Hearing Protection

Hearing Conservation

Effectively preventing noise-induced hearing loss

By Peggy E. Ross

IMAGINE BEING UNABLE TO HEAR music, birds chirping or the voice of a small child. Rabinowitz (2000) describes noise as "perhaps the most common occupational and environmental hazard" (p. 2749). NIOSH estimates that up to 30 million Americans are exposed to hazardous noise in the workplace. Furthermore, at least 10 million Americans suffer noise-induced hearing loss (NIHL) as a result of exposure to noise at work or during nonoccupational activities (Berg). While hearing loss or deafness cannot be seen, it is a disability that impacts communication, promotes isolation and may result in an increased safety risk when workers are unable to hear warning signals or evacuation alarms (ACOEM, 2002, p. 2). By understanding the harmful effects of noise and implementing a comprehensive hearing conservation program, NIHL can be effectively prevented.

Noise, the Ear & Noise-Induced Hearing Loss

Noise is best defined as unpleasant or unwanted sound (Plog, Niland & Quinlan, 1996, p. 199). Unfortunately, *unwanted sound* is a relative term, as demonstrated by a motorcycle without a muffler or the speakers near the front row at a rock concert. Understanding harmful effects of noise on hearing requires learning about sound, noise and how hearing occurs.

Plog, et al. (1996) define sound as "any pressure variation (in air, water or some other medium) that the human ear can detect" (p. 199). Sound waves travel through the auditory canal of the ear and hit the tympanic membrane, causing it to vibrate. Sound waves are transmitted from the tympanic membrane via the bones of the middle ear (incus, stapes and anvil) to the cochlea of the inner ear and continue on to the auditory nerve, where sound is ultimately interpreted by the brain.

Peggy E. Ross, R.N., CSP, COHN-S/CM/SM, COHC, *has worked in the occupational safety and health field for 20 years. Following 7 years in occupational health, she assumed a role as a division safety and health manager in the metals industry supporting 11 facilities. Since joining Baxter as a regional EHS manager in 2002, Ross has supported various aspects of safety and health for Baxter facilities. Her current focus is on ergonomics, case management and promoting leading indicators for safety and health. A professional member of the Northeastern Illinois Chapter and a member of the Industrial Hygiene Practice Specialty, Ross is currently pursuing a master's in safety and health from Columbia Southern University.*

It is the cochlea of the inner ear and the approximately 30,000 delicate hairlike receptor cells, known as cilia, within the cochlea that are damaged by excessive noise (Suter, 1993, chap. 3). Rabinowitz (2000) describes damage to the cilia as an excessive shearing force resulting in "cellular metabolic overload, cell damage and cell death" (p. 2750). Council for Accreditation in Occupational Hearing Conservation describes NIHL as sensorineural hearing loss resulting from damaged cilia that is permanent in nature, impacts speech frequencies and is rarely treatable (Suter, 1993, p. 20). Goetsch (2005) defines NIHL as "a sensorineural hearing loss that is attributed to noise and for which no other etiology can be determined" (p. 375).

Noise can cause two major types of hearing loss. First, a temporary threshold shift (TTS) may occur following exposure to loud noise such as a rock concert or jet engine. As the name implies, this type of hearing loss is transient. It may be described as tinnitus (ringing) or fullness; recovery is likely within a few hours or days if the trauma is not recurrent (Seidman, 1999, p. 46). Sudden immediate hearing loss may also occur as a result of acoustic trauma such as an explosion. Usually, occupational NIHL develops slowly, over several years, as a result of exposure to continuous or intermittent loud noise (ACOEM, 2002, p. 1). This article will focus on the most common, gradual NIHL seen in industry.

The intensity (loudness), frequency and duration of exposure to noise determine whether hair cells in the cochlea are damaged (Rabinowitz, 2000, p. 2749). Loudness depends primarily on sound pressure (variations in atmospheric pressure) but is also impacted by frequency (Plog et al., 1996, p. 204). OSHA describes sound frequency as the number of sound vibrations in one second. Frequency is commonly known as *pitch.* Higher pitch is associated with more frequent sound waves. Frequency is measured

in hertz (Hz). One Hz is equal to one cycle per second. While humans may be able to hear between 20 and 20000 Hz when they are young, speech frequencies between 2000 and 4000 Hz are easily impacted by noise (OSHA "Noise & Health Effects").

Another important aspect is how sound is actually measured. The decibel logarithmic scale was developed as a unit of measure that describes sound level relative to an arbitrary zero reference level determined based on human hearing (Suter, 1993, p. 26). "One decibel represents the smallest difference in the level of sound that can be heard by the human ear" (Goetsch, 2005, p. 376). Furthermore, A-weighted scales are typically used to measure sound levels in the work environment. The A scale filters out sounds not heard by the human ear and is referred to as a dBA measurement. Suter (1993) states that "it is generally agreed that exposure to average sound levels above about 85 dB may be harmful to hearing if they are experienced for many years" (p. 27). While this is generally accepted, Rabinowitz (2000) advises that susceptibility to NIHL varies greatly among individuals (p. 2750). Exposure to sound levels at or below 80 dBA are generally considered safe (Goetsch, 2005, p. 378).

Variations in hearing loss with different exposure levels may, in part, be related to additional factors that can impact hearing. Activities outside the workplace expose individuals to varying levels of noise. A lawnmower is estimated at 90 dBA, a gunshot peak-level ranges from 140 to 170 dBA. A rock concert or chainsaw may result in exposure of 110 to 120 dBA. Individuals often do not wear hearing protection during noisy outdoor activities. Some work activities may not be harmful while other activities during the day may be well within the harmful range. Carpenters, cement masons, bricklayers and laborers may be exposed to noise levels exceeding 85 dBA for 40% or more of their workshift. Electricians may perform work in excessively loud areas. This has been well documented in many construction trades by the University of Washington (2004) (Table 1).

Since other factors beyond the activities discussed also may result in hearing loss, it is essential

Abstract: *NIOSH estimates that up to 30 million Americans are exposed to hazardous noise in the workplace, and at least 10 million suffer noise-induced hearing loss (NIHL) as a result of exposure to noise at work or during nonoccupational activities. By understanding the harmful effects of noise and implementing a comprehensive hearing conservation program, NIHL can be effectively prevented. This article focuses on the most common, gradual NIHL seen in industry.*

to record a valid history when determining whether hearing loss is caused by noise at work. First, recall that the eustachian tube contains sebaceous glands that produce cerumen (ear wax) to lubricate the canal. Sometimes, excessive cerumen may occlude the auditory canal and interfere with the ability of sound vibration to reach the tympanic membrane. This type of loss is conductive hearing loss. It is easily identified by inspection of the ear canal with an otoscope. Hearing returns when the cerumen is removed (Suter, 1993, p. 56).

Once the elements of noise and hearing loss are understood, prevention of hearing loss is best accomplished by first assessing exposure to noise, then initiating a robust hearing conservation program, as appropriate.

Inflammation associated with infection may also cause hearing loss (Plog et al., 1996, p. 96). In addition, Fletcher (2004) advises that "auditory system injury can result from exposure to a wide variety of drug and chemical exposures." These are described as "ototoxic agents" (p. 728). Also, some chemicals such as solvents and heavy metals may potentiate NIHL (Rabinowitz, 2000, p. 2750). This may increase variability in response to noise. The individual may participate in noisy hobbies or take ototoxic medications that also cause hearing loss. Disease processes such as mumps also often affect hearing.

Finally, hearing loss occurs as part of the normal aging process. Age-related hearing loss (presbycusis) must be assessed when reviewing audiometric results to determine the proximate cause of hearing loss. Schultz (2006) advises that it is "useful and beneficial to have a way to estimate the effects of both noise and aging on hearing levels" (p. 6). However, while age-correction is allowed by OSHA when assessing the impact of noise on an individual's hearing, "NIOSH does not recommend age correction on individual audiograms citing the delay that it can create and the fact that applying a median population value to all individuals is not scientifically valid" (Schulz, 2006, p. 6).

Schultz recommends assessing audiometric results without age correction to catch early NIHL before it becomes OSHA recordable. Due to the range of factors that affect hearing loss, a qualified professional should perform audiometric testing, conduct an otoscopic exam, and review the noise exposure levels, hearing health history, audiometric baseline and current audiometric test to determine the type and cause of hearing loss. Hearing loss may be attributed to both occupational and nonoccupational factors.

Sound-Level Monitoring

Once the elements of noise and hearing loss are understood, prevention of hearing loss is best accomplished by first assessing exposure to noise, then initiating a robust hearing conservation program, as appropriate. The first step in this process is determining how much noise workers are actually exposed to. Using a calibrated sound-level meter or dosimeter, conduct a preliminary facility-wide noise level survey using A-weighted sound levels.

A "rule of thumb" is to conduct a noise survey in all areas where the voice must be raised to speak with a person who is 3 ft away. It is helpful to use a site map to record results, noting the location and type of equipment (noise sources). Next, determine the location of workers with respect to the sound and the duration of worker exposure. Interview workers or supervisors to determine whether employees remain in one location for the entire shift or work in multiple areas. This will help identify which locations require area monitoring or whether personal monitoring is appropriate. Assess the type of noise involved. Take note of whether noise is intermittent or continuous. Are high impact forces involved such as punch presses or hammers? If so, check the peak sound level during impact. Check at various times, including when the noise is at maximum level. If levels never exceed 85 dBA, it is assumed that further testing is not required (Plog et al., 1996, chap. 9).

Next, the preliminary survey results are analyzed to determine where a detailed noise survey should be conducted. OSHA 1910.95 (d)(2)(ii) requires calibration of monitoring equipment to ensure accurate assessment. Calibration checks should be conducted "before, during and after the sound-level survey" (Plog et al., 1996, p. 212). In addition, an annual factory calibration should be completed in accordance with the instrument instruction manual guidelines. Written documentation confirming calibration results should be maintained for 2 years in accordance with 29 CFR 1910.95 (m)(3)(i). If the equipment does not calibrate appropriately, test results should be considered invalid and the equipment should be sent for factory calibration and/or repair. Do not use equipment that has been dropped.

The detailed noise survey is necessary to determine where engineering or administrative controls are appropriate and to help prioritize risk reduction efforts. Area sampling provides information about the noise level of the general area and for specific pieces of equipment. When employees are stationary, as with assembly-line production, conduct sampling at several different representative locations.

The detailed survey is also used to determine individual 8-hour time-weighted average (TWA) exposure to noise. This is required to evaluate which employees should be included in the hearing conservation program—who is required to have audiometric testing, training and hearing protection. A noise dosimeter is used to test for the slow response, 8-hour time-weighted dBA measurement. This is important because "it has been found that the A-network gives a better estimation of the threat to human hearing" and is required by OSHA for noise level monitoring (OSHA "Noise & Health Effects,"

p. 7). In addition, OSHA requires including all noise from continuous, intermittent and impulsive noise when conducting noise-level monitoring (Suter, 1993, p. 77).

It should be noted that employee peak exposure cannot exceed 140 dBA. When conducting noise dosimetry sampling, always use personal samples for individuals who have varying work patterns. Place the dosimeter near the hearing zone and conduct 8-hour TWA samples. Sampling one employee may represent others working in the same area, performing similar tasks.

When employees are exposed to different noise levels during the day but remain in each area for extended periods, noise dose may be calculated and compared to permissible exposure limits (PELs) established by OSHA Appendix A (Plog et al., 1996, chap. 9). "The noise dose is the noise exposure expressed as a percentage of the allowable daily exposure" (Goetsch, 2005, p. 375). The dosimeter may calculate this electronically. If an employee is exposed to various noise levels for specific periods of time, daily noise dose may be calculated manually to determine whether the dose exceeds 50% (action level) or 100% (PEL). For example, if an employee is exposed to:

- 85 dBA for 2.5 hours;
- 95 dBA for 2 hours;
- 92 dBA for 2 hours;
- 105 dBA for 0.5 hour;
- 90 dBA for 1 hour;

calculate using the number of hours exposed divided by the OSHA permissible noise exposure duration allowed (29 CFR 1910.95 Appendix A).

Dose = 100 (2.5/0 {no limit} + 2/4 + 2/6 + .5/1 + 1/8) = 145%

Since the 8-hour TWA exceeds 100%, noise exposure exceeds the PEL (Plog et al., 1996, p. 215).

For employees working extended-hour work shifts, manual calculations are required to reflect an 8-hour TWA (Krieger & Montgomery, 1997, p. 171). OSHA allows observation of sound-level monitoring and requires employers to notify employees of monitoring results. OSHA 29 CFR 1910.95 requires remonitoring "whenever a change in production, process, equipment or control measures increases exposures" and this increase would expose additional employees or render hearing protection ineffective (OSHA, 1983, p. 9776).

Recalling that the decibel is a logarithmic measurement, it is important to note that they cannot be added using normal algebraic addition. Plog, et al. (1996) report that "60 dB plus 60 dB does not equal 120 dB but only 63 dB" (p. 203). Understanding this concept is critical when determining the effect of adding additional pieces of equipment or when projecting the anticipated effects of noise-reduction strategies.

For precise calculations, a logarithmic formula may be used to calculate exposure. A simplified formula recommended by Plog, et al. suggests looking at the differences in the decibel values of the two pieces of equipment and adding a prescribed dB to the higher value:

- 0 or 1 dB difference, add 3 dB;
- 2 or 3 dB difference, add 2 dB;
- 4 to 9 dB difference, add 1 dB;
- 10 dB or more, add 0 dB.

For example, if two pieces of equipment are present, one with 83 dB sound level and the other with 82 dB, the difference is 1 dB so 3 is added to the higher number: 83 + 3 = 86 dB cumulative effect of placing these two machines together.

If more than two sources exist, compute for the two highest first and repeat the process using the new value (Plog et al., 1996, p. 204).

Table 1

Average Sound Levels of Common Activities & Work Tasks

Activity	Noise level (dBA)
Whisper	30
Normal conversation	60
Forklift	98.4
Lawnmower	90
Welding	91.2
Hand power sander	96.6
Bulldozer	100.2
Chainsaw	110
Gunshot	140

Note. *From* Construction Industry Noise Exposures: Operating Engineers, *by University of Washington Department of Environmental and Occupational Health Sciences, 2004.*

Written Hearing Conservation Program

OSHA regulations require implementation of a written hearing conservation program when exposures exceed the permissible exposure limits (PEL) defined in 1910.95 (b)(2), Table G-16. A hearing conservation program is required when employees are exposed to a dose of 50% or exposure at or above the action-level of 85 dBA for an 8-hour TWA. A hearing conservation program should include: noise monitoring (as discussed), noise control methods (engineering and administrative), audiometric testing, recordkeeping, training and PPE requirements.

Control Methods

The foundation of an effective hearing conservation program is to control risk associated with noise exposure. Risk is determined by evaluating the noise exposure level (loudness and frequency), duration of exposure, regulatory requirements, number of employees exposed, whether hearing losses have been observed and perceived reputation impact for outside noise sources. Prioritization of noise reduction projects should be formulated in a plan that establishes target dates and assigns responsibility. Dosimetry results and area surveys should be analyzed to determine the appropriate control method to reduce risk associated with employee exposure to noise. Cost-effectiveness of solutions should be evaluated (NIOSH "Noise & Hearing Loss").

Engineering controls are the preferred control method. Examples include mufflers, damping, reducing vibration, adding sound-absorptive material or enclosing a noisy machine. Developing a quiet room for employees to operate controls for equipment located outside the control area is a method this author has seen used effectively at a U.S.-based steel company. The employer could also substitute quieter tools, equipment or processes (Plog et al., 1996, chap. 9). Large, low-speed fans may replace smaller, noisy fans. If possible, control noise at the source. If this is not possible, assess whether it is possible to reduce noise along its path.

When determining the most appropriate engineering controls, consideration should be given to whether in-house expertise is available or if it is necessary to consult an experienced noise-control professional.

When determining which engineering controls are the most appropriate, consideration should be given to whether in-house expertise is available or if it is necessary to consult a professional with experience in noise-reduction engineering (NIOSH, "Noise & Hearing Loss," p. 2).

Administrative controls may be used effectively to reduce noise as well. Examples include implementing scheduled preventive maintenance, providing quiet break areas or running noisy equipment during the night when fewer employees are exposed. The site may also move people to different areas during a shift to reduce exposure time. A good example would be to provide a quiet area to complete required paperwork. Or, if a noisy operation requires 8 hours to complete, the site may consider scheduling 4 hours one day and 4 hours on a different day. Establishing controls that reduce noise are the most effective method of reducing NIHL. In this author's experience, a metal manufacturing facility in the U.K. was able to successfully reduce all noise levels below 85 dBA and eliminate PPE and audiometric testing requirements from the facility. Obviously, this is ideal hearing conservation.

Audiometric Testing

In the U.S., employees who are exposed to the action-level (8-hour TWA of 85 dBA) or above must be included in annual audiometric testing. Baseline audiometric testing must be completed within 6 months of initial exposure. If the company uses a mobile van service, testing must occur within 1 year. Testing should be conducted on rested ears with 14 hours free of exposure to occupational noise (OSHA, 1983). The occupational hearing conservationist (OHC) should examine the ears with an otoscope and take a hearing history (often referred to as an aural history). History questions should cover topics such as hobbies, military history, hunting, prior noisy jobs, chemical exposure, motorcycle riding, power tools, loud music, tinnitus and family history. Workers with a head cold should be rescheduled (Suter, 1993, p. 50).

Testing should be done using an audiometer and earphones manufactured in accordance with American National Standard Specification for Audiometers (ANSI S3.6 1989, ASA 81-1989) (Suter, 1993, p. 43). The testing must be conducted in an area that meets audiometric test room requirements established by OSHA in 29 CFR 1910.95, Appendix D. Equipment must be calibrated at least annually in accordance with 29 CFR 1910.95, Appendix E. "A technician who performs tests must be responsible to an audiologist, otolaryngologist or physician" (OSHA, 1983, p. 9777). If an outside clinic is used, inquire about tester qualifications.

OSHA requires audiometric testing to include pure tone, air-conduction hearing threshold examinations and testing at 500, 1000, 2000, 3000, 4000 and 6000 Hz (OSHA, 1983, p. 9777). However, "typically, the first sign of hearing loss due to noise exposure is notching of the audiogram at 3000, 4000 or 6000 with recovery at 8000 Hz." The location of the notch is dependent on the ear canal length and frequency of the noise (ACOEM, 2002, p.1). Since the notch is very typical of NIHL, companies may decide to test 8000 Hz to help with causal assessment of NIHL. However, it should be recognized that age-related hearing loss may eliminate the recovery at 8000 Hz. This will make the determination more difficult (ACOEM, 2002, p. 1).

After an audiometric test is completed, the OHC compares the test to baseline to determine whether the test is valid and whether a standard threshold shift (STS) has occurred. An STS is defined as a "change in hearing threshold relative to the baseline audiogram of an average of 10 dB or more at 2000, 3000 and 4000 Hz in either ear (NIOSH "Common Hearing Loss," p. 4). The OHC reviews all relevant information. Age correction may be applied to the test results using guidelines established by OSHA in 1910.95, Appendix F.

If an STS occurs, the employee may be retested within 30 days. If the STS remains, OSHA requires that the employee be informed of the test, in writing, within 21 days (OSHA, 1983). If medical pathology is suspected, such as an asymmetrical (one-sided) hearing loss without a valid explanation, the individual may be referred for further testing and a complete clinical audiological exam. Unless the hearing loss is determined to not be work-related, hearing protection must be provided and the employee *must* wear it. Further, the employer must ensure that the noise-reduction rating (NRR) of provided hearing protection is sufficient using one of the methods outlined in 29 CFR 1910.95, Appendix B.

Records & Recordkeeping

OSHA requires documentation be maintained regarding NIHL. This should include the amount of hearing ability lost and the date recorded. Age-correction may be applied. Records must include the exposure level, frequency and duration of exposure, length of employment, an explanation of any follow-up measures taken and any other pertinent information (OSHA, 1983). This could include information such as retraining, refitting of hearing protection PPE or referral to an audiologist.

The employer must also meet recordkeeping requirements for NIHL as outlined in 29 CFR 1904.10. Basic requirements obligate employers to record STS in one or both ears on the OSHA 300 log when the STS is work-related "and the employee's hearing level is 25 dB or more above audiometric zero (averaged at 2000, 3000 and 4000 Hz)" (OSHA, 1983). The confirmatory retest results may be used to determine OSHA recordability.

Once an STS is recorded, the employer revises its records for the ear(s) involved to reflect a revised baseline and compares future audiometric testing results to the revised baseline that reflects hearing level at the time of the recorded STS. Records relating to noise-level monitoring, employee exposure levels, audiometric testing, hearing history and diagnostic reports shall be retained by the employer. Further, OSHA's Access to Records standard allows the employee, his/her representative and/or legal authorities to view medical and exposure records maintained by the employer. "Some exposure records may have to be retained for 30 years, while medical records must be retained for the duration of employment plus 30 years" (Krieger & Montgomery, 1997, p. 271). In addition to other recordkeeping requirements, the hearing conservation standard should be posted in the workplace.

Training

All employees exposed to noise levels at or exceeding an 8-hour TWA of 85 dBA must receive annual training in hearing conservation in accordance with 29 CFR 1910.95(k). For training to be effective, it should be conducted by a qualified instructor (NIOSH "Noise & Hearing Loss"). Supervisors and managers should be included in the training to ensure that they understand the requirements of the company hearing conservation program (Suter, 1993, p. 96). Training should explain the effects of noise, including NIHL, distraction and fatigue. Instructors should help employees understand that NIHL affects speech frequencies and is permanent. Individual audiometric testing results should be reviewed with the employee. This author recommends discussing exposure to noise outside the workplace and other factors that can impact hearing as well. Training in the selection, care and use of PPE is also required. Employee should demonstrate proper insertion of plug-type hearing protection.

Personal Protective Equipment

Employees exposed to noise at the action-level must be offered hearing protection devices (HPD).

Clockwise from left: Photo 1: To determine how much noise workers are actually exposed to, an SH&E professional should use a calibrated sound-level meter to conduct a facility-wide noise level survey. Photos 2 and 3: Employees exposed to noise at the action level must be offered hearing protection devices such as earplugs. HPD selection must take into account factors such as NRR, the work environment, comfort and fit.

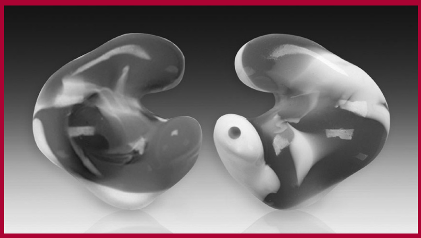

PHOTO 1 COURTESY QUEST TECHNOLOGIES. PHOTOS 2 & 3 COURTESY E.A.R. INC.

OSHA requires mandatory hearing protection for employees exposed to an 8-hour TWA of 90 dBA or greater. Signs must be posted in required hearing protection areas. Employees who experience a work-related STS are also required to wear HPD. "NIOSH recommends requiring the HPD use if noises equal or exceed 85 dBA regardless of exposure time" (NIOSH "Noise & Hearing Loss," p. 4). The company should decide whether mandatory HPD at 85 dBA will be a requirement of its hearing conservation program or if it will use the mandatory legal requirement of 90 dBA (8-hour TWA) as its enforcement level. International companies may choose the lower level to mirror legal requirements outside the U.S. Hearing protection must be provided at no cost to the employee and wearing of hearing protection must be enforced (OSHA, 1983). After defining areas or people in the facility requiring hearing protection, the site should select the types of hearing protection that will be made available to employees and enforce usage as required.

PPE selection should be based on a number of factors. First, the NRR should be considered. Keep in mind that the real-world noise reduction is often lower than the NRR reported by the product manufacturer. "This may occur even when users have been taught how to fit the devices" (Suter, 1993, p. 11). When selecting an appropriate NRR for a specific work area, the University of Washington (2004) offers a good decision model. For noise levels below 85 dBA, hearing protection is optional and a low NRR (less than 17 dB) is adequate. For levels in the 85 to 90 dBA range, low or moderate NRR would be adequate. Moderate NRR range from 17 to 24 dB rated protection levels. For noise in the 90 to 95 dBA range, moderate NRR is recommended. For exposures in the 95 to 105 dBA range, high NRR (above 24 dB) is recommended unless the exposure duration is very short. For exposures above 105 dBA, high NRR may be adequate for exposures less than 1 hour and double protection is recommended for longer duration (Daniell & Swan, 2005, p. 13).

Next, assess environmental factors. For example, if the work area is very dirty (e.g., a foundry) and workers reenter the area frequently, rolling earplugs with dirty hands would not be a recommended option. Consider how long hearing protection is required (Plog et al., 1996, p. 224). Finally, consider the comfort and preference of the individual. Provide several types of HPD so the employee can find one that fits comfortably. General types of available HPD are earplugs, canal caps and earmuffs.

To be effective, the HPD must be worn consistently. Since comfort and fit are key to consistent use, a worker should be encouraged to try several types until one is found that fits correctly and is comfortable to wear.

Expandable earplugs are an inexpensive, comfortable, portable and affordable HPD. Formable plugs fit most people and are designed to be thrown away after use (Goetsch, 2005, p. 390). Formable plugs are generally made of an expandable soft polymer foam or fiberglass (Suter, 1993, pp. 81-82). Pod-type foam plugs include a small handle that keeps the portion inserted into the ear clean; these work well in a dirty environment. Tapered plugs promote greater comfort. Foam earplugs are inexpensive and ideal for workers who wear glasses, work in hot environments and/or are required to wear hearing protection for extended periods. They are also ideal for visitors because of their low cost and disposable nature.

To be effective, the HPD *must* be properly inserted and worn consistently. Earplugs have several disadvantages. When removed in a dirty environment such as where dust or metal shavings are present, debris is often transferred onto the plug when the worker rolls the plug with dirty hands prior to reinsertion. Also, due to their small size, plugs are easily lost, and it is difficult to visibly verify proper insertion (Suter, 1993, p. 86). "Some individuals, especially women with small ear canals, have difficulty rolling typical plugs small enough to make them fit" (Stephenson, p. 1).

Since comfort and fit are key to consistent use, a worker should be encouraged to try several types until one is found that fits correctly and is comfortable to wear. Premolded plugs are more durable. They are commonly made of vinyl, silicone or other flexible material. They are washable and may be reused (Suter, 1993, p. 82). Premolded plugs must be sized appropriately for the wearer's ear. They often are inserted with an attached flange and would be preferred over the foam plug in an area where clean hands may be an issue. Both user-formed and premolded earplugs offer effective, portable hearing protection. Earplugs may also be custom fit, if necessary. Custom-molded earplugs are much more expensive but offer a perfect fit, greatest comfort and are often less visible than other plugs. Custom molded plugs are often used by musicians. Suter advises that making a custom-molded plug requires great skill and that attenuation is variable (p. 86).

Plugs are also available to protect employees from the sudden noise associated with arc flash. "If an arc flash occurs, the calibrated noise filter activates immediately to suppress the noise to a safer level" (Aearo Co., 2005).

Canal caps (known as semiaurals) resemble earplugs but are on a flexible band that can be worn over the head, behind the neck or under the chin. They are convenient and can hang around the neck when not in use. They are quickly reinserted and allow the individual to insert the plug without touching the plug. Some people find the pressure from the band uncomfortable. "Not all canal caps have tips that adequately block all types of noise" (Stephenson, p. 1). Canal caps generally offer less attenuation than other types of HPD. They must be properly inserted to offer sufficient protection and are "intended for short-duration, on and off wearing since they are often uncomfortable if worn for extended periods of time" (Suter, 1993, p. 84). "Generally, the canal caps that resemble stand-alone earplugs seem to block the most noise (Stephenson, pp. 1-2).

Earmuffs may also be selected as the preferred HPD. Earmuffs are preferred when hearing protection must be applied and removed frequently or for dirty environments such as construction sites (Plog et al., 1996, chap. 9). Earmuffs must fit snugly. Some are designed to fit directly onto a hardhat. While ear muffs do not come in a variety of sizes, some types fit differently than others so several styles should be available and they should be individually fitted (Suter, 1993, p. 83). There are several disadvantages of earmuffs. Sterrett (2002) states that muffs may not be compatible with other PPE (p. 47). Because a seal is required, when muffs are worn with other PPE such as safety glasses or hardhats, the worker may have difficulty obtaining a proper seal required to effectively reduce noise. Because of their size, muffs may not be appropriate when headroom is an issue such as with a firefighter's helmet or when working in confined spaces. Earmuffs are often described as hot and heavy as well (Stephenson, p. 2).

Special level-dependent muffs are available to facilitate understanding voices while still blocking noise. Some are passive and function by incorporating holes or valves while others are active hearing protectors that contain electronic circuitry (Suter, 1993, p. 85). Noise-canceling headphones are also available and are often worn on airplanes to reduce engine noise and allow the wearer to listen to air traffic control or music.

For workers who must wear hearing aids while continuing to work in a noisy environment, an audiologist should be consulted before recommending hearing protection. This author has seen a digital circuitry hearing aid prescribed that completely fills the bowl of the ear combined with a valve muff that closes to attenuate high and low frequency.

In very high noise environments (exceeding 105 dBA), ear plugs may be recommended in combination with earmuffs. It is important to note that using two devices does not double the hearing protection but would increase protection approximately 5 to 10 dB over the attenuation of either device. When a muff is combined with a foam plug, "the increase is particularly large in the low frequencies" (Suter, 1993, p. 84). Double hearing protection using a plug and an active, level-dependent design muff is recommended by NIOSH for military and police use during gunfire target practice (NIOSH "Do Sound Restoration," p. 1).

Hearing protection must be readily available at no cost to the employee. This author recommends supplying HPD for home use as well. Hearing protection should be checked for wear and replaced when necessary. The bottom line for hearing protection is that to effectively protect hearing the HPD must be worn whenever the employee is in a noisy environment.

Evaluating audiometric testing results can help the program administrator determine whether hearing protection devices are being worn properly and/or consistently. Retraining regarding fit must be conducted if hearing loss is observed. In addition, looking at results collectively will help the SH&E professional determine whether the company hearing protection program is effective.

Conclusion

Noise-induced hearing loss is preventable. To effectively prevent NIHL, a facility should first determine the noise levels to which employees are exposed. For noises that exceed 85 dBA 8-hour TWA, a hearing conservation program is required. Ideally, noise levels may be reduced using engineering and/or administrative controls. When levels cannot be reduced below the action-level, the site must provide audiometric testing and training to those individuals exposed. Avoid simply documenting deafness. Use results as an alert to evaluate hearing protective measures. Provide effective training. Follow up to ensure that hearing protection is worn properly. Consider posters and other information as reminders to wear HPD. Reducing NIHL will benefit the employer by promoting worker satisfaction and reducing workers' compensation costs associated with work-related hearing loss. ■

References

Aearo Co. (2005). *New E-A-R ARC Plug* [Product literature]. Retrieved April 24, 2007, from http://www.aearo.com/pdf/ARC%20Plug%20Sell%20Sheet%2010-10-05.pdf.

American College of Occupational and Environmental Medicine (ACOEM). (2002, Oct. 27). *Noise-induced hearing loss* [Position statement]. Elk Grove Village, IL: Author. Retrieved April 23, 2007, from http://www.acoem.org/guidelines.aspx?id=846#.

Berg, S.Z. *Sound advice—Protect your ears in noisy work environments.* Washington, DC: NIOSH. Retrieved May 24, 2006, from http://www.cdc.gov/niosh/topics/noise/abouthlp/soundadvice.html.

Daniell, W. & Swan, S. (2005). *Occupational noise exposure and hearing loss prevention: A technical report and guidebook for sheet metal manufacturing companies.* Olympia, WA: Department of Environmental and Occupational Health Sciences, University of Washington.

Fletcher, L.D. (2004). Promotion of noise-induced hearing loss by chemical contaminants. *Journal of Toxicology and Environmental Health, 67,* 727-740.

Goetsch, D.L. (2005). *Occupational safety and health for technologists, engineers and managers* (5th ed.). Upper Saddle River, NJ: Prentice-Hall.

Krieger, G.F. & Montgomery, J.F. (1997). *Accident prevention manual for business and industry: Administration and programs* (11th ed.). Itasca, IL: National Safety Council.

NIOSH. *Common hearing loss prevention terms.* Washington, DC: NIOSH. Retrieved May 24, 2006, from http://www.cdc.gov/niosh/hpterms.html.

NIOSH. *Do sound restoration hearing protectors provide adequate attenuation for gunfire noise?* Washington, DC: Author. Retrieved Dec. 27, 2006, from http://www.cdc.gov/niosh/topics/noise/pubs/presentations.html.

NIOSH. *Noise and hearing loss prevention: Hearing conservation program evaluation checklist.* Washington, DC: NIOSH. Retrieved May 24, 2006, from http://www.cdc.gov/niosh/topics/noise/workplacesolutions/hearingchecklist.html.

OSHA. Noise and health effects: Appendix I:A. Physics of sound. *OSHA Technical Manual.* Washington, DC: Author. Retrieved June 2, 2006, from http://www.osha.gov/SLTC/etools/construction/physics.html.

OSHA. (1983, Mar. 8). Occupational noise exposure. 29 CFR 1910.95. *Federal Register, 48*(46), 9776-9785. Washington, DC: Author. Retrieved June 3, 2006, from http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9735.

Plog, B.A., Niland, J. & Quinlan, P.J. (1996). *Fundamentals of industrial hygiene* (4th ed.). Itasca, IL: National Safety Council.

Rabinowitz, P.M. (2000, May 1). Noise-induced hearing loss. *American Family Physician, 61*(9), 2749-2756.

Schulz, T.Y. (2006, Summer). Age correction of audiograms. *CAOHC Update, 18*(2), 3-7.

Seidman, M.D. (1999, Winter). Noise-induced hearing loss. *Volta Review, 101*(1), 45-59.

Stephenson, C.M. *Choose the hearing protection that's right for you.* Washington, DC: NIOSH. Retrieved May 24, 2006, from http://www.cdc.gov/niosh/topics/noise/abouthlp/chooseprotection.html.

Sterrett, M.L. (2002, August). Keeping an ear to the ground: Tech solutions to hearing protection compliance. *Professional Safety, 47*(8), 46-48.

Suter, A.H. (1993). *Hearing conservation manual* (3rd ed.). Milwaukee, WI: Council for Accreditation in Occupational Hearing Conservation.

University of Washington Department of Environmental and Occupational Health Sciences. (2004). *Construction industry noise exposures: Operating engineers.* Seattle, WA: Author. 2, 7-10.

ASSE on Hearing Protection

ASSE offers resources to help SH&E professionals effectively manage their company's hearing protection programs.

Noise Control

This book covers what is required in the OSHA standards, the legal limits on noise, monitoring, an audiometric testing program, hearing protectors, workers' rights under OSHA and OSHA's 2002 recordkeeping requirements. (ASSE *Order #4403)*

ANSI/ASSE A10.46-2007, Hearing Loss Prevention for Construction & Demolition Workers

This standard establishes criteria for hearing loss prevention programs to be used for construction and demolition operations. Intended to help employers prevent occupational hearing loss among construction and demolition workers, it applies to all construction and demolition workers with potential noise exposures. *(ASSE Order #A10-46-2007-ecd)*