Engineering Controls for Occupational Noise Exposure

The Best Way to Save Hearing

Alice H. Suter, Alice Suter and Associates, Portland, Oregon

Despite significant advances in hearing protection technology, "Hearing Conservation Programs" are not an adequate substitute for engineering and administrative controls. Studies of small and medium companies have found clinically significant hearing losses in all age brackets. Several have found widespread and serious gaps in compliance with requirements such as audiometric testing, training, record keeping, and exposure measurement. These failures are particularly prevalent among small companies. Although opponents of requirements for engineering controls maintain that they are particularly difficult for small companies to implement, the per-worker costs of hearing conservation requirements for small companies are much greater than for large companies, and the use of engineering and administrative controls is likely to be more cost-effective than hearing protection devices (HPDs) for small businesses. Hearing protection devices can be effective in certain circumstances, but they are too often rejected for a variety of reasons – discomfort, unreliability, and the potential cause of safety hazards, especially among workers who have already incurred noise-induced hearing loss. HPDs can have an adverse effect on the ability to hear speech and warning signals and can seriously impact the ability to localize necessary signals.

The Existing Enforcement Policy should be Changed

The existing enforcement policy for the Occupational Safety and Health Administration's (OSHA, under the U.S. Department of Labor) general industry and construction noise standards has been in effect for 28 years. OSHA's Federal Register notice of October 19, 2010, described Commissioner Cleary's view being that "the majority's adoption of a cost-benefit test amounted to an unauthorized amendment of the standard" (75 Fed. Reg. 201, 64218). From the beginning, this policy was put forward without benefit of rule-making, and its legality has always been suspect.

Now in light of the dramatic change in the legal landscape, it is particularly relevant that OSHA withdraw the old policy. OSHA now appears to have a legal obligation to enforce the provision for feasible engineering or administrative controls as the first line of defense against hazardous noise exposures, at least those above a time-weighted average level of 90 dBA, without the necessity of a cost-benefit analysis. It is important for the public to understand that this is not a change in the noise standard, not a rule-making, but merely a return to the original enforcement practice and the literal and legal interpretation of the standard's requirement.

The Supreme Court has held that "feasible" means "capable of being done" and that cost-benefit analysis is not necessary, so the burden of compliance should be shifted away from the employee (and also from the OSHA compliance officer) and onto the employer. The intent of Congress in enacting the Occupational Safety and Health Act of 1970 was to place the burden on employers to provide a safe workplace for employees and not to put the burden on workers to protect themselves. Engineering and administrative controls are the responsibility of employers, and only in cases where they are infeasible, according to the court's definition, should hearing protectors be solely relied upon. This is not to say that employers should not provide hearing protectors and all other components of the program until engineering controls are successfully installed. Nor should they refrain from considering costs as they prepare plans for controlling excessive noise, but to quote a recent study of alternative interventions:

> *. . . it is important to keep in mind that from an ethical standpoint, no monetary values should be put on a reduction to exposure to health risks and improved health outcomes, because they should fall in the category of basic human rights.*
>
> — Lahiri, *et al.*, 2011

As a result of OSHA's announcement in October of 2010, there has been vehement protests by certain industry groups concerned that this policy interpretation will shut down businesses, cause jobs to be shipped overseas, and cost the nation's businesses billions of dollars in a time of deep recession. There are several reasons why these are over-reactions and predictions that would not be realized.

First, some industry sources have claimed that millions of jobs will be affected, since all noise *levels* higher than 90 dBA must be controlled, and it is true that many workers are exposed to noise *levels* over 90. However, the standard calls for noise reduction in cases where time-weighted average *exposures* exceed 90 dBA. Since most industrial settings involve time-varying noise, far fewer employees would be affected than if just noise *levels* were considered.

A second reason why this policy reinterpretation would have less impact than industry sources anticipate is that there are fewer jobs that would be affected than 30 years ago, due mainly to outsourced manufacturing. In 1981, OSHA estimated approximately 19% of the 5.5 million workers exposed to noise had time-weighted average exposures (TWAs) higher than 90 dBA, but the current figure is probably more like 10% (Driscoll, *et al.*, 2010).

OSHA's 1983 policy memo and its subsequent incorporation into the Industrial Hygiene Field Operations Manual has crippled the application of engineering noise control in U.S. industries, a point that has been brought out in a recent report by the National Academy of Engineering (NAE, 2010). Moreover, allowing employees' TWAs to exceed 100 dBA before corrective action is taken is extreme and contrary to the policies of other nations, both industrialized and developing, nearly all of which have adopted an 85-dBA permissible exposure limit (PEL) and a 3-dBA exchange rate (Suter, 2007).[1] Not only does this policy disregard the hearing health of American workers, it is an embarrassment to U.S. policy makers and health professionals.

Because noise is measured using a logarithmic scale (the decibel), a seemingly small 10-dB increment is in fact an increase of *10 times* the sound energy. In other words, 100 dBA is 10 times as intense as 90 dBA. By failing to enforce the requirement for noise control until the TWA reaches 100 dBA, OSHA perpetuates the misconception that exposures up to this point are not hazardous. As OSHA is widely regarded outside the professional community as an authority on safety and health, the agency sets an example that reverberates among the general public. These negligent safety practices are exported from the workplace into employees' homes, to their families, to peripheral fields (medicine, for example), and to the mainstream.

Importance of Saving Hearing

The importance of good hearing has been overlooked for the past several decades, as the fact attests that this is the only OSHA standard whose policy is to waive engineering and administrative controls. Since 1971, OSHA has publicly acknowledged in its guidelines that the 90-dBA PEL still allows significant risk of

[1] While the majority of other nations use an 85-dBA limit for engineering controls, some still use 90 dBA for engineering requirements and exposures of 85 dBA or below for the implementation of other aspects of the hearing conservation program (NAE, 2010). Nowhere are there allowances for TWAs above 90 dBA.

Background

In October of 2010 the OSHA announced that it would no longer abide by its "100-dB policy" and begin to enforce the requirements for engineering and administrative controls at exposures above 90 dBA, as required by the original noise standard. OSHA published a notice in the Federal Register declaring its intention of changing the current policy by redefining the word "feasible" as it relates to the noise standard as "capable of being done." The Agency did say that if a noise control remedy threatened an employer's viability (the capacity to remain in business), it would not be considered feasible. OSHA encouraged the public to comment on the proposed change with a deadline of Dec. 20th 2010, which was subsequently extended to March 21st 2011.

Within a few weeks of its publication, there was a firestorm of objection from major business associations, such as the U.S. Chamber of Commerce and the National Association of Manufacturers, claiming that the policy change was not needed and that it would have an adverse effect on jobs. These groups maintained that employees were sufficiently protected with hearing protectors and other elements of the hearing conservation program. They conveyed the impression to their members that OSHA would crack down on them immediately (an impossibility), that the policy applied to workers exposed to noise levels over 90 dBA, when in fact it's TWAs (averages not levels, resulting in far fewer overexposed workers). They also maintained that this was something new rather than something that had been an integral part of the noise standard since 1971. As a result of this intense pressure, OSHA withdrew its policy on January 19, 2011, stating that the process required "much more public outreach" and that they needed to examine other alternatives.

In this article, Dr. Suter responds to various objections to the attempt by OSHA to enforce its noise standard, 29 CFR 1910.95. These comments were submitted in March of 2011 to OSHA's docket #2010-0032.

impairment and that it is: "the upper limit of a daily dose which will not produce disabling loss of hearing in more than 20 percent of the exposed population" (DOL, 1971). NIOSH estimates that these limits will result in up to 32% of the exposed population incurring material impairment of hearing over the course of a working lifetime (NIOSH, 1998).

According to Helen Keller, it is worse to be deaf than blind, because blindness cuts you off from things while deafness cuts you off from people. Hearing loss impairs communication, the vital contact with others. It decreases the quality of life, and most importantly, it has an adverse effect on intimate relationships. Unlike vision problems, hearing impairment is not readily apparent. Professionals in occupational health tend to forget that individuals with noise-induced hearing loss have a greater handicap than one would think at first encounter. When hearing-impaired people are queried closely, and especially the spouses of those with hearing impairments, the nature of the handicap is seen as more serious and gives added impetus to the need for prevention.

The popular notion is that hearing impairment from noise is only a problem in a person's later years, but the truth is that it affects people throughout their work life. Even before a hearing loss becomes permanent, temporary hearing loss occurs. Workers come home with a hearing impairment and it affects their family life, even if their hearing seems to return to normal during the night. They may have difficulty communicating with their spouse or children, or hearing the radio or TV. They may also need a quiet period when first coming home from work due to fatigue and nervousness caused by the noise. Then, as permanent hearing impairment builds up, it is overlaid by temporary hearing impairment, which makes the handicap more severe. Workers exposed to high levels of occupational noise will tend to incur most of their hearing loss, at least in the high frequencies, within the first five to 10 years of exposure. Although the loss will progress with aging, it may begin at a relatively young age.

The impact of noise-induced hearing loss (NIHL) and the resulting handicap may be experienced in several areas of a person's life:

- Safety and communication at work
- Social and communication impacts at home with family and friends
- Self-esteem
- Problems relating to sounds in one's environment

These difficulties may apply to all levels of hearing handicap, even mild impairments.

Pioneering research on the impact of NIHL has been conducted by Hetú, *et al.* on Canadian workers (Hetú, *et al.*, 1987, 1988, 1990, 1993). The results of their studies elucidate the stigma of NIHL evidenced by the reluctance of workers to acknowledge difficulties, the psychosocial disadvantages experienced in social and family life, and the impact of hearing loss on intimate relationships. They indicate that hearing rehabilitation programs for workers with NIHL would be helpful, although such programs are rare.

A comprehensive study of the effects of NIHL at work was performed at NIOSH (Morata, *et al.*, 2005). The study involved collecting information from 31 workers with self-reported noise exposure and hearing loss, along with eight supervisors and program managers, through a series of focus groups. The results showed serious concerns about job safety, impaired ability to hear communication and warning signals, especially when using hearing protection devices (HPDs), impaired ability to monitor the sounds of machinery and other environmental sounds, concerns about future quality of life, and concerns about future employability. Similar perceptions were voiced by supervisors and, to a lesser extent, by hearing conservation program managers. The adverse effects of HPDs on communication and the ability to monitor the environment were among the top concerns, as were safety and the ability to hear warning signals. Workers frequently stated that they had to remove HPDs to communicate, exacerbating the risk of hearing loss.

Overemphasis on Nonoccupational Noise Exposure

Another factor that industry groups have raised in defense of the current OSHA practice is the contribution of noise exposure away from work, such as personal listening devices and mowing the lawn. This concern is often used as an excuse to do nothing about occupational exposures, which are almost always more intense than the nonoccupational ones. There is no denying that recreational noise, such as habitual exposure to loud music, weapons, and firecrackers can be hazardous to hearing, but these exposures are usually occasional, while workplace exposures continue on a daily basis for decades.

Although there seems to be a common perception that nonoccupational exposures are increasing, results of population studies show little change in the hearing of young adults over recent decades. In a Swedish study of 611 boys, the authors conclude that 18-year-old conscripts had hearing no poorer in 1998 than 29 years earlier (Augustsson and Engstrand, 2006). In the U.S., Rabinowitz examined baseline audiograms of 2526 beginning employees between 1985 and 2004 and found that the rate of audiometric "notches" remained consistent over the 20-year period (Rabinowitz, *et al.*, 2006).

Some studies have measured actual off-work noise exposures of workers. In recent studies of construction workers (Neitzel, *et al.*, 2004a and 2004b), the authors found that average exposures away from work tended to be below 80 dBA. They found that 79% of the construction workers measured showed average (calculated with the 3-dB exchange rate) off-work exposures below 70 dBA (Neitzel, *et al.*, 2004a). In a longitudinal study of construction apprentices, they found an average nonoccupational exposure of 78 dBA (Neitzel, *et al.*, 2004b).

These results are consistent with the mean 24-hour average exposure level of 78 dBA measured earlier by Berger and Kieper (1994) on 20 subjects, most of whom were nonoccupationally exposed. However, Neitzel and his colleagues did not include

noise levels from firearms because of a lack of consensus on the method by which impulse noise should be included in the resulting measurement. They concluded that for shooters, who comprised 22% of the apprentices, the average nonoccupational exposure level would be higher.

These results should be weighed against the proposed policy change, which applies only to the control of noise exposures above a TWA of 90 dBA and is measured using the less protective 5-dBA exchange rate. In other words, the environmental exposures reported above would be even lower if they were measured using the 5-dBA exchange rate, and they are all well below the level at which engineering or administrative controls would be required by OSHA.

Hierarchy of Controls

As noted above, the noise standard is the only OSHA standard in which engineering and administrative controls are not given the first priority. In the hierarchy of control solutions, engineering controls hold the primary place, because they reduce or eliminate hazards in the most reliable manner. They also reduce the hazard at a collective rather than an individual level. Noise control predictably affects the environment of all persons in the area, while personal protective solutions perform variably across workers. In other OSHA standards, as well as in the European Community, the UK, Australia, New Zealand, and most other nations, engineering noise control takes primary place.

As an example, the new draft Australian Code of Practice outlines the hierarchy as follows (Safe Work Australia, 2010):

- Eliminate the source of noise as far as reasonably practicable: cease the use of a noisy machine; change the way the work is carried out; or refrain from introducing the hazard into the workplace.
- Substitute quieter plant or processes: use quieter plant or processes; modify the plant or process to reduce noise; or isolate the source of noise from people by using distance, barriers, enclosures, and sound-absorbing surfaces.
- Implement administrative control measures: organize schedules so that noisy work is done when few workers are present; notify workers and others in advance so they can limit their exposure; provide quiet areas for rest breaks; limit time workers spend in noisy areas.
- Provide workers with personal hearing protectors: select appropriate devices; maintain, repair, and replace as necessary; provide information, instruction, and training, and ensure that devices are used properly.

Barriers to Noise Control

As the report by the National Academy of Engineering has demonstrated, the major barrier to the use of engineering noise control in the U.S. workplace is the absence of regulatory requirements and OSHA's lenient 100-dBA policy. A decade ago, a conference on workplace controls reached the consensus that "existing, proven technology exists and is readily available to control worker exposure to hazardous noise. . . ." (NIOSH, 1998b). But these noise control solutions are little implemented in the workplace.

One of the most common barriers is the misperception that noise control is too difficult and too expensive. Contributing to this misunderstanding is a lack of coordinated dissemination of noise control information. Although many evaluations and case studies of noise control solutions have been published in the professional literature, there is no central repository of searchable information readily available to worksite personnel in the U.S. As a result, the range of available solutions is wider than what is actually implemented.

Another significant barrier in reducing noise is the lack of clear, correct, and comprehensible noise emission information for equipment. In Germany, the Blue Angel labeling program has assisted buyers in identifying quiet equipment (www.blauer-engel.de/en/blauer_engel/index.php). "Buy quiet" programs exist elsewhere in Eurpoe (NAE, 2010) and in the U.S. at NASA (Cooper and Nelson, 19196). They have been promoted by NIOSH and recommended by professionals in acoustics (Bruce 2009; Anderson, 2011) as a sensible and efficient means of reducing hazardous noise exposures.

Lack of trained acoustical engineers is also a barrier to accomplishing the extent of noise control needed in industry. The serious lack of academic training programs in acoustics has resulted in engineers graduating with little or no knowledge regarding noise control. Dissemination of existing noise control information would also facilitate incorporation of noise abatement techniques into engineering training programs, as well as assist current engineers who are assigned engineering noise-control responsibilities.

Although noise control in industrial environments has not been as widely implemented as it could be, successes in other venues can serve as a guide. Aviation, defense, and mining have all achieved substantial success in reducing noise levels. These accomplishments have been attributed to the following crucial factors (Bruce and Wood, 2003):

- Recognition of the need for control based on the prevalence of noise-induced hearing loss
- Established technologies for reducing noise
- Political will to reduce noise levels
- Demonstration of successful solutions
- Collaboration across interested parties (government, industry, etc.)

Several of these components for success already exist in the general industrial sector. Efforts to increase the recognition of need and improve collaboration to disseminate existing knowledge would be enhanced by greater political will.

Faulty Perception of the Decline in Hearing Loss

The apparent decrease in reportable hearing loss mentioned by several groups opposed to OSHA's policy revision can be explained by several factors. One fairly obvious factor could be the loss of jobs in manufacturing due to the recent recession and the consequent decrease in the total number of workers in manufacturing.

The numbers reported by the Bureau of Labor Statistics are already a significant underestimate of the workers actually losing their hearing. Hearing losses do not become recordable until they have reached an average level of 25 dB in relation to audiometric zero, and only then if they have suffered a significant threshold shift (STS), referred to as a "standard" threshold shift (a long-standing misnomer). So the level of hearing loss already allowed is considerable.

But another factor is also operating: once a worker has incurred a persistent STS, the baseline audiogram is then revised to reflect the new hearing threshold levels so as to avoid identifying the same STS each year on the annual audiometric test. Although this is a convenience to service providers and employers, it masks the progression of hearing loss in that another STS would be required before the follow-up requirements are triggered, and the loss is considered recordable. So older workers, the ones remaining in the workforce after the more recent employees have been laid off, are less likely to show additional recordable losses because they have already suffered significant shifts in hearing.

A third, and probably the most salient reason for this decline in recordable hearing losses is that employers have learned how to avoid reporting hearing loss on the OSHA 300 Log. If a professional reviewer of audiograms determines that a loss is work related, the employer will find another who will determine otherwise, or just neglect to record it. It is common knowledge that occupational injuries and illnesses are under-reported due to economic and other kinds of incentives (Alexander, 2008; Elgin, 2010; Lin et al., 2010), and that this is the reason why OSHA launched its National Emphasis Program.

A survey of members of the National Hearing Conservation Association (NHCA) revealed a substantial portion of the respondents were concerned that true cases of work-related hearing loss were being under-reported (Wells, 2006). Audiologists and other hearing conservation providers regularly report pressure from their clients not to make determinations that a hearing loss is work related. Some companies have threatened to take their business elsewhere if a professional reviewer would make any determination of work-relatedness. Supervisors, managers, and health care workers have reported the existence of incentives, both positive and negative, not

to make determinations of work-relatedness. All of this conspires to make the BLS data for hearing loss virtually meaningless.

Hearing Conservation Programs Too Often Ineffective

Even before the current economic downturn, companies have been asking their employees to do more with less. Especially recently, hearing conservation service providers report that many employers provide insufficient time for individual attention to workers who are losing their hearing. There is no time for counseling, observing the way workers fit their HPDs, or checking to see if another HPD would be more effective. Most service providers are not given time to explain the audiogram to workers and point out hearing shifts that are beginning but that do not yet qualify as an actual STS. A few companies have purchased fit-check devices to assess the attenuation of HPDs on the job, but do not always make the time to use them.

As mentioned above, the practice of revising the baseline audiogram has practical benefits for the employer and service provider. But it has the adverse effect of withdrawing attention from the progression of hearing loss until a whole new STS occurs, moving the hearing impairment into a more serious category of hearing handicap. If used properly and followed with adequate interventions, audiometric testing can be a useful tool to prevent minor hearing losses from becoming major ones. However, professionals from other nations sometimes advocate against it, because it is so often used only to document the progress of hearing loss rather than preventing it. This is why the late Canadian researcher Raymond Hetú called it "medical voyeurism." Too many U.S. employers believe that they are "saving" hearing by providing audiometric testing programs and then failing to take adequate intervention. This is why members of the NHCA continue to see rates of STS at 5-7% *annually*.

It is an unfortunate fact that hearing conservation programs (HCPs) are often inadequate or even absent in noisy industries. A study of hearing conservation programs in small and medium-sized companies in the state of Washington found clinically significant hearing losses in all age brackets over 36 years (Daniell, *et al.*, 2002). In a larger, follow-up study, the authors documented the efforts of company managers to provide HCPs to employees exposed to average levels of 85 dBA and above (Daniell, *et al.*, 2006). Most of these companies had conducted noise measurements, but most kept no records. The use of noise control was low in all industries, although 51% reported that they had made some kind of change to reduce noise. But only 10% reported that they had measured the noise levels afterward. All of the companies provided employees with HPDs, but only 34% had policies requiring their use. Training in HPD fitting was provided by 63% of the companies, and 74% conducted annual audiometric testing. When employees exhibited an OSHA STS, only 62% provided written notification, and a mere 37% provided retraining.

A large study of an occupational hearing loss surveillance system in Michigan showed that some 46% of individuals with noise-induced hearing loss did not receive regular audiometric testing (Reilly, *et al.*, 1998). Lack of adequate HCPs was particularly characteristic of companies with less than 100 employees, although 30-47% of the larger companies still had not provided audiometric testing in the 1990s.

Hearing conservation programs are particularly lacking in small companies, where resources and health personnel are scarce, and yet noise-induced hearing loss can still be a significant risk. The per-worker cost of HCPs will be much greater than for larger companies, which benefit from economies of scale. Ironically, while the economic hardship of small business appears to be a major political force against requiring engineering noise control, the use of engineering controls is likely to be more cost-effective for small businesses than the other elements of the hearing conservation program. The solution upon which much of small business has relied is to do nothing.

Over-Reliance on HPDs

There is no doubt that hearing protection devices (HPDs) can be helpful in reducing the amount of sound energy that reaches the ear. They can be a very useful resource as an adjunct to engineering and administrative controls and other elements of the hearing conservation program. But as most professionals in the hearing health field would admit, they are not the final solution to the problem of hazardous noise exposure. There are too many disadvantages, and their use is insufficiently applied and monitored by employers.

HPDs are often rejected by workers for many reasons, such as discomfort, improper sizing, hygiene, and the inability to hear necessary communication and warning signals. Studies have shown that the percentage of workers who wear HPDs can vary from 0% to more than 49% (Suter, 2002). One study found that 34% of workers exposed to noise *never* used hearing protection (Tak, *et al.*, 2009). Despite the requirements of the hearing conservation amendment, workers are seldom given adequate training in the selection, fitting, use, and care of these devices, and in many instances are not given a choice of type or size. Hearing protector comfort is often neglected, although the wearability of an HPD may be the single most important factor in its consistent use. HPDs that are not comfortable or sized appropriately will not be worn effectively if at all. Moreover, reliance on HPDs puts the burden on employees to protect themselves rather than on the employer. It is a form of voluntary compliance on the part of the company.

Federal regulations issued by the EPA mandate that hearing protectors be labeled with a noise reduction rating (NRR), which was designed to predict the amount of protection 98% of wearers would achieve by wearing the devices correctly (EPA, 1979). However, research has shown that fewer than 5% of workers actually receive the protection predicted by the NRR (Berger, *et al.*, 1994). It has been the tendency of employers to select HPDs with the highest attenuation, but studies have shown poor predictability between the magnitude of the NRR and the amount of attenuation achieved in actual field use. This practice also leads to the possibility of overprotection, causing workers to receive so much attenuation that they are unable to hear important communication and warning signals. Hearing protectors should not reduce noise levels to below 70 dBA (European Standard EN 458, 1993), because overprotection can cause workers to feel isolated from their environment and can impede communication, with the result that workers will remove their protectors (Williams and Dillon, 2005).

Employers and workers alike are often misled in thinking that wearing a protector for part of the time will be sufficient, but this is not the case. For example, a hearing protector with an NRR of 30 and removed for only 10% of an eight-hour shift causes a reduction in the effective attenuation to less than 10 dB (Arezes and Miguel, 2002).

Many workers are anxious about their ability to hear important communication and warnings on the job, such as a call from a colleague to "watch out" or the sound of a mal-functioning machine (Morata, *et al.*,2005). These concerns are justified.

Noise, Hearing Protectors, and Safety

The fact that noise can interfere with or mask speech communication and warning signals would seem to be common sense. While some industrial processes can be carried out very well with a minimum of communication among workers, other jobs rely heavily on speech communication, auditory monitoring of the equipment or environment, and the identification of warning signals. It is also common sense that noise can interfere with safety, and although it is a difficult and complex area in which to obtain data, increasing attention is being given to this problem in recent research.

Studies have implicated noise and hearing loss in a large percentage of the injuries among shipyard workers (Moll van Charante and Mulder, 1990) and other types of jobs, such as equipment operators and laborers (Zwerling, *et al.*, 1997). There have also been numerous anecdotal reports of workers who have gotten clothing or hands caught in machines and have been seriously injured while their coworkers were oblivious to their cries for help. Recently, related studies (Choi, *et al.*, 2005) have found that hearing loss and the occasional use of hearing protectors were significantly associated with the risk of injury among agricultural workers.

Researchers at Michigan State and Wayne State Universities have undertaken an epidemiological surveillance system for workplace

fatalities, a portion of which is to assess the role of noise and hearing impairment in the identified fatalities (Mich. State Univ., 2000). The research team notes that being struck by an object or caught or compressed by equipment or collapsing material accounted for 20% of the fatalities, the second leading type of fatal events in Michigan, where noisy manufacturing is a major industry. They also note that a number of studies suggest a relationship between noise and hearing impairment to injuries and fatalities in the workplace. Unfortunately, in Michigan and elsewhere in the U.S., OSHA inspections of workplace fatalities do not investigate the role of noise as a contributing factor.

Much useful information about the effects of industrial noise on workers has been gathered through the large Israeli study known as the CORDIS study (Melamed, *et al.*, 1992). Some 2,368 workers from industries such as textiles, metalworking, and food products were divided into noise exposure categories of low (<75 dBA), moderate (75-84 dBA), and high (≥ 85 dBA). The authors found that higher noise levels were associated with increased accidents and absences for both male and female workers, and that accidents increased by nearly 50% for both sexes at high noise levels compared to low noise levels.

Another problem increasingly recognized by professionals in hearing conservation and occupational safety is that HPDs can interfere with the perception of speech and warning signals. This is particularly true when the wearers already have hearing losses. Studies show that HPDs usually have an adverse effect on speech communication when the listener's hearing threshold levels exceed an average of about 30 dB at the frequencies 2000, 3000, and 4000 Hz, or when the environmental noise levels fall below about 85 dBA. Sound localization is often adversely affected, particularly in the case of earmuffs, which drastically impede localization in the vertical plane (Suter, 1992).

A study of sound source identification while wearing earmuffs led Abel and Paik (2005) to conclude that "earmuffs should not be used in situations where the perception of the direction of hazard is a concern." Recent investigations of the effects of HPDs on localization have concentrated on the effects of double protection (muffs over plugs), indicating severe disruptions relative to the open-ear condition (Abel and Odell, 2006; Brungart, *et al.*, 2003; Simpson, *et al.*, 2005). These finding raise serious safety implications for policies and regulations that require double protection in high noise levels.

Council Directive 89/656 of the EEC requires employers to perform an assessment of personal protective equipment and the risks that it may introduce. Further information is available for European Standards EN 458 (1993) on hearing protectors and EN 457 (1992) regarding auditory danger signals and other European standards (Liedtka, 2005; Toppila, *et al.*, 2009).

Research has shown that people who wear HPDs often use lower voice levels than they would in the open-ear condition when communicating with co-workers, causing their speech to be less intelligible in a noisy background, especially when the listener also wears HPDs (Hörmann, *et al.*, 1984; Howell and Martin, 1975; Tufts and Frank, 2003).

Several kinds of special HPDs have been developed to enhance speech communication and warning signal detection during noise exposure and to permit it during quiet intervals. Speech intelligibility testing indicates performance advantages under some conditions but not others. Although these devices can be helpful, their costs can be prohibitive, ranging from up to $70 for communication earmuffs to more than $1000 for the more sophisticated versions. It is doubtful that most employers, especially in small companies, would make these kinds of investments as part of their hearing conservation programs.

All of this information supplies ample evidence that hearing protection devices are not the solution to the problem of occupational noise exposure. It is as if we are encouraging workers, especially those who have already suffered noise-induced hearing loss, to become additionally hearing impaired on the job and therefore at risk of becoming safety hazards themselves. Controlling the noise by engineering means is the only satisfactory way to deal with this situation.

Economics of Noise Control

Industry and trade association representatives have made much of the assumed costs of controlling noise to the 90 dBA level. Assuming that the use of the term "noise level" instead of "exposure level" or "average exposure level" is not a deliberate misrepresentation, it is important for legislators, regulators, and the general public to understand that far fewer jobs entail *average exposure levels* above 90 dBA than noise *levels* above 90 dBA. And as stated previously, those with exposures above 90 dBA are a relatively small portion of the noise-exposed population in general industry.

According to certain industry representatives, compliance by engineering controls with a 90-dBA TWA will cost the nation's businesses billions of dollars, businesses will be closed, and more jobs will be sent overseas. According to Michael Frederich, president of MCM Composites Corp.: "The free market is providing all the necessary incentives" to protect worker safety (BNA, 2011). If that were really the case, there would be no need for the Occupational Safety and Health Act, and the nation may as well return to the days of carnage in the workplace.

The marketplace has never provided sufficient incentives to control occupational hazards, just as the nation has not been able to function without a tax system and traffic signals. One reason for this kind of backlash to OSHA proposals is that the public is unaware of the economic benefits of controlling occupational hazards. The Europeans have been much more successful at controlling occupational noise than we in the U.S. And aside from a recent insufficiently regulated financial mess, they are more prosperous, and their factories are more modern and often more efficient.

Typical of the overstatement of the economic cost of regulation is a report commissioned by the Small Business Administration's Office of Advocacy, which sets the total cost of all government regulations as $1.75 trillion (Crain and Crain, 2010), while the Office of Management and Budget (OMB) sets the annual regulatory costs from $62-$73 billion.[2] Moreover, the OMB set the total *benefits* derived from these regulations ranging anywhere from $153 to $806 billion! In other words, regulations can be considered a plus for the nation's economy (Shapiro, 2011), putting forward the concept that regulations can actually be "job creators" rather than the currently overused mantra, "job killers."

A recent study of the economic costs and benefits of implementing a noise control program has been conducted by U.S. researchers in conjunction with the Singapore Ministry of Manpower to test the application of a net-cost model on workplace interventions (Lahiri, *et al.*, 2011). In addition to the costs of noise controls, the model includes costs avoided, such as productivity losses and medical care, as well as gains from the employer's perspective.

Four case studies are presented with varying degrees of economic benefits to the employer. The authors conclude that although cost-benefit analysis may not be a requirement (and workers should be protected for humanitarian reasons, regardless), it can be helpful to determine whether there is a "business case" for noise control investments. Such a model can also help companies prioritize their activities when developing a noise control plan. The results showed that one company achieved a significant enhancement in productivity, and each of the companies gained lost work time and benefited from health costs avoided. Two of the companies showed positive benefit-to-cost ratios (one of them dramatic), and two showed slightly more cost than economic benefit, although the per-worker cost of the intervention was small. These examples are not necessarily reflective of all the costs, or particularly all the benefits in a U.S. scenario, but they provide a potentially useful model.

When OSHA revised its hearing conservation amendment to the noise standard in 1983, the agency estimated the average cost per worker for compliance with all parts of the program (except for engineering and administrative controls) as $41 per worker per year (OSHA 1983). Those costs have proved to be underestimates.

[2] Analysis of the Crain and Crain report suggests that it is the "result of secret calculations, an unreliable methodology and a presentation calculated to mislead." (Shapiro, 2011)

In 1992 OSHA's Philadelphia Regional Office estimated an annual average of $86 per worker, but the number varied according to the size of the establishment and the number of workers overexposed (Phila. OSHA, 1992). The instruction from OSHA's Office of Technical Support gives a table by which to adjust the per-worker cost depending on the total number of employees in the HCP:

- A company with 250+ noise-exposed employees would have no adjustment
- 50-99 employees in its HPC would need to increase the cost by 8%
- 20-49 workers would need to increase by 75%
- 1-19 employees by 125%

So the cost of an HCP to a small company would be about $194 per employee per year.

It appears that the 1992 cost estimates in the Philadelphia Regional Office are underestimated by today's standards. A recent survey of 13 plants yielded an estimate of $310 per worker per year (Driscoll, 2011). These plants were part of a large multinational company with annual revenues of $20 billion; each of the 13 selected plants had about 200-300 employees. The survey included many of the costs that are not necessarily obvious when considering a hearing conservation program. Not only did it include noise assessment, employee education and training, hearing protection programs, audiometric testing, audiometric data analysis, and recordkeeping, but the estimates also included audiometric follow-up and retests, recordability determination, training materials, calibration, employee time away from work, HCP administrative time, maintenance of acoustical instrumentation, space allocation, certification expenses, and workers' compensation costs. At a recent conference of the American Industrial Hygiene Association, Driscoll surveyed 48 attendees with a questionnaire that included most of these same items and asked participants to estimate the costs of the HCPs they administered or were involved in. The estimates ranged from a low of $300 to a high of $1200 per worker per year, with a median of $350 (Driscoll, 2011).

If the median of $350 per employee per year is subject to the 125% adjustment recommended by the Philadelphia Regional Office, the cost for small businesses would be more like $788 per employee per year. This could help explain why small businesses so often have no hearing conservation program at all, or if they do, it is only a gesture toward what is actually required in OSHA's hearing conservation amendment and likely to be completely ineffective. Too often simple engineering controls would be available and affordable, but because there is no incentive to use them, they are overlooked.

The project goal of the company for which Driscoll consulted was to implement a systematic noise control program that would reduce and maintain noise exposures to the level where an HCP would no longer be necessary; so it was important to quantify as accurately as possible the costs of the HCP as well as the necessary engineering controls. Although most of the average noise levels were not above 90 dBA, the company wanted to reduce and maintain levels to below 80 dBA. The estimated return on the investment, taking both engineering and HCP costs into account, was 4.79 years (Driscoll, 2011).

Socioeconomic Costs

All of the above expenses are strictly monetary ones to be borne (or saved) by the companies, without consideration for the expenses borne by workers and by society if hazardous noise is not controlled. For example, binaural hearing aids cost from $2000 to $8000 and need to replaced every three to four years. Earmuffs or headsets designed for communication as well as protection against noise are not usually provided by employers and can cost up to about $1000. The costs of medical visits are often left to the worker as well. To the extent that employers would assume these expenses, the costs of hearing conservation programs would be even greater and provide added incentive to control the exposure through engineering means.

The cost of worker compensation awards has often been cited as a reason to control noise. In the preamble to the hearing conservation amendment, OSHA stated: "workers' compensation payments are transfer payments from employers to impaired workers. The true social cost is the incidence of occupational hearing impairment and the various other ill effects of noise; the true social benefit is the reduction in the number of hearing impairments and ill effects" (OSHA, 1981, p. 4116). Benefits from noise reduction that the agency recognized but was unable to quantify were the extra-auditory health benefits, reduced medical costs, annoyance or aversion to noise and to the use of hearing protection devices, and worker productivity.

Although they represent the low end of the valuation of human hearing, the total costs of worker's compensation are not negligible. In Oregon, workers' compensation claims for noise-induced hearing loss totaled $6.9 million between 1984 and 1998, with an average settlement of about $5,000 (McCall and Horwitz, 2004). Daniell, *et al.*, (2002) estimated compensatory costs for work-related hearing loss in the State of Washington as $45.7 million for the year 1998, with an average settlement of $7,180 per worker.

Awards resulting from civil suits, the schedules used by the Veterans Administration and the U.S. Department of Labor for federal employees, as well as other types of valuations result in considerably higher estimates. The U.S. Veterans Administration reported compensation costs for service-connected hearing loss and tinnitus exceeded $1.2 billion in fiscal year 2006; an additional $288 million is spent annually on hearing aids and audiological services for affected veterans (Saunders and Griest, 2009).

However, economic costs are not the only costs borne by society as the result of occupational hearing loss, and it can be argued that the financial burden is not the most significant. Ruttenberg (1997) points out that some dictionary definitions of cost focus on pain, suffering, sacrifice, and distress rather than monetary outlay, and the benefit in terms of value and welfare rather than financial savings. To understand the true costs of occupational hearing loss and the benefits of prevention, one must include long-term costs and benefits (beyond the quarterly or annual accounting summary), indirect costs and benefits (such as loss of income or reduced absenteeism), positive and negative secondary effects (such as extended equipment life or creation of new markets), and quality of life issues.

Noise exposure and occupational hearing loss have substantial consequences for society as a whole. These consequences include the economic costs associated with diagnosis, treatment, rehabilitation, and compensation of affected workers and the social costs of disease burden reflected by reduced quality of life, disability, and suffering (Alleyne l, *et al.*, 1989; Access Economics, 2006). They also include other costs of noise exposure, such as accidents and absenteeism, most of which have been inadequately documented in the U.S. but have been studied more extensively elsewhere in the world (Melamed, *et al.*, 1992; Toppila, *et al.*, 2009).

Controlling workers' exposures can have other benefits for companies that utilize engineering controls. For example, Ruttenberg (1997) cites examples of simple noise control measures that not only reduced worker exposures but also extended the life of the equipment by reducing vibration. This type of secondary advantage may be figured into the company's analysis of the benefits obtained from its noise control investment.

In a wider sense, noise reduction does not affect just the individual company that implements these programs. New businesses are created to meet evolving safety needs, stimulating economic growth in the broader community (Ruttenberg, 1997). Development of new technologies can find applications beyond noise control. Scientific advances could generate public attention, resulting in awareness of noise hazards outside the workplace and an overall reduction in hearing loss. On the negative side, payment of unnecessary damages can stifle a company's competitiveness, reducing employment and removing wealth from the community (Atherley, 1989).

Positive Experience with Noise Control

Although they rarely appear in the popular press, there are several examples of positive experiences with engineering noise control. Both California and Washington, which are "state-plan" states, have been using the original interpretation of the word

"feasible" with respect to engineering noise control and have no experience of companies being forced to close or to lose jobs because of their enforcement efforts.

Federal OSHA may, as Cal/OSHA does, accept alternative abatements, lower the penalty, or provide for long-term compliance periods so that costs may be amortized in cases of financial difficulty on the part of employers. Several California legal decisions that address issues of feasibility and effectiveness provide the framework under which Cal/OSHA enforces the requirements for engineering controls. These decisions could be helpful to Federal OSHA. They are: Golden State Engineering, Erickson Lumber Co., Oakland Tribune, Latchford Glass, and Delco Remy. The Golden State decision quoted the appeals board, stating that "…injury to an employee's hearing must be recognized as important as the loss of a limb or other disabling injuries" (Donaldson, *et al.*, 1987). Federal OSHA should investigate the experiences in these states as well as in North Carolina and other state-plan states.

Large U.S. and multinational companies such as Alcoa (Dixon-Ernst, 2011), Ford Motor Company (Lick, 1999) and General Motors, among others, have incorporated engineering noise control into their hearing conservation programs for many years. Sometimes even small companies, such as a dairy farm in Bangor, Maine, has taken pains to control all of its sources to below 90 dBA and many to below 85 dBA (Barry, 2011). Such measures are not beyond the capabilities of conscientious employers. NIOSH recently initiated a program called the "Safe-in-Sound" award to recognize companies that have successfully controlled their problems of hazardous noise. Two companies have provided outstanding examples: The Pratt & Whitney Corp. (NHCA, 2009) and Shaw Industries (NHCA, 2011). Each company included its staff in implementing and maintaining controls and willingly shared its successes with other branches of the company and attendees at the NHCA's annual meeting. While this kind of openness is rare in the U.S., there is much experience to be gained from other nations, such Australia, the UK, and others in Europe.

One consequence of the apparent shortage of noise control solutions in the U.S. is the reluctance of companies to share their successes openly. This does not seem to be as great a problem in other nations, where government and other organizations have stepped in. For example, organizations in Australia, such as the National Occupational Health and Safety Commission and Work Safe Australia disseminate all kinds of information and databases on noise control solutions, guides for noise management at work, reports on designing for quiet, and buy-quiet programs. The health and safety executive of the UK puts out booklets on reducing noise at work, noise in construction, and buying new machinery. The Workers Compensation Board of British Columbia has developed reports on noise control.[3] A program conducted by the Swiss National Accident Insurance Fund (SUVA) provides assistance for small businesses in assessing and controlling noise hazards (Hohmann, 2008; 2009).

Summary

There is ample evidence that OSHA should continue with the process of returning to its original policy on enforcing the engineering and administrative control requirements of its noise standards. Twenty-eight years is too long for American workers to have been the subjects in what has been largely a failed experiment. Noise-induced hearing loss is still too prevalent in American workplaces as the attempts at "hearing conservation programs" have proven inadequate. Hearing protection devices are neither an efficient nor a humane replacement for eliminating the noise hazard and should once again be allotted their proper place in the control hierarchy. Europe, Australia, and many other nations are far ahead of the U.S. both in their standards and criteria, and in their success at controlling noise through engineering means. The practice of American companies to market quieter equipment to their European clients and noisier versions within the U.S. is a disgrace.

Noise control solutions are readily available for many exposure conditions exceeding 90 dBA, and where challenges arise, OSHA can work with employers to develop reasonable abatement plans. Programs within OSHA already exist to do just that. OSHA should also work with NIOSH, the NAE, and other agencies and organizations to facilitate the dissemination of noise control materials and solutions to managers, professionals, and employee groups.

[3] These materials are included in a report and packet developed on contract to Jim Maddux of OSHA's Office of Safety Standards, Feb. 7, 2001. Although they are now 10 years old, they still contain useful information and, more importantly, have probably been succeeded by materials and information that is more contemporary.

References

Abel, S.M., Odell, P., 2006. Sound attenuation from earmuffs and earplugs in combination: Maximum benefits vs. missed information. *Aviat. Space Environ. Med.,* 77(9):899-904.

Abel, S.M., Paik, J.E.. 2005. Sound source identification with ANR earmuffs. *Noise Health,* 7(27):1-10.

Access Economics. 2006. *Listen Hear! The Economic Impact and Cost of Hearing Loss in Australia.* Access Economics Pty Ltd. Available online at www.audiology.asn.au/pdf/ListenHearFinal.pdf. Accessed March 23, 2009.

Alexander, A., 2008. Doctors feel push to downplay injuries. *Charlotte Observer,* 4-19-08.

Alleyne, B.C., Dufresne, R.M., Kanji, N., Reesal, M.R., 1989. Costs of workers' compensation claims for hearing loss. *J. Occup. Med*., 31(2):134-138.

Anderson, R.R.. 2011. Application of engineering controls to reduce industrial employee noise exposure. Presentation to the National Hearing Conservation Association, annual meeting. Mesa, AZ, 2-25-11.

Arezes, P.M., Miguel, A.S., 2002. Hearing protectors acceptability in noisy environments. *Ann. Occup. Hyg.*, 46(6):531-536

Atherley, G., 1989. Prevention of occupational deafness: A coming crisis? *J. Occup. Med*., 31(2):139-140.

Augustsson, I., Engstrand, I., 2006. Hearing ability according to screening at conscription: Comparison with earlier reports and with previous screening results for individuals without known ear disease. *Int. J. Pediatr. Otorhinolaryngol,* 70(5):909-13.

Barry, J., 2011. Personal communication via email.

Berger. E., Kieper, R., 1994. Representative 24-hour Leqs arising from a combination of occupational and nonoccupational noise exposures. *J, Acoust, Soc, Am.*, 2890.

Berger, E.H., Franks, J.R., Lindgren, F., 1994. International review of field studies of hearing protector attenuation. *Proceedings of the 5th International Symposium on the Effects of Noise on Hearing*, Gothenburg, Sweden.

Bruce, R.D., 2009. A new approach to noise control in the workplace. *Proceedings of INTER-NOISE 09.* The 22009 International Congress and Exposition on Noise Control Engineering, Ottawa, Ontario, Canada.

Bruce, R.D., Wood, E.W., 2003. The USA needs a new national policy for occupational noise. *Noise Control Eng. J.*, 51(3):162-165.

Brungart, D.S., Kordik, A.J., Simpson, B.D., McKinley, R.L., 2003. Auditory localization in the horizontal plane with single and double hearing protection. *Aviat. Space. Environ. Med.,* 74(9):937-46.

Choi, S.W., Peek-Asa, C., Sprince, N.L., Rautiainen, R.H., Donham, K.J., Flamme, G.A., Whitten, P.S., Zwerling, C., 2005. Hearing loss as a risk factor for agricultural injuries. *Am. J. Ind. Med.,* 48(4):293-301.

Cooper, B.A., Nelson, D.A., 1996. A "Buy Quiet" program for NASA Lewis Research Center: Specifying low equipment noise emission levels. *Proceeding of NOISE-CON 97.* The 1997 National Conference on Noise Control Engineering. Univ. Park, PA, June 15-17, 1997.

Crain, N.V., Crain, W.M., 2010. The regulation tax keeps growing. *Wall St. J. Opinion,* 9-27-10.

Daniell, W.E., Fulton-Kehoe, D., Cohen, M., Swan, S.S., Franklin, G.M., 2002. Increased reporting of occupational hearing loss: Workers' compensation in Washington State, 1984-1998. *Am. J. Ind. Med*., 42:502-510.

Dixon-Ernst, C., 2011. Thirty years of the OSHA hearing conservation; An industry perspective. *36th Annual Hearing Conservation Conference.* National Hearing Conservation Association. Feb. 24-26. Mesa, AZ.

DOL. 1971. *Guidelines to the Department of Labor's Occupational Noise Standards for Federal Supply Contracts.* U.S. Dept. of Labor, Bureau of Labor Standards, Washington DC.

Donaldson, E.W., Harrington, L.A., Monagan, M.R., 1987. In the matter of the appeal of Golden State Engineering, Inc., Docket no. 85-R3D4-1231. 9-21-87.

Driscoll, D., Neitzel, R., 2011. Personal communications via email.

Driscoll, D., 2011. One company's game plan for eliminating the need for hearing conservation. Presentation to the National Hearing Conservation Association, annual meeting. Mesa, AZ, 2-25-11.

Elgin, B., 2010. Caution: Stats may be slippery. *Business Week.* 3-9-10.

EPA. 1979. Noise labeling requirements for hearing protectors. Environmental Protection Agency, *Fed. Reg.*, 44(190), 40CFR Part 211, 56130-56147.

European Standard EN 458.1993. *Hearing protectors – selection, use, and maintenance.*

Hetu, R., Jones, L., Getty, L., 1993. The impact of acquired hearing impairment on intimate relationships: Implications for rehabilitation. *Audiology* 32:363-81.

Hetu, R., Lalande, M., Getty, L., 1987. Psychosocial disadvantages associated with occupational hearing loss as experienced in the family. *Audiology,* 26:141-52.

Hetu, R., Riverin, L., Getty, L., Lalande, N.M., St-Cyr, C., 1990. The reluctance to acknowledge hearing difficulties among hearing-impaired workers.

Brit. J. Audiology, 24:265-76.
Hetu, R., Riverin, L., Lalande, N., Getty, L., St-Cyr, C., 1988. Qualitative analysis of the handicap associated with occupational hearing loss. *Brit. J. Audiology* 22:251-64.
Hohmann, B.W., 2008. Simple evaluation of occupational noise exposure without measurements. Paper presented at *Acoustics '08 Paris*. June 28-July 4, 2008.
Hömann, H., Lazarus-Mainka, G., Schubeius, M., Lazarus, H., 1984. The effect of noise and the wearing of ear protectors on verbal communication. *Noise Control Eng. J.,* 23:69-77.
Howell, K., Martin, A.M., 1975. An investigation of the effects of hearing protectors on vocal communication in noise. *J. Sound Vib.* 41:181-96.
Lahiri, S., Low, C., Barry, M., 2011. A business case evaluation of workplace engineering noise control: A Net-Cost model. *JOEM,* 53(3):329-337.
Liedtke, M., 2005. Risk by use of hearing protectors – Expert programme supports SMEs in appropriate selection and use. *Noise Heath,* 7(26):31-7.
Lick, H.B., 1999. Ford's annual report to the United Auto Workers (UAW)-Ford National Joint Committee on Health and Safety. *Best Practices in Hearing Loss Prevention.* U.S. DHHS, NIOSH, Pub. No. 2000-136.
Lin, J., Huber, B., Richmond, M., Replogle, J., Levin, M., 2010. Dubious data clouds job safety gains. *So. Calif. Public Radio,* 3-25-10.
McCall, B.P., Horwitz, I.B., 2004. An assessment of the effects of increased regulatory enforcement and legislative reform on occupational hearing loss workers' compensation claims: Oregon 1984-1998. *Am. J. Ind. Med.*, 45:417-427.
Melamed, S., Luz, J., Green, M.S., 1992. Noise exposure, noise annoyance and their relation to psychological distress, accident and sickness absence among blue-collar workers – The Cordis Study. *Israel J. Med. Sci.,* 28(8-9):629-35.
Mich. State Univ., 2000. Noise, hearing impairment and work-related trauma. *Now Hear This…* 3(3):1-4.
Moll van Charante, A.W.,, Mulder, P.G.H., 1990. Perceptual acuity and the risk of industrial accidents. *Am. J. Epidemiol.,* 131:652-63.
Morata, T.C., Themann, C.L., Randolph, R.F., Verbsky, B.L., Byrne, D.C., Reeves, E.R., 2005. Working in noise with a hearing loss: Perceptions from workers, supervisors, and hearing conservation program managers. *Ear. Hear.,* 26(6): 529-45.
NAE, 2010. *Technology for a Quieter America*. National Academy of Engineering, Washington DC.
Neitzel, R., Seixas, N., Goldman. B., Daniell, W., 2004a. Contributions of nonoccupational activities to total noise exposure of construction workers. *Ann. Occup. Hyg.,* 48(5):463-73.
Neitzel, R., Seixas, N., Olson, J., Daniell, W., Goldman, B., 2004b. Nonoccupational noise: Exposures associated with routine activities. *J. Acoust. Soc. Am.,* 115(1): 237-45.
NHCA. 2009. Conserve to hear the future. *34th Annual Hearing Conservation Conference.* National Hearing Conservation Association. Feb. 12-14. Atlanta, GA.
NHCA. 2011. Innovation & technology. *36th annual Hearing Conservation Conference.* National Hearing Conservation Association. Feb. 24-26. Mesa, AZ.
NIOSH. 1998a. Criteria for a recommended standard: Occupational noise exposure; Revised Criteria. Report No. (NIOSH) 98-126. DHHS, Centers for Disease Control, National Institute for Occupational Safety and Health.
NIOSH 1998b. *Proceedings for Control of Workplace Hazards for the 21st Century: Setting the Research Agenda*. Conference and Workshop held March 10-12, 1998.
OHSA. 1981. Occupational noise exposure: Hearing conservation amendment. US DOL, Occupational Safety and Health Administration.
OSHA. 1993. *Occupational noise exposure; hearing conservation amendment; Final rule*. U.S. Dept. Labor, Occupational Safety and Health Administration, *48 Fed. Reg.* 9738-9782.
Phil. OSHA. 1992. Enforcement of the occupational noise exposure standards: 29 CFR 1910.95, 1926.52. and 1926.101, Inspection procedures and interpretive guidance. Philadelphia Rectional Office, US Dept. Labor, 5-31-92.
Rabinowitz, P.M., Slade, M.D., Galusha, D., Dixon-Ernst, C., Cullen, M.R., 2004. Trends in the prevalence of hearing loss among young adults entering an industrial workforce 1985 to 2004. *Ear Hear.*. 27(4):369-75.
Ruttenberg, R., 1997. Can protecting human health and the environment be justified on cost-benefit grounds? *Ann. NY Acad. Sci*, 837(Dec 26):456-61.
Safe Work Australia. 2010. Code of Practice: Managing noise and preventing hearing loss at work (draft). www.safeworkaustralia.gov.au.
Saunders, G.H., Griest, S.E., 2009. Hearing loss in veterans and the need for hearing loss prevention programs. *Noise & Health*, 11(42):14-21.
Shapiro, S., 2011. SBA's report on "Cots of Regulation" debunked. Center for Progressive Reform. www.progressivereform.org. 2-8-11.
Simpson, B.D., Bolia, R.S., McKinley, R.L., Brungart, D.S., 2005. The impact of hearing protection on localization and orienting behavior. *Hum. Factors,* 47(1):188-98.
Suter, A.H., 1992. Communication and job performance in noise: A review. *ASHA Monographs no. 28*. American Speech-Language-Hearing Assoc., Rockville, MD.
Suter, A.H., 2002. Construction noise: Exposure, effects, and the potential for remediation; A review and analysis. *Am. Ind. Hyg. Assoc. J.,* 63, 768-787.
Suter, A.H., 2007. Development of standards and regulations for occupational noise. In Crocker M (Ed.) *Handbook of Noise and Vibration Control*, Hoboken, NJ: John Wiley & Sons, 377-382.
Tak, S.W., Davis, R.R., Calvert, G.M., 2009. Exposure to hazardous workplace noise and use of hearing protection devices among US workers – NHANES 1999-2004. *Am. J. Ind. Med.,* 52(5):358-371.
Toppila, E., Pyykko, I., Paakkonen, R., 2009. Evaluation of the increased accident risk from workplace noise. *Int. J. Occup. Safety Ergonomics (JOSE),* 15(2):155-162.
Tufts, J.B., Frank, T., 2003. Speech production in noise with and without hearing protection. *J. Acoust. Soc. Am.,* 114(2):1069-80
Wells, L., 2006. Has the OSHA recordkeeping rule changed hearing loss prevention programs? *CAOHC Update.* 18(2):1-4.
Williams, W., Dillon, H., (2005). Hearing protector performance and standard deviation. *Noise & Health*, 7(28):51-60.
Zwerling, C., Whitten, P.S., Davis, C.S., Sprince, N.L., 1997. Occupational injuries among workers with disabilities. *Journal Am. Med. Assoc.,* 278:2163-6. SV

Alice Suter has worked in the area of noise effects and hearing conservation for more than 30 years. She has an M.S. in education of the deaf and a Ph.D. in audiology. Suter has been influential in noise criteria development, regulation, and public policy, first at the U.S. EPA's Office of Noise Abatement and later at OSHA. At the EPA, She participated in the development of criteria for noise effects, including the psychological, extra-auditory physiological, performance, and communication effects, in addition to the effects of noise on hearing. As senior scientist and manager of the Noise Standard at OSHA, Suter was principal author of the hearing conservation amendment to the noise standard. She has also held positions of visiting scientist and research audiologist at NIOSH. Suter is now a consultant living in Portland, OR. She is holds fellowships in the Acoustical Society of American and the American-Speech-Language-Hearing Association and has received several honors for her work, including the Alice Hamilton Award from the American Industrial Hygiene Association and the Lifetime Achievement Award from the National Hearing Conservation Association. She may be contacted at ahsuter@comcast.net.