noise is insidious. Individuals with noise-induced hearing loss may not become aware of the condition until it is of handicapping proportion; and by that time, it is permanent. More than 9 million people are exposed to occupational noise levels above 85 dB(A) in the U.S., the majority of whom work in manufacturing and utilities. Table 1 shows the distribution of workers exposed to noise by employment area.

High levels of noise are particularly common in industries where metal-on-metal impacts occur, such as primary metals and metal fabrication, but are also characteristic of food processing, textiles, lumber and wood, and many other industries.

Noise-induced hearing loss

There is a good general agreement that daily average noise levels below 80 dB(A) are innocuous, and that noise levels above 90 dB(A) are hazardous. Individuals exposed between 85 and 90 dB(A) need to be monitored because some of the more susceptible ones will develop a hearing impairment if they are exposed for sufficiently long durations.

(see Workplace noise on page 2)
It is impossible to assess the risk of noise-induced hearing loss without considering exposure duration. Even noise levels as high as 130 to 140 dB(A) can be harmless if the duration is only a matter of a few milliseconds and there are no or few repetitions. Gunfire would be an example of this kind of occasional exposure, but hearing protection should be worn for sport shooting or target practice, since these exposures are generally repeated. The relationship between a criterion noise level (such as 90 dB(A)) and exposure duration has been called the time-intensity tradeoff, or nowadays, the exchange rate. OSHA uses a 5-dB exchange rate. EPA, as well as many European countries, uses the more conservative 3-dB exchange rate. OSHA allows 8-hour exposures at levels of 90 dB(A), 4-hour exposures at 95 dB(A), and so forth up to 15 minutes at 115 dB(A) before requiring noise control or hearing protection. More details on noise standards will be given in the next article.

Unless there is a sudden, traumatic exposure at a very high noise level (such as an explosion), noise-induced hearing loss occurs gradually. It starts as a temporary threshold shift (TTS), which eventually becomes permanent. The process will be accelerated if any individual’s TTS does not recover fully before the next noise exposure. Some individuals are more susceptible to noise exposure than others. Certain population studies indicate that males and fair-skinned people are more susceptible to noise-induced hearing loss than females and dark-skinned people, but no method has been developed to predict susceptibility on an individual basis.

Figure 1 gives a hypothetical example of the progression of noise-induced hearing loss over a 30-year period. This individual may have been exposed to an average daily level of about 95 dB(A). Along the abcissa of this “audiogram” is frequency (perceived as pitch), and the ordinate gives hearing threshold level, the intensity level at which a sound is barely audible, referenced to audiometric zero (ANSI, 1969). The parameter is years of exposure. One can see that noise affects the higher frequencies first, eventually moving down to impair the 1000-Hz and 500-Hz frequencies. This person might not notice the hearing loss at first, but by the time the loss has progressed to the 10-year level, this individual would begin to have difficulty understanding conversation at parties, at restaurants, or in any situation involving background noise. Eventually, by year 25 or 30, the hearing loss would be severe enough to become a burden in everyday life. These kinds of hearing losses are almost always exacerbated by “presbycusis,” the hearing loss that usually accompanies the aging process.

Noise-induced hearing loss typically results in difficulties not in hearing speech, but in understanding it. This is because the consonant sounds provide the meaning to speech, and yet they are considerably higher in frequency and softer in terms of sound energy than vowel sounds, which are generally low-frequency, and much more intense. Small amounts of hearing impairment, whatever the cause, usually pose no problem, but impairments become handicapping when they reach an average of about 25 dB at the frequencies 1000, 2000, and 3000 Hz. At this hearing level, hearing-impaired individuals will no longer be able to function in everyday communication situations like their normally-hearing counterparts. Even small impairments, however, should be avoided in the occupational setting because they can combine with presbycusis to become handicapping later in life.

**Communication interference**

In most noisy workplaces, people communicate only minimally and have learned a system of gestures to supplement speech. In certain jobs, however, effective communication is necessary, and noise masking can be a serious problem. Normal conversation in quiet results in voice levels of about 50 to 55 dB(A), measured at one meter. In noisy backgrounds, individuals will automatically raise their voices 5 or 6 dB(A) for every 10 dB(A) increase in noise level over approximately 45 dB(A), so as to be intelligible over the background din. Table 2 gives voice levels that could be expected in various

**Table 1**

<table>
<thead>
<tr>
<th>Employment Area</th>
<th>Number of Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>323,000</td>
</tr>
<tr>
<td>Mining</td>
<td>161,000</td>
</tr>
<tr>
<td>Construction</td>
<td>513,000</td>
</tr>
<tr>
<td>Manufacturing and Utilities</td>
<td>5,124,000</td>
</tr>
<tr>
<td>Transportation</td>
<td>1,934,000</td>
</tr>
<tr>
<td>Military</td>
<td>976,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9,031,000</strong></td>
</tr>
</tbody>
</table>

(see Workplace noise on page 3)
levels of background noise. In speech-to-noise ratios of 0 dB or less (where, for example, the speech and noise are at the same level), communication involving short, familiar sentences or phrases can be satisfactory, but unexpected words or speech articulated unclearly can be quite difficult to understand. As the speech-to-noise ratio becomes negative, a large percentage of the message will be missed.

Although the human voice is capable of producing levels as high as 100 dB(A), shouting at these high levels of vocal effort becomes extremely tiring, and people cannot sustain voice levels higher than about 78 dB(A) for prolonged periods. Therefore, communication in noise levels above 85 dB(A) is not satisfactory, either for talker or listener. In addition, people can incur pathologies, such as hoarseness or vocal nodules from the continuing vocal strain. These conditions can be remedied by noise abatement procedures or by the use of special telephonic or FM communication systems.

Noise can also mask acoustic warning signals and the sounds of improperly functioning machinery. In this regard, noise can be considered a safety hazard. Although there is anecdotal evidence of accidents and injuries attributable to high noise levels, there are no systematic studies of this effect. Again, the solution lies in noise abatement, although some companies have installed visual warning systems to improve detectability.

Effects on job performance

There is a substantial amount of research literature concerning the effects of noise on performance, and many of these studies have produced conflicting results. There is, however, sufficient evidence to conclude that high levels of noise can adversely affect performance under certain circumstances. In general, simple, routine tasks are unaffected, even in noise levels as high as 130 or 140 dB(A). Above these levels, however, visual and motor effects can occur. Complex tasks, especially those involving simultaneous performance, can be disrupted at much lower levels, generally at 95 dB(A) and above, although particularly sensitive tasks can be affected at levels as low as 80 to 85 dB(A). Intermittent and impulsive noise is more disruptive than continuous noise, especially when the noise bursts are unpredictable.

Table 2

<table>
<thead>
<tr>
<th>Background noise level in dB(A)</th>
<th>Estimated voice level in dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiet</td>
<td>55</td>
</tr>
<tr>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>95</td>
<td>85</td>
</tr>
</tbody>
</table>

Effects of noise on health

The research literature on the effects of noise on general health is as voluminous as that on noise and performance, and the results are somewhat more controversial. Most of the studies have been conducted in Soviet and Eastern European countries, and quite often lack vital methodological details. There is conflicting evidence among American and European studies, but most scientists would agree that...
OSHA’s noise standard defines hazard, protection

Walsh-Healey noise standard

Although OSHA’s hearing conservation amendment (HCA) came out in a flurry of publicity about a decade ago, the noise standard to which it was amended has actually been around for quite a while. In 1969, shortly before OSHA came into being, the Department of Labor issued a noise standard under the authority of the Walsh-Healey Public Contracts Act. This meant that the standard applied to all employers having contracts with the federal government. In 1971, the standard became an OSHA standard, and along with a large number of other government and consensus standards, it became the law for all noisy workplaces in the U.S.

Still nicknamed the “Walsh-Healey noise standard,” it calls for a maximum noise exposure level of 90 dB(A) as an 8-hour, time-weighted average level (TWA). Higher levels are permitted for shorter durations, with a 5-dB relationship between noise level and duration (see Table 3). Thus, 95 dB(A) is permissible for 4 hours, 100 dB(A) for 2 hours, and so forth, up to a maximum exposure for continuous noise of 15 minutes at 115 dB(A). Continuous noise is defined as noise whose maxima (highest levels) occur more often than once per second. Thus, impulsive noise is assumed to have peaks occurring less often than once a second, and is limited to peak sound pressure levels of 140 dB. Employers must use feasible engineering or administrative controls to reduce exposures whenever the levels in Table 3 are exceeded. Employers must also issue hearing protectors and employees must wear them when overexposed.

For further reading


The process of revision

Shortly after the noise standard was adopted by OSHA, controversy arose as to the definition of a “continuing, effective hearing conservation program.” The standard itself offered little clarification and OSHA’s guidelines on the subject were challenged as not having the weight of a regulation. The process of revising the standard, which would seem simple enough, lasted more than a decade. NIOSH sent OSHA a criteria document in 1972, recommending a reduction of the permissible exposure limit (PEL) to 85 dB(A), and giving detailed specifications for hearing conservation programs. OSHA called together an advisory committee, invited public comment, drafted economic impact statements, issued a proposed revised standard and held public hearings. The major
issues revolved around: (1) the PEL, whether it should be 90 or 85 dB(A); and (2) the method of control, whether to keep the primacy of engineering and administrative controls, or to allow hearing protectors to have equal weight. Finally, after years of deliberation, OSHA decided to leave the PEL at 90 dB(A) and to affirm engineering and administrative controls as the primary means of compliance, but to amend the standard with detailed requirements for hearing conservation programs.

OSHA published the HCA on January 16, 1981. Under most circumstances the regulation would have become effective (enforceable) in April of that year. On January 20, however, there was a change of administration and OSHA’s top management was completely reshuffled. The new administration delayed the amendment’s effective date, releasing part of the standard in August of 1981, and making revisions to other parts. The revised version was finally issued in 1983 and has not been altered since then. The requirements for hearing protectors remained essentially unchanged between 1981 and 1983.

Professionals with the responsibility for hearing conservation programs should become thoroughly familiar with the revised version of the HCA. It may be found as CFR 1910.95 in the Code of Federal Regulations, which is available from the Government Printing Office at (202) 512-0000. Anyone who has access to the Federal Register can also find it in the March 8, 1983 issue of the Federal Register, pages 9738-9784. The actual standard appears on pages 9776-9784, which is, of course, the most important section. Much of the standard is explained in the preamble of the 1981 version, found in the January 16, 1981 issue of the Federal Register, pages 4078-4179. The Code of Federal Regulations and the Federal Register are available in many libraries.

Summary of the hearing conservation amendment

To summarize the current HCA’s major provisions, hearing conservation programs must be available to all employees whose TWAs equal or exceed 85 dB(A). Employers must monitor, at least once, the noise exposures of workers whose TWAs are 85 dB(A) or greater. Remonitoring is necessary with a change in equipment or work process that causes a significant increase in exposure level. All continuous, intermittent, and impulsive noise between the levels of 80 and 130 dB(A) must be included in the exposure assessment. Area monitoring is permitted, but employers must use personal exposure monitoring when there is considerable variation of noise level over time. Workers must be allowed to observe the monitoring procedures and must be told about their exposures.

Employers must provide baseline audiograms within the first six months of an employee’s exposure to 85 dB(A) or above (or one year if the company uses mobile test services), and annual audiograms must be provided thereafter. The test must be conducted by trained and competent personnel and supervised by an audiologist or physician. Tests must be carried out in rooms that meet or exceed the 1969 ANSI criteria for background sound levels, and equipment must be calibrated according to specific schedules. Workers who experience “standard” threshold shifts must be notified in writing, counselled as to the fitting and use of hearing protection, and referred to a specialist if necessary. A standard threshold shift is defined as an average shift from baseline hearing levels of 10 dB or more at the audiometric frequencies 2000, 3000, and 4000 Hz.

Hearing protection must be provided at no cost to employees and must be worn by all workers exposed to a TWA of 90 dB(A) and above. Hearing protection is also mandatory for those exposed to 85 dB(A) and above if they have not yet had a baseline audiogram and for all employees who have experienced a standard threshold shift. Employers must offer hearing protectors to workers exposed above 85 dB(A), and all must be given a variety of suitable protectors from which to choose. Employees must be trained in the use and care of the protectors. Employers must ensure proper initial fitting of protectors and need to supervise their correct use. Hearing protectors must attenuate to a TWA of 90 dB(A) or less and to 85 dB(A) when employees have experienced a standard shift. Attenuation must be re-evaluated when necessary and protectors must be replaced when they are worn out.

Employers must provide hearing protectors that are suitable for the specific noise environments in which they are to be worn. OSHA allows employers to use any of three methods for assessing the adequacy of hearing protector attenuation. These methods are spelled out in the HCA’s Appendix B. The standard recommends using the Noise Reduction Rating (NRR), which should appear on the protector package. To estimate the noise level under the protector, the employer subtracts the NRR from the worker’s C-weighted exposure level. If C-weighted levels are not available, 7 dB must be subtracted from the NRR to obtain the A-weighted sound level at the ear.

Training and education sessions must be given at least annually to workers exposed above 85 dB(A). These sessions must include information on the effects of noise on hearing, the purposes and procedures of audiometric tests, and the proper selection, fitting, use, and care of hearing protectors.

Finally, employers need to keep records of noise measurements.
OSHA's noise standard
(continued from page 5)

audiograms, audiometer calibrations, and background levels in audiometric test rooms. These records must be given to employees or their representatives on request.

Interpretations

The preamble to the 1981 and 1983 versions of the HCA describe and interpret most of the provisions relating to hearing protectors that appear in the 1983 regulation. Some of these interpretations may be of interest to Job Health Highlights readers.

- **Who must wear hearing protectors?** Workers whose TWAs exceed 90 dB(A), those exposed above 85 dB(A) who have incurred standard threshold shifts, and those who have waited six months or more for a baseline audiogram.

- **Why is the use of hearing protectors between 85 and 90 dB(A) non-mandatory for most workers?** Hearing protectors may interfere with speech communication at these moderate noise levels, especially if the noise is intermittent and if wearers have noise-induced hearing losses. Employers who choose to make hearing protection above 85 dB(A) a company policy are free to do so.

- **What constitutes “a variety of suitable protectors?”** OSHA interprets this as a choice of at least one plug and one muff, preferably more. Differing environmental conditions as well as individual differences in ear canal and head shapes and sizes may cause certain protectors to be much more comfortable than others.

- **What are employers’ responsibilities to replace hearing protectors?** Hearing protectors do wear out, some more quickly than others. Earmuff seals can become inflexible, and acoustical leaks will result, or the headband can lose its tension. Malleable and premolded plugs can lose their elasticity. Some protectors will need to be replaced daily. OSHA does not hold employers responsible for damage due to worker misuse or loss due to worker negligence. However, OSHA does recommend that employers encourage workers to take their hearing protectors home if they engage in noisy hobbies or other noisy non-occupational pursuits.

- **Is the 7-dB adjustment to the NRR a form of “derating”?** No. OSHA acknowledged that hearing protector attenuation in the field is not nearly as good as it is in the laboratory. However, the agency chose not to tackle the issue of derating at the time the amendment was issued. The 7-dB adjustment is for uncertainty in the spectrum of the noise environment. Because of the importance of low-frequency noise in the assessment of hearing protector attenuation, the NRR is designed to be used with C-weighted environmental noise levels. When only A-weighted levels are available, the 7-dB penalty must be subtracted to allow for this spectral uncertainty.

### OSHA's enforcement directive

Soon after the revised HCA was promulgated in 1983, OSHA issued a directive to its regional and area offices stating certain enforcement principles. The result is that in most circumstances, Federal OSHA inspectors are not to issue citations for lack of feasible engineering or administrative controls until workers’ TWAs are 100 dB(A) or above.* Inspectors may issue citations if they decide that engineering or administrative controls are less costly than hearing conservation programs, or if the hearing conservation programs are “ineffective.” Little guidance is given on the definitions of “effective” or “ineffective,” except that “the results of audiometric testing [must] indicate that any existing controls and hearing protectors are adequately protecting employees.” In assessing the adequacy of hearing protector attenuation for purposes of this directive, the inspector must apply a safety factor of 50% to the laboratory-based attenuation; in other words, divide the NRR by 2. If C-weighted noise measurements are not available and the 7-dB correction must be used, the 7 dB should be subtracted from the NRR before the 50% safety factor is applied (NRR-7dB/2).

Because this directive constitutes OSHA policy, not regulation, it can be revoked at any time. Readers wishing to obtain a copy of it may call OSHA’s Office of Information at (202) 219-8148 and ask for OSHA Instruction CPL 2-2.35 dated November 9, 1983.

For further reading


* Certain states that have their own state OSHA plans have not subscribed to this directive.
The noise reduction rating - fact and fiction

NRR’s checkered career

The Noise Reduction Rating, popularly known as the NRR, had a lot to recommend it when it first appeared on the scene in the 1970s. Prior to that time the attenuation of hearing protectors had to be assessed using a lot of complicated calculations. The NRR, however, offered a simple, single-number method that manufacturers were required to print on the hearing protector’s package. Even those who were totally unfamiliar with acoustics could get an idea of how much attenuation (noise reduction) a protector afforded and compare that with the amount of attenuation that was needed in the user’s workplace.

But problems with the NRR have developed over the years. First, consumers have taken the NRRs too literally, expecting them to provide exactly that amount of attenuation in the workplace, which they do not. Then, in an effort to compensate for the NRR’s lack of realism, the purchasers often adopt a “bigger is better” mentality, selecting a protector with an unnecessarily large NRR when only a few decibels of attenuation may be necessary. The trick is to understand what the NRR does and doesn’t do so that it may be used in a realistic and practical manner.

How the NRR came to be

The NRR is based on a laboratory method to evaluate the attenuation of hearing protection devices developed by the National Institute for Occupational Safety and Health (NIOSH) and published in 1975. Around that time the U.S. Environmental Protection Agency (EPA) had been charged with setting labeling standards for products that emitted high levels of noise and for products that were designed to protect people from noise. The EPA chose the latter type of product for its first (and, it happens, its only) noise labeling regulation.

Accordingly, EPA notified hearing protector manufacturers that they must test their products in a suitable laboratory, arrive at a Noise Reduction Rating, and print that rating on a prescribed label on the hearing protector package. Figure 2 shows the label for the 3M 1110 corded ear plug, with its NRR, along with the other wording required by the EPA. Note that the NRR is 29 dB “when used as directed,” indicating that the user may not receive this much attenuation if the plug is not inserted and worn correctly.

Laboratory procedures for arriving at the NRR

The standardized procedure required by the EPA is detailed in its regulation (40 Code of Federal Regulations, Part 211, Subpart B). It uses a well established method for testing hearing protector attenuation called “real-ear attenuation at threshold” or REAT. The laboratory procedures are outlined in an ANSI standard, the latest version of which is ANSI S12.6-1984. Noise signals at a variety of sound frequencies are presented to trained listeners in the laboratory, and hearing threshold levels with and without hearing protectors are obtained. The difference between the two conditions reflects the hearing protector’s attenuation. The examiner combines the attenuation results obtained over a series of tests for each frequency for a group of at least 10 listeners, and calculates mean attenuation values and standard deviations.

At this stage the evaluator may use the “long method” (NIOSH method #1) to estimate the protector’s attenuation in a particular noise environment. Some individuals prefer to use the long method rather than the NRR because it yields the most accurate information for a particular noise spectrum. It is especially useful for noises with unusual spectra, such as noises with strong low-frequency components. One must remember, however, that the way the protector is fitted, inserted, and worn usually has a much greater effect on the actual sound level arriving at the ear drum than the method one has used to calculated its attenuation.

Figure 2. The EPA requires hearing protector package labels to list a Noise Reduction Rating.
To use the long method, the evaluator first measures the noise levels at certain octave-band center frequencies in the wearer’s environment using a sound level meter with an octave-band analyzer. The range of frequencies measured extends from 125 Hz to 8000 Hz. Standard adjustments for A-weighting are then applied to these measurements and the hearing protector’s mean attenuation values and two standard deviations are subtracted at each frequency. The two standard deviations are subtracted to account for variations in anatomical shapes and sizes as well as individual response in the laboratory. They are not intended to reflect the differences in wearing practices encountered in actual use. Finally, the resulting levels are added logarithmically to obtain the estimated A-weighted sound level beneath the ear protector in the users environment.

The NRR simplifies this procedure considerably. First, a noise with a standard spectrum (“pink” noise) is substituted for the real thing, and a small adjustment is made in the calculation for “spectral uncertainty.” Because these stages are performed in the laboratory, the consumer does not need to make so many measurements or calculations in the field. As in the long method, the NRR incorporates the two-standard-deviation subtraction, and the values for each frequency have been summed logarithmically to produce a single number.

**Using the NRR on the job**

Use of the NRR does not avoid the need to evaluate a worker’s noise exposure in his or her particular environment, but octave-band measurements are no longer necessary. The employer or purchaser must subtract the NRR from the C-weighted noise exposure level in the worker’s environment to obtain the estimate A-weighted sound level under the protector. There is a good reason this seeming inconsistency. The sound level meter’s A-weighting network acts as a filter, causing most mid- and high-frequency sounds to pass through and be measured at their actual levels. Low-frequency sounds, however, are increasingly attenuated as the frequency spectrum becomes lower. One way of saying it is that the A-weighting network “discriminates” against low-frequency sound.

The C-weighting network, on the other hand, allows most low-frequency sounds to be measured at their actual levels. The difference between A-weighted and C-weighted measurements provides a good estimation of the relative contribution of low frequencies in a particular noise.

Most hearing protectors attenuate the high frequencies significantly more than the low frequencies. Because of this fact, and also because most industrial noise tends to have either a low-frequency emphasis or a relatively flat configuration, both the EPA and OSHA recommend that the NRR be subtracted from the C-weighted noise level in the user’s environment. This is especially true when the noise appears to be predominantly low-frequency or if the A-weighted exposure levels are relatively high (above about 95 dB).

In some cases the employer may not have access to C-weighted measurements. While most sound level meters provide the option to take C-weighted measurements, many noise dosimeters do not. In cases where only A-weighted measurements are available, the OSHA standard requires that employers subtract 7 dB from the NRR before subtracting it from the worker’s environmental noise level. Take the example of the employer who wishes to use the 3M 1110 Corded Foam Ear Plug, which has an NRR of 29 dB, and the individual who will use the plugs, and who has an A-weighted noise exposure level of 97 dB. The estimated level under the plug would be 75 dB(A). (29-7=22, 97-22=75.) The reader must remember that the 7-dB adjustment is necessary because of the lack of information about the noise’s spectrum and not because of the difference between laboratory and real-life use of the protector.

Many employers, who have designated “noise hazard” areas, will choose to measure noise levels with sound level meters and estimate the A-weighted protected level on the basis of C-weighted levels in these areas. In situations where workers move around quite a bit, where the noise levels fluctuate, or where there is a significant component of impulse noise in the environment, employers will have to conduct personal noise monitoring. In these cases, a dosimeter is the measuring instrument of choice and the result will be displayed in terms of time-weighted average exposure level (TWA) or noise dose in percent, which can be converted easily to TWA. Although dosimeters did not formerly have this capacity, some modern dosimeters can display the noise dose or TWA both in dBC and in dB(A), a very convenient feature. The employer then subtracts the NRR from the C-weighted TWA. If the dosimeter does not have C-weighting, the NRR is reduced by 7 dB and the remainder is subtracted from the A-weighted TWA.

**Practicalities**

As mentioned above, hearing protectors seldom give the same results in actual use that they do in...
the laboratory, so the result is that
the NRR gives a highly optimistic
picture of the actual attenuation.

Hearing conservation
professionals have used special
equipment in the field to mimic the
procedures for evaluating hearing
protector attenuation in the
laboratory. A series of studies using
a variety of hearing protectors has
shown that the average attenuation
that people receive in the workplace
is only about one-third to one-half
the attenuation that laboratory
subjects receive. In addition, the
variability among wearers, as shown
by the standard deviation, is two to
three times greater than in the
laboratory. It appears that the
differences between field and
laboratory results are greater for
plugs than for muffs, although the
foam plugs appear to perform
somewhat better than most of the
other plug varieties.

One of the consequences of this
disparity between the NRR and
actual field attenuation is reflected in
a 1983 enforcement memo issued by
the federal* OSHA’s Office of Health
Compliance Assistance. The memo
instructs federal OSHA inspectors
to derate the NRR in the prescribed way. They
instruct its inspectors to derate the
NRR of 14.5 dB, and the estimated
A-weighted level under the plug
would be 89.5 dB(A). According
to the OSHA memo, the company
would be in compliance and
engineering controls would not be
required.

If, however, the factory worker
had experienced a standard
threshold shift in hearing (STS)
sometime during his tenure with the
company, the company would not
be in compliance because OSHA
requires that employees who have
incurred an STS must have hearing
protectors that attenuate to
85 dB(A) or below.

The situation becomes still more
complicated if the employer does not
have access to instruments that
measure with the C-weighting
network. If the operator of the
factory mentioned above had to use
the employee’s A-weighted sound
level, 7 dB would need to be
subtracted from the NRR before
it was derated and the resulting
estimated level under the protector
would be a too-high 91 dB(A).

\[
(29-7=22/2=11, 102-11=91.)
\]

This company would probably be
required to use a protector with more
attenuation (or a muff and a plug), or
institute engineering controls.

What next?

The reader must bear in mind
that the OSHA enforcement policy
is just a guideline and not a
regulation. It could be withdrawn
overnight, and with the change in
administration this year, the policy
might very well disappear. But that
would not solve the problem of the
NRR. The fact is that the NRR does
not solve the problem of the
attenuation in actual field use,
although it does give the purchaser
a little information about the
relative attenuation of one device
versus another.

Recently a new ANSI working
group, S12/WG11, has undertaken
the task of developing a new
method for evaluating the
attenuation of hearing protectors.
This group is attempting to find
a laboratory method that will
correlate reasonably well with the
results found in the field studies.
The chances are that any new NRRs
resulting from their procedures
would be considerably lower than
the present ones. Although the
process of drafting an ANSI standard
is long and laborious, the initial
results of this working group show
some promise. In the mean time,
purchasers of hearing protectors will
need to follow the requirements of
OSHA’s noise standard. For most,
this will mean continuing to use the
NRR in the prescribed way. They
should, however, view the NRR with
certain amount of healthy skepticism.

For further reading

American National Standard Method for the
Measurement of the Real-Ear Attenuation of Hearing

Berger, J.C. Morrill, L.H. Royster, and W.D. Ward
(Eds.), Noise and Hearing Conservation Manual
(4th ed.) American Industrial Hygiene Assoc. Akron, OH,
1986. (Now located in Fairfax, VA).

Gasaway, D.C. Chapter 8 in Hearing
Conservation: A Practical Manual and Guide

and Health Administration. Occupational Noise
Exposure; Hearing Conservation Amendment. Fed.
Reg., 46, pp. 4078-4179 (especially pp. 4151-4155).

U.S. Code of Federal Regulations,

211 Subpart B. (EPA regulation for the NRR).

* While many state OSHA programs have followed suit,
the reader should be aware that some states do not use
this compliance policy.

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### Note

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Noise reduction rating

(continued from page 8)
Using hearing protectors in the real world

With such big NRRs, why are people losing hearing?

The previous article on hearing protectors, “The noise reduction rating - fact and fiction,” discussed the discrepancies between the NRR and the attenuation that workers actually receive on the job. In general, the attenuation realized in the field is only about one-half to one-third of the laboratory values on which the NRR is based and the field attenuation varies quite a bit both among individual users and among protectors.

As a rule, ear muffs tend to give somewhat more attenuation than ear plugs because they are more easily sized and fitted and they do not need to be carefully inserted into the ear canal. Also, both types of protectors provide considerably less attenuation for low frequency sound than they do for the high frequencies. Thus, the high-pitched noise of aluminum sawing, for example, may be more easily attenuated than the rumble of a locomotive engine, even though they may both be at approximately the same overall sound level.

But there are many more reasons why hearing protectors may give less noise reduction in the workplace than their laboratory-based NRR would indicate.

The laboratory provides “ideal” conditions

Laboratory testing of hearing protector attenuation is done according to a predetermined protocol set forth in ANSI standard S12.6-1984 or S3.19-1974. The subjects are trained listeners, most of whom have performed the test many times. They insert the plugs or don the muffs under the close supervision of a laboratory experimenter. Protectors are sized correctly and, of course, they are new and in good condition. The subjects insert the plugs deeply into the ear canal. If a muff’s headband is uncomfortably tight, they usually ignore it. They can put up with some discomfort for the limited duration of the test. These procedures are followed to try to provide uniform testing so products can be compared.

Workplace conditions are the real world

In the workplace, employees must wear hearing protectors for extended periods, often for the whole day, so comfort becomes a vitally important factor. If a protector is uncomfortable, it will be worn loosely, or possibly not at all. In addition, workers put on and take off their protectors without benefit of a laboratory experimenter, and usually without any supervision at all. Ear protectors that are improperly inserted or fit loosely are likely to develop leaks through which the noise can easily enter the ear canal. Consequently, the protector’s attenuation is greatly reduced.

There are many reasons why protectors will develop attenuation leaks when they are worn on the job. Here are the major ones:

1. Improper sizing. Ear plugs sometimes come in several sizes. It is important to offer all sizes and to pick the correct size. Wearers tend to fit plugs too loosely, causing gaps between the plug and the ear canal, or too tightly, causing a comfort problem, which can result in plugs that are worn in the pocket rather than in the ear. In some cases, the same individual will have two differently-sized ear canals, so each ear should be sized separately.

2. Faulty insertion. This is probably the most common reason for attenuation leaks in ear plugs. Most users have had little or no training in inserting ear plugs, so they may not know how to do it properly. Also, unlike the laboratory situation, users tend to insert the plugs loosely if they know that they must wear them for long periods of time.

3. Compatibility problems. Hearing protection often needs to be worn with other types of protective gear, such as helmets and safety glasses. Ear muffs are incompatible with helmets unless they are specially mounted on the helmet. Temple bars of safety glasses can break the seal of ear muff cushions, allowing noise to leak into the ear. The small pads through which certain temple bars may be inserted will certainly improve the worker’s comfort, but the muff’s attenuation will still be somewhat reduced. In addition to safety equipment, long hair, beards, and large earrings can interfere with the seal of ear muff cushions.

4. Communication. Workers will often remove their hearing protectors or loosen them so that they can communicate with each other, hear warning signals, or hear the sounds of their machines. Safety and health professionals will point out that the protector will attenuate both the desired signal and the unwanted noise by the same amount, so one need not remove or loosen the protector.

Although this is theoretically true, most protectors do change the nature of sounds (by changing the frequency spectrum) because they attenuate the high frequencies more than the low frequencies. In addition, workers who already have a noise-induced

(see Hearing protectors on page 11)
Hearing protectors

(continued from page 10)

The ideal way to measure hearing protector attenuation in the workplace is to use methods and equipment that resemble the laboratory attenuation test. Such methods have been used in several field experiments of ear plug attenuation, but the equipment is not yet commercially available and the methods are not standardized. Just to get a good idea of on-the-job attenuation, however, employers or hearing conservation professionals may use commercially-available noise-reducing earphone enclosures (large, dome-shaped earphones) or even conventional supra-aural headsets (the kind that accompany audiometers).

Those who use this method should keep in mind that the test could be influenced somewhat if the ear plug’s stem or other external part should come in contact with the earphone’s receiver, its sound transmitting part. There are two types of noise-reducing earphone enclosures, the “Audiomate” and the “Madsen ME-70,” in which the earphone is slightly recessed, which may lessen the chance of interference by a protruding ear plug.

The way to test ear plug attenuation on the job is to approach a worker, unannounced, during the work shift and hand the worker a sign that says “Please don’t touch your ear plugs” and “Follow me.” Then take him or her to the audiometric test room or booth and proceed to test the hearing with the plugs in place. After that, instruct the worker to remove the plugs and conduct another audiometric test. The difference between the two audiograms represents the amount of attenuation that the plug is providing at each test frequency. Usually it is necessary to test only a few frequencies in each ear, such as 500, 1000, and 2000 Hz. It is always a good idea to follow these sessions with some counseling, indicating to the worker whether or not adequate attenuation is occurring, and, if the attenuation is inadequate, providing advice on how to improve it.

Another useful procedure is to give a group of workers an audiometric test before the beginning of the work shift and again at the end of the shift. If the hearing threshold levels in certain workers show a deterioration in the second test, then the hearing protectors are not providing sufficient attenuation or perhaps they are not even being worn. Counselling, refitting, and retraining should improve the situation, and the tests may be repeated at a later date.

(see Hearing protectors on page 12)
The attenuation of ear muffs can also be tested in the field, but the procedure is a bit more complicated. It requires the use of two dosimeters with the smallest possible microphones. One of the microphones is worn on the worker’s shoulder and the other is placed carefully inside the ear muff. At the end of the work shift the two dosimetric readings are compared, converted to time-weighted average exposure level in decibels (TWA). The difference between the two readings is the attenuation provided by the muff. This procedure should be carried out by someone who is trained in the use of this kind of instrumentation.

The development of a new ANSI standard

At this time professionals in hearing conservation are working on the development of a new ANSI standard. ANSI Standard S12 Working Group 11 is attempting to develop a laboratory standard that will more closely approximate the use of hearing protection in the real world. Several laboratories are working together on important issues, such as the selection and training of subjects and the supervision of hearing protector fitting. Because this kind of consensus standardization usually takes years to accomplish, a new standard may not be available for quite some time. But there is some promise that the gap between the NRR and the attenuation realized in the field may be narrowed.

How hearing protection affects the perception of speech and warning signals

Workers’ resistance to hearing protection

Hearing conservation professionals, such as industrial hygienists and audiologists, have struggled for years with workers’ resistance to wearing hearing protectors. One of the most frequently-cited objections by workers is that they feel they are unable to hear speech and warning signals when they are wearing these devices. Hearing conservationists then explain to workers that hearing protectors reduce the sound level of both speech and background noise by the same amount, and therefore, the desired signal should be unaffected. In fact, the ability to communicate can actually be improved because hearing protectors can reduce overall noise levels to a point where the ear is not so stressed and less distortion is likely to occur. This improvement does often occur in high noise levels, over 90 dB(A) and especially over 100 dB(A).

For many workers, however, this benefit does not seem to be realized. Studies have shown that as many as one-half of the workers who wear hearing protection believe that the protectors “block” or partially block essential sounds. Part of the problem is that workers, especially when they are not used to wearing the devices, need some time to adjust to changes in the sounds of their machines and in other important signals. Although time and persistence sometimes help, the problem is often more complicated than it seems.

The acoustics of the problem

Hearing speech

If hearing protectors did indeed attenuate (reduce) all sounds by the same amount, then speech and warning sounds should be perceived as readily with or without protectors. Nearly all protectors, however, attenuate high frequency sounds more efficiently than low frequency sounds. This is especially true of ear muffs. Thus, the frequency spectrum is changed when one wears protectors, making high-pitched sounds more difficult to hear. This can make it difficult to understand speech communication because most of the meaning in speech is carried by consonants, which are higher in pitch and softer than vowels. The result is that one hears a person is speaking but cannot understand what is being said.

The problem is compounded by high-frequency hearing loss, which is very common among industrial workers. Both noise and the aging process tend to damage hearing for high-frequency sounds sooner and more severely than hearing for low-and middle-frequency sounds. For example, a worker who has been working unprotected in high levels of noise for a number of years will develop a hearing loss. Then, when hearing protection is initiated, the device’s high-frequency attenuation may reduce the level of the consonant sounds to the point where speech is unintelligible or completely inaudible.

An interesting side effect of hearing protection stems from what is called the “occlusion effect,” which causes the wearer’s own voice to sound unusually loud. This effect occurs most often when ear plugs are inserted only superficially. The result is that hearing protection wearers tend to lower their voices, and others may

(see Perception on page 13)
have difficulty hearing their speech in a background of noise. Speech communication may be even more difficult when both parties in a conversation are wearing hearing protectors. These types of problems are alleviated when both communicators are able to see each other and use visual cues, such as lip reading and gesturing.

Hearing warning signals

When workers wear hearing protectors, they also complain they cannot hear non-verbal warning signals, such as sirens, buzzers or the sounds of machinery malfunctioning. In some cases, warning signal perception will be unaffected or even improved by the use of hearing protectors if the warning signal is loud enough, if its acoustical characteristics are sufficiently different from the background noise, and if it is not affected by the high-frequency attenuation of the hearing protector. Otherwise, studies have shown that workers wearing protectors do tend to have difficulty hearing warning signals, especially when they have some amount of hearing loss.

Another effect has not received very much attention: hearing protectors can adversely affect the ability to localize sound (i.e. to determine the location of a sound signal). Both plugs and muffs can cause difficulty determining whether a signal is coming from ahead or behind. Ear muffs can also cause confusion between left and right sound sources and can drastically impede the ability to localize a sound in the vertical plane. This can mean extra problems for a person, such as a construction worker, who must watch out for falling objects or for the approach of potentially dangerous equipment.

We have to remember, however, that both the noise in the workers’ environment and the hearing loss the noise can produce will also adversely affect workers’ abilities to hear and understand speech, to hear and correctly diagnose mechanical problems, to hear warning signals and to localize the sounds of danger. Failure to reduce the offending noise or to protect workers adequately with hearing protectors can cause a handicapping hearing loss, which in turn, will exacerbate the problems we are trying to avoid. So those who issue and those who wear hearing protectors are walking a fine line. Fortunately, there are solutions to these problems.

Solutions

1. The most effective solution is always to control the noise at the source or in the worker’s environment so that the risk of hearing loss will be minimized and the use of hearing protectors will not be necessary. This solution, however, is not always possible.

2. Workers need to be carefully trained in fitting and using hearing protection. When an ear plug is fitted properly it is likely to attenuate somewhat more evenly across the frequency spectrum instead of attenuating only high frequencies. Also, workers need to be told that their machines may sound different when they wear hearing protectors, and they need to be encouraged to get used to the new sound. A training program should include practice in communicating while wearing hearing protection. Workers should also be encouraged to keep their voice levels from dropping and to use visual cues whenever possible.

3. Those who purchase hearing protectors and fit workers with them need to be sensitive to workers’ complaints about the interference with speech and warning signals and should be careful not to select a protector with too much attenuation. For example, why select a protector with an NRR of 35 dB when only 15 dB of attenuation is needed?

4. Warning signals should be tailored to the noise environment in which they are to be used. Acoustic signals can be replaced with flashing lights or other visual signals; a frequency spectrum can be changed so as not to be masked either by the noise environment or by the hearing protector’s attenuation. It may be helpful to consult an acoustical engineer or an industrial hygienist well-versed in acoustics for this solution.

5. In situations where speech communication is essential, the use of electronic communication systems should be given serious consideration. Cordless, as well as cored systems, are now available and ear plugs can be worn successfully under head phones if more attenuation is needed. One helpful technology that is just emerging is the noise-canceling headset, which reduces low-frequency sounds considerably more than high-frequency sounds. When worn in combination with conventional ear plugs, the resulting attenuation can be very effective, yet allow much of the high-frequency sound energy to be audible.

For further reading


Motivating, training and educating for hearing protection

Some good reasons to protect hearing

Most of us need to be taught, or at least reminded of, the reasons for preserving hearing. Some of them are obvious — like preserving the ability to hear our families, friends and children. Protecting hearing is also important for the ability to hear our grandchildren, because the aging process slowly and inevitably adds to the burden caused by noise-induced hearing loss. But there are other reasons to protect hearing.

One of the most vital is to avoid the social isolation, loneliness and depression that often accompany hearing impairment, especially later in life. Another reason is to avoid the other reasons to protect hearing.

The importance of motivation

If employees are adequately motivated to wear hearing protectors, a hearing conservation program’s chances of success are significantly better. This is especially true when working in moderate noise exposure levels (about 85 dB(A)) to values in the low 90s, as well as in intermittent noise conditions, where workers need to turn protectors and take them off periodically. In addition, older workers, who have been exposed to noise for many years and who may have acquired some noise-induced hearing loss, may lack motivation for wearing hearing protection. They may feel they are already hearing-impaired, saying, “why bother to wear these things?”

It seems to be more difficult to instill an understanding of the risks and hazards of noise than it is for many other safety and health hazards. For one thing, noise-induced hearing loss is invisible — ears don’t bleed or appear to be affected in any way. Also, the growth of hearing loss is insidious. Some workers may notice a temporary dullness of hearing after the workshift, but the hearing often improves after 16 hours of rest. What they are not aware of is that this temporary loss begins to become permanent if it continues, day after day.

In addition, the nature of noise-induced hearing loss tends to be ambiguous, meaning that a person may be able to hear well in some circumstances, such as face-to-face conversation in quiet surroundings, but will have difficulty in other situations, such as conversation in groups or in places where there is background noise.

Finally, there is a reluctance to acknowledge hearing loss because it is often associated with old age and infirmity. This results in denial, both of the noise hazard and the hearing loss it causes. For these reasons, the people who conduct hearing conservation programs need to be diplomatic, understanding, knowledgeable and vigilant in the training and motivation of workers.

OSHA’s requirements for training programs

Section (k) of OSHA’s noise standard requires that employers conduct annual training programs for all employees exposed to noise at or above an 8-hour TWA (time-weighted average) noise level of 85 dB(A). The program must include (1) information on the effects of noise on hearing; (2) the purposes of hearing protectors, including their advantages and disadvantages, the attenuation provided by various types, and instructions on their selection, fitting, use and care; and (3) the purpose of audiometric testing and an explanation of the testing procedures.

Management must be involved

If the hearing conservation program is to be successful, salaried personnel, even top management, must support and be involved in the program. These people often need to be motivated themselves. They need to understand the reasons for the program, why hearing is so important to preserve, what happens to the unprotected noise-exposed ear, and that they should always wear hearing protectors in posted areas, not only to provide a consistent example for employees, but to protect their own hearing.

Conducting training and motivation programs

Training and motivation should occur in groups as well as individually. Group programs provide employees with the opportunity to ask questions, learn (see Training on page 15)
from each other, and know that they are not alone in their concerns. Videos and pamphlets can be useful but they must never take the place of face-to-face instruction. The groups should not be so large that they preclude an informal, seminar-type atmosphere. Sessions should not be too long; a maximum of 15-20 minutes. Instructors should be knowledgeable in their subject matter and should relate well to workers. They should encourage workers to ask questions and to come forward with any problems. In turn, these problems should be resolved as promptly and efficiently as possible.

Training sessions should be interesting but not too technical. Many employees, however, will be curious about the workings of the ear, so a chart showing a cross-section of the hearing mechanism may be useful, along with an explanation of how the ear operates, both normally and when exposed by noise. Some trainers like to use the metaphor of grass to represent the inner ear’s tiny hair cells, (the sensory cells of the inner ear). You can walk on a patch of grass causing the blades to bend over, but after you leave, they will usually regenerate. If, however, you keep treading on the same patch day after day and year after year, the grass will eventually die off, leaving a bare spot. The same is true of the ear’s hair cells.

The group should be told about the keys to identifying noise-induced hearing loss: persistent tinnitus (ringing in the ears), a sensation of “muffled” hearing after the workshift, difficulty understanding what people are saying when listening in groups or in noisy surroundings, and the belief that people are mumbling and not speaking clearly.

Training and motivating does not end with the group session. The program must be an on-going concern. The trainer or hearing conservationist should stop and speak to employees on the job, during breaks, and whenever appropriate, notice whether ear plugs are inserted correctly, check ear muff headbands and cushions, and ask questions about their use and comfort. The annual audiometric test (or the follow-up re-test) is also a good time to counsel employees about the status of their hearing and their use of hearing protectors.

If individual employees have problems adjusting to wearing hearing protectors, a break-in period may be required. During the break-in period, an employee wears the protector for only a few minutes the first day, then for longer and longer periods on subsequent days, working up to the necessary durations as quickly as possible. Sometimes workers will complain that their machines sound different when they wear protectors. They may need a gradual break-in period to become used to the new “acoustic signature” of the machine.

Motivational techniques

One of the most valuable and simple techniques for motivating employees is to explain their audiometric test results; teaching them the meaning of the audiogram and comparing a current audiogram to previous audiograms and possibly to that of a hypothetical person with “normal” hearing, matched for age and sex. If threshold levels remain stable, the employee should appreciate this good news. If threshold levels are deteriorating, the time is ripe for a counseling session, which should include a refresher course in fitting and wearing hearing protection.

It is important to reward employees for wearing hearing protection effectively and not to reward them for failure to use it or for using it ineffectively. This involves working with the employee to improve the situation. The protector may be uncomfortable, requiring a change to a different size or type, or it may be damaged or worn, requiring a replacement. Alternatively, the employee may be wearing the protector, but failing to insert it correctly.

Then again, the worker may be fearful of a safety hazard caused by the inability to hear indications of trouble, such as malfunctions in his or her machine. A worker also may fear the inability to communicate when protectors are worn properly. This problem needs considerable sensitivity on the part of the hearing conservationist or supervisor, because the employee’s fears could be quite legitimate. The professional needs to work with the employee to uncover the problem areas and investigate solutions. Noise control measures may need to be undertaken, or the employee may need to be fitted with special protectors that attenuate evenly across the frequency spectrum. If communication is an integral part of the job, ear muffs with active noise reduction or communication headsets would be indicated.

Some companies provide institutional rewards, such as cash or lottery tickets for employees or departments with good safety records, including hearing conservation. Some companies make hearing wearing protectors a condition of employment and some use disciplinary actions for recalcitrant employees. Punishment, if it is a company policy, should be used only as a last resort, because many cases of resistance are due either to ignorance or to legitimate concerns, and there are many positive methods that may be employed to change uncooperative behavior.

Demonstrations

Certain demonstrations may be useful in motivating workers to protect their hearing. One that can be very effective is practical at this time only with ear plugs (not muffs), (see Training on page 16)
and can only be conducted in an audiometric booth or in a mobile audiometric testing unit. The demonstration involves taking individual workers away from the work station, cautioning them not to touch their plugs, and then testing their hearing with the plugs in place. After that, the plugs are removed and the test is repeated. The difference between the “plugged” and “unplugged” hearing thresholds gives an approximation of the attenuation currently being achieved. This is not a scientific test because the results may not be exact for various reasons. For example, during the test, the ear plug may come into contact with the headphone’s cushion or receiver. However, the demonstration gives a good indication of how well the plugs are working.

Another interesting demonstration involves testing a worker’s hearing before and after the workshift. If the protectors are working properly, the post-workshift threshold levels should be just as good as or slightly better than the pre-workshift levels. If they are worse, it is an indication that a temporary threshold shift (TTS) is taking place and there is inadequate protection from noise.

Audiograms may also be used as a demonstration in group training sessions. The trainer may make a composite audiogram for a particular group or department, or may create a hypothetical audiogram, typical of the group, and compare it to another, standard audiogram, matched for age and other factors. It is not good practice to use an individual employee’s audiogram in front of the group, especially if it is identified with an employee’s name.

Educational aids

As mentioned above, educational materials, such as videos and pamphlets, are not a substitute for person-to-person contact, but can be helpful as supplemental aids. Videos should be lively and informative, and no longer than about 10-12 minutes. Written materials should be readable, easy to understand and up-to-date. All materials should reflect the hearing protector options provided by the specific company, and, if possible, should reflect the conditions encountered within that company. For example, a video filmed in a textile plant would not be appropriate for workers in metal fabrication plant.

It’s worth the time and effort

Hearing conservation programs administered to unmotivated employees are likely to be a waste of time and resources. But, when employees are given the information and attention they need, encouraged to participate in the program and rewarded for wearing protectors effectively, the success in terms of hearing conserved is worth the time and effort.

Involving the family

Employees sometimes seem to be more interested in the hearing health of their families than they are in their own hearing health!