and lens(es) as workers may install side shields on non-safety rated prescription eyewear thinking that they are protected, even though the eyewear may not provide the impact resistance specified in the standards.

Face shields (Figure 13.10) are designed to provide additional protection for the eyes and face when significant amounts of particles are being generated or when high-pressure air/water is being used. Like safety glasses, face shields are designed for impact resistance and must conform to ANSI Z87.1 or EN 166. As mentioned above, face shields are not eye protection and must be worn in conjunction with safety glasses or goggles to provide adequate protection to the wearer. Various types of face shields are available, ranging from those that are worn directly on the head to those that attach or secure around an industrial helmet to allow the wearer to

Figure 13.10 Face shield (OSHA, 1996).

be fully protected on a work site. Most face shields are constructed of a frame and shield, similar to the safety eyewear discussed in this section. Unlike eyewear, the frame is not an integral part of the impact resistance and hence is not required to have ANSI Z87.1 certification; however, the shield must be so certified and marked.

13.3.9
Eye and Face Protection for Welding, Burning, and Brazing Activities

Welding, burning, and brazing activities produce light and infrared (IR) and ultraviolet (UV) radiation that can damage the face and eyes of personnel in the immediate area of the activity. To protect against these hazards, welding goggles or shields equipped with a tinted lens (Figure 13.11) are used to limit the light that reaches the wearer's eyes and to block completely the IR and/or UV radiation from the wearer.

Historically, this protection was provided by glass or polycarbonate permanently tinted to a given level of light transmission, which required the wearer needed to move the shield or filter out of the way for a clear view of the work area. Recently, auto-dimming filters have become more common as a system that allows for a clear view of the work area and automatically darkens when an arc is detected by the unit. The system always provides maximum IR and UV protection and varies the light transmission to balance visibility of the work area with protection from the welding or burning activity. While these automatic dimming filters provide convenience, the filters provide a specified level of protection and still need to be evaluated against the activity to ensure that they provide an adequate level of protection.

Figure 13.11 Welding helmet with tinted shield (OSHA, 1996).

In both the United States and EU, the light energy transmitted is indicated on a numerical scale from 1.5 to 14, with the level of protection increasing (via a reduction in the amount of light energy transmitted through the filter) as the numerical rating increases (Grainger, 2012a). Lower rated filters are most appropriate for low-energy applications such as torch soldering and brazing, and higher rated filters are most appropriate for high-energy applications such as shielded-metal arc welding and carbon arc welding. The need for a more protective filter also increases as the current utilized in the welding activity increases. Requirements for shade use are published in regulations such as OSHA's eye and face protection standards for general industry (29 CFR 1910.133) (OSHA, 2009b), construction (29 CFR 1926.102) (OSHA, 1993), the EU's personal eye protection standard (EN 169:2002) (European Committee for Standardization, 2002), and ANSI Z87.1 (American National Standards Institute, 2010). Local regulation or the most applicable of these standards should be used when selecting welding filters. Often welding filter suppliers will provide guidance based on the requirements where the products are imported or sold, and although these provide additional information from which to select a filter, it is up to the employer to ensure that their selection complies with local requirements.

13.3.10
Eye Protection for Lasers

Laser energy is another type of non-ionizing radiation that can be mitigated through the use of PPE. Lasers produce intense, highly-focused beams of light that can cause damage, especially to the eyes, when the tissue absorbs the beam's energy and is heated or otherwise affected. Two key factors to consider when selecting laser protective eyewear are the wavelength and energy or power density of the laser being used. Selection of the lens is based on the wavelength and power density of the laser, with the former used to determine the optical spectrum range that is to be filtered, and the latter the optical density of the lens, or the amount of attenuation that is provided. The wavelengths included in laser safety generally range from 400 to 800 nm (Laser Institute of America, 2012). The optical density is the base-10 logarithm of attenuation provided by the lens, for example, a lens with an optical density of 5 attenuates the beam's energy density by a factor of 100 000($\mathrm{W\,cm^{-2}}$ or $\mathrm{J\,cm^{-2}}$). In the EU, laser protective eyewear is rated for the maximum power rating of the laser rather than optical density, negating the need to calculate attenuation.

In the EU, laser safety eyewear (Figure 13.12) must conform to EN 207 (European Committee for Standardization, 2009a) and EN 208 (European Committee for Standardization, 2009b). The US equivalent requirements are defined in OSHA's eye and face protection standard (29 CFR 1926.102) (OSHA, 1993), with ANSI Z136 (American National Standards Institute, 2007a) providing additional guidance on laser safety.

Figure 13.12 Laser safety glasses (OSHA, 1996).

13.3.11
Foot

Safety footwear is most commonly identified with steel-toed boots (Figure 13.13); however, there are several hazards that modern safety footwear can protect against. Impact- and compression-resistant toes are still the most common applications; however, footwear can be selected to protect against punctures, slips, elevated

Figure 13.13 General safety boots with steel toes (OSHA, 1996).

temperatures, electrical exposure, electrostatic generation, chain saw strikes, cold, and water penetration. Like other forms of PPE, the key to selecting the right safety footwear is conducting a comprehensive hazard analysis of the workplace and tasks to identify the specific hazards that are to be protected against. Once the hazards have been identified, it is a matter of selecting footwear that conforms to the applicable standards or requirements and bears the appropriate markings.

In the United States, OSHA sets requirements for industrial foot protection in its PPE standard (29 CFR 1910.136) when there is ‘‘danger of foot injuries due to falling or rolling objects, or objects piercing the sole, and where such employee’s feet are exposed to electrical hazards’’ (OSHA, 2009d). In this standard, OSHA also requires that any protective footwear used complies with ASTM F-2412-2005 (superseded by ASTM F2412-11), Standard Test Methods for Foot Protection (ASTM International, 2011a), ASTM F2413-2005 (superseded by ASTM F2413-11), Standard Specification for Performance Requirements for Protective Footwear (ASTM International, 2011b), ANSI Z41 (superseded by ASTM F2412-11), American National Standard for Personal Protection – Protective Footwear, or that is demonstrated by the employer to be as effective as one of the standards above. It is worth noting that the ASTM and ANSI standards do not include provisions for add-on devices such as removable toe caps or metatarsal guards; however, these are not specifically prohibited by OSHA if the employer can demonstrate equivalent effectiveness (Grainger, 2012b). Any use of these add-on devices needs to be proactively evaluated for effectiveness to ensure that an adequate level of protection is provided.

In the EU, protective footwear is evaluated against EN ISO 20344 (European Committee for Standardization, 2011b), 20345 (European Committee for Standardization, 2011a), 20346 (European Committee for Standardization, 2004a), and 20347 (European Committee for Standardization, 2012b), which were developed from the EN 344, 345, 346, and 347 standards. EN ISO 20344 provides general information regarding types of footwear, requirements, and markings. EN ISO 20345 covers safety footwear, which requires a toe cap and resistance to impact and compression at higher loads (200 J/15 000 N). EN ISO 20346 covers protective footwear, which requires a toe cap and resistance to impact and compression at lower loads (100 J/10 000 N). EN ISO 20347 covers occupational footwear which is not rated for impact and compression resistance (Scherer, 2010). Additionally, EN ISO 17249 covers protective footwear for chain saw use (European Committee for Standardization, 2004c) and EN 15090 covers footwear specifically suited for firefighting activities (European Committee for Standardization, 2012a).

Both US and EU certified footwear include codes and symbols that indicate the specific conditions and hazards that the footwear has been certified for; keys and additional information are available in the respective ASTM or EN ISO standards as referenced above.

13.3.12
Ear

The hearing protective device (HPD) is one aspect of protecting employees from industrial noise. While there are several methods that can be used to reduce or attenuate the noise produced by industrial equipment and machinery, HPDs provide physical protection of the worker from hazardous noise that cannot be otherwise mitigated. In protecting personnel from noise, the hazard to be addressed is the amount of pressure that sound waves exert on the eardrums and inner ear of the individual, known as sound or acoustic pressure. This pressure is typically measured in pascals (Pa) in the SI system and the Imperial system equivalent of pounds per square inch (psi). In applied use, these pressure values are expressed as sound pressure levels (SPLs), which are expressed in decibels (dB), which is a logarithmic ratio of the actual sound pressure to a reference level:

$$L_{\mathrm{dB}} = 20\log_{10}\left(\frac{p_{\mathrm{actual}}}{p_{\mathrm{reference}}}\right) \tag{13.1}$$

where the value of $p_{\mathrm{reference}}$ is generally 20 μPa, or the threshold of human hearing, L_{dB} represents the SPL in dB, and p_{actual} is the measured sound pressure in micropascals (μPa) (American National Standards Institute, 2004).

Human ears respond differently to the various frequencies that comprise the audible spectrum, resulting in sounds in the 1000–8000 Hz range being perceived as louder than sounds with equivalent pressure in the 31.5–500 and 8000–16 000 Hz ranges (Sengpiel, 2012). In contrast, noise level measuring equipment responds equally to sound pressures regardless of the frequency. To account for this difference in response between human ears and measuring equipment, weighting filters are used to adjust the measured SPLs to match better the human ear's response (Brauer, 1994).

The two weighting filters commonly used today are referred to as the A scale (dBA) and C scale (dBC), with dBA being most commonly used in permissible exposure limits and dBC primarily in the reductions in hearing protector effectiveness described below (3M United States, 2011). As shown in Figure 13.14, the A scale significantly reduces low-frequency response up to 2000 Hz and the high-frequency response above 8000 Hz, whereas the C scale remains flatter with more subtle reductions in the low- and high-frequency ranges.

The primary mechanism of hearing protection is a physical barrier between the inner ear and ambient sound levels, reducing or attenuating the amount of energy in the form of sound waves that reach the inner ear components. This can be accomplished through plugs (Figure 13.15) or caps (Figure 13.16) that fit into the outer ear canal or via ear muffs (Figure 13.17) that fit over the external ear with the sound energy being reduced as it is blocked by or passes through the HPD.

The amount of attenuation provided by the HPD is expressed by a number called the noise reduction rating (NRR) in the United States, single number rating (SNR) in the EU, and the sound level conversion value (SLC) in Australia and New Zealand (Berger, 2010). Although these ratings have slightly different calculations,

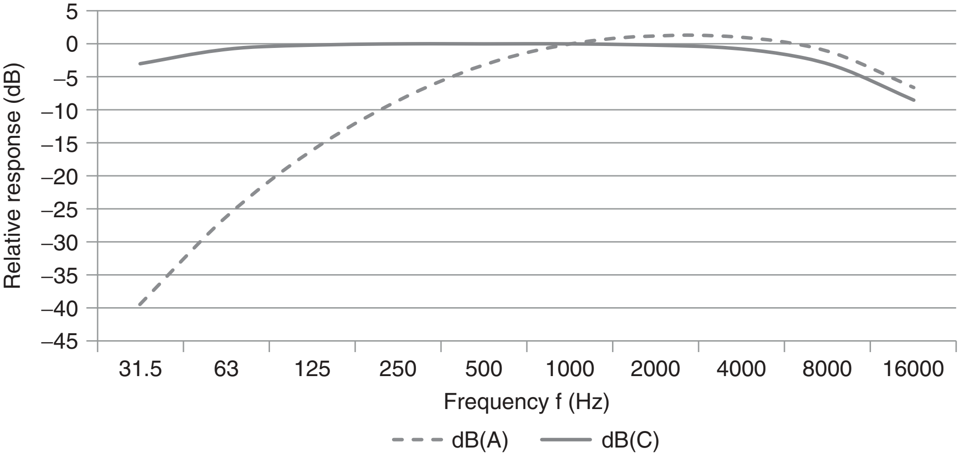

Figure 13.14 Relative response values for dBA and dBC scales (Sengpiel, 2012).

Figure 13.15 Corded and non-corded foam moldable earplugs (OSHA, 1996).

the underlying concepts are similar in that laboratory testing is completed across a range of frequencies with the attenuation measured at each frequency and logarithmically summed to calculate an overall attenuation rating (NIOSH, 2005). The previous source provides background and equations for calculating a variety of reduction ratings. As an example, the NRR calculation is based on the dBC scale, requiring the experienced SPL to be measured on the dBC scale with the expected exposure in dBA calculated using the equation

$$\mathrm{dBA}_{\mathrm{protected}} = \mathrm{dBC}_{\mathrm{unprotected}} - \mathrm{NRR} \tag{13.2}$$

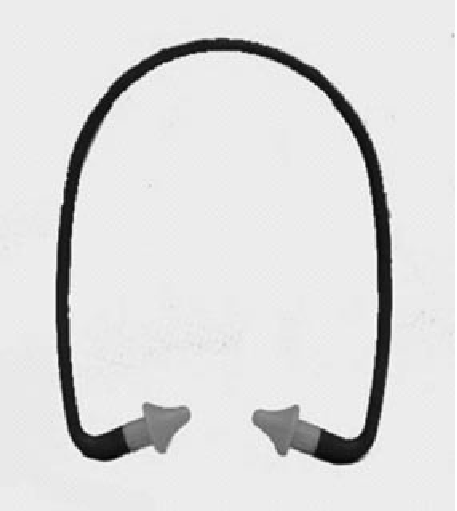

Figure 13.16 Plastic ear canal caps (OSHA, 1996).

Figure 13.17 Earmuffs (OSHA, 1996).

While these performance ratings provide some indication of the amount of attenuation that can be expected, it is important to remember that these reduction ratings are calculated based on laboratory conditions and do not take into account the real-world reductions in attenuation due to fit, user installation, and actual frequencies of the sound encountered by the user. In fact, in the United States, OSHA compliance officers are directed to de-rate the NRR by 50% during inspections, while the National Institute for Occupational Safety and Health (NIOSH) recommends that HPDs be de-rated based on the likelihood that they will be used correctly, with a recommended de-rating for earmuffs of 25%, formable earplugs of 50%, and all other types of earplugs of 70% (NIOSH, 1998). Additionally, because of the differences in SPL determination on the A and C scales, when measurements are conducted on the A scale, NIOSH recommends removing a further 7 dB from the NRR.

An NRR is determined for each HPD through testing to determine the level of attenuation. It is important to understand that these NRRs are calculated in laboratory conditions, with real-world performance potentially being significantly impacted by fit, quality of installation by the wearer, and the actual frequencies encountered by the wearer.

In the United States, occupational noise exposure is regulated by OSHA's Occupational Noise Exposure Standards for general industry at 29 CFR 1910.95 (OSHA, 2008) and construction at 29 CFR 1926.52 (OSHA, 2002b). Additional requirements for HPDs in construction activities are set forth in the Hearing Protection Standard at 29 CFR 1926.101 (OSHA, 2002a).

In the EU, requirements for managing exposure to noise in the workplace are provided in the Noise at Work Directive (2003/10/EC) (Council of the European Communities, 2003) which sets noise exposure limits similar to those set by OSHA in the United States. Additional specifications, testing methods, and requirements can be found in EN 352-1 through EN 352-8, EN 458, EN ISO 4869-2, EN ISO 4869-3, EN 13819, and EN 24869.

Additionally, several consensus standards are available providing additional testing methods and selection guidance, including ANSI/ASA S12.6 (American National Standards Institute, 2008), ANSI/ASSE A10.46-2007 (American National Standards Institute, 2007b), and the World Health Organization's *Occupational Exposure to Noise: Evaluation, Prevention, and Control* (Goelzer, Hansen, and Sehrndt, 2001).

13.3.13
Heat, Flame, and Electric Arc

The hazards of heat, flame, and electric arc are combined in this section as the PPE used for general exposure is similar for all three. Heat and flame in this section refer to a flash fire situation and exclude high-temperature operations such as in foundries and activities where sustained exposure to flame and high temperature are expected to occur, such as firefighting. Protective equipment for use in high ambient temperature environments is generally held to the same standards as the categories of PPE covered above, although it may include additional insulation, made from slightly different materials, or covered with a reflective surface to reflect radiant heat. As noted previously, this section focuses on flash fire and arc flash protection for general exposures, or minimum levels of protection for workers who may encounter these hazards. Protective equipment for personnel working directly with electrical components or in areas where a flash fire is likely will be more substantial than what is discussed in this chapter. Additionally, PPE for firefighting or other activities involving extended exposure to flame or extreme heat are outside the scope of a discussion on PPE for general workplaces.

A full PPE ensemble worn to protect against flash fires and arc flashes usually includes head protection, face protection, hand protection, and body protection. Head, face/eye, and hand protection devices for flash fire and electric arc exposures are generally required first to meet the general requirements discussed above, with additional markings to certify that they protect against these specific hazards. Protective clothing (defined here at shirts, pants, coveralls, and outerwear used to protect the trunk, arms, and legs) used to protect the wearer from thermal and electric arc hazards is more unique than general-purpose work clothing and therefore is subject to specific standards.

13.4
Conclusion

PPE has become an integral component of the modern loss prevention program. Advances in technology and regulation have led to products that can effectively isolate the wearer from a multitude of hazards. These advances, however, have not changed the fact that PPE does not remove the hazard from the work environment; rather, PPE provides a barrier between the wearer and the hazard.

As discussed in this chapter, there are a multitude of regulations and consensus standards that specify how specific types of PPE are to be designed, manufactured, tested, and used to ensure that it provides the expected level of protection. When quality PPE is properly selected based on the specific hazards identified in a risk assessment or job safety analysis, it can provide an additional, independent layer of protection that enhances worker safety.

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