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NIOSH Hearing Loss Prevention Program for Mining

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ABSTRACT

Noise-induced hearing loss (NIHL) continues to be a pervasive problem for the nation's workforce, particularly the nation's mining personnel. As one of the leading health and safety organizations in the world, the National Institute for Occupational Health and Safety (NIOSH) in Pittsburgh maintains a Hearing Loss Prevention Program (HLPP) to conduct research to reduce NIHL loss among the nation's miners. This document provides a brief overview of this HLPP, describing some of the research techniques involved in the development of engineering noise controls, methods for the development of administrative noise controls, and some of the products available to the public to protect the nation's workers hearing.

KEYWORDS: NIOSH, hearing conservation, hearing loss prevention, hearing protection, mining, noise controls, NIHL

Noise-induced hearing loss (NIHL) due to excessive occupational noise exposure is one of the most common work-related illnesses in the United States.[1] In 2009, as reported by Tak et al, there were about 22 million U.S. workers exposed to hazardous workplace noise.[2] In 2000, a publication by the National Institute for Occupational Safety and Health (NIOSH) estimated that $242 million is spent annually on workers' compensation for hearing loss disability. In the mining industry, NIHL is particularly severe. Therefore, the NIOSH Pittsburgh Mining Research Division (PMRD) maintains a robust HLPP to conduct research to protect the hearing of the nation's mining workforce. NIOSH, the Occupational Safety and Health

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Table 1 Organizational noise exposure criterion

	NIOSH-recommended exposure level	MSHA-permissible exposure level	OSHA-permissible exposure level	OSHA action level
Criterion (dBA)[a]	85	90	90	85
Threshold (dBA)[b]	40	90	90	80
Exchange rate (dB)[c]	3	5	5	5

[a]The sound level which, if constantly applied for 8 hours, results in a dose of 100% of that permitted by the standard.
[b]The minimum sound level contributing to the noise dose.
[c]An increment of decibels that requires the halving of exposure time, or a decrement of decibels that requires the doubling of exposure time.

Administration (OSHA), and the Mine Safety and Health Administration (MSHA) all have noise exposure level requirements for workplaces (Table 1). For the Mining Program, NIOSH research seeks to reduce a miner's noise exposure to below the MSHA Permissible Exposure Level (PEL) of an 8-hour time-weighted average of less than 90 dBA. Research within the HLPP is guided by a hierarchy of noise controls as follows:

1. Control the noise at the source (with engineering noise controls).
2. Avoid noise sources (with administrative noise controls).
3. Protect your ears (with hearing protection).

Of course, the apparently simplest (and most cost-effective) method to protect one's hearing is to wear hearing protection. A downside to this is that wearing hearing protection hinders verbal communication, reduces the user's ability to hear warning signals, introduces the inconvenience of wearing the protection, and a variety of other factors. Additionally, hearing protection protects only the user. Engineering noise controls are the preferred method of noise controls, if feasible and properly utilized. They also have the additional advantage of protecting all personnel in the vicinity. But retrofit noise controls are typically expensive and time-consuming to develop. They may also be difficult or impossible to implement given the equipment or environment under consideration. Quiet-by-design noise controls, once developed, and included in the original construction of the equipment, would be cheaper alternatives.

PMRD RESEARCH FACILITIES

NIOSH PMRD maintains two large acoustical laboratories and a mobile trailer unit for hearing loss prevention research purposes. First, the acoustic test chamber (ATC) is a large reverberation room used for sound power testing (Fig. 1). NIOSH maintains National Voluntary Laboratory Accreditation Program (NVLAP) accreditation per the ANSI S12.51/ISO 3741 acoustic standard for precision-grade sound power determination for this facility.[3] Both accredited and non-accredited testing can be conducted per this standard. Additionally, NIOSH conducts engineering-grade sound power testing in the ATC per the ISO 3743-2 acoustic standard[4] that are not accredited.

Built in 1983 as a facility of the Bureau of Mines, the ATC's design specifications called for the chamber to be able to withstand (with a safety factor of 2) continuous sound pressure levels of 130 dB at any single frequency down to 100 Hz.[5] Given the large size of expected test products, the general room dimensions are 18.3 m × 10.3 m × 6.7 m (60′ × 34′ × 22′), providing for a chamber surface area of 784 m^2 and a volume of 1,286 m^3. There is a large sliding steel equipment door for device-under-test (DUT) access and egress. To provide electrical power for prospective DUTs, there is a 480-VDC 3-phase voltage available inside the ATC and also an external load center.

To expand the testing capabilities of the HLPP, in 2006 NIOSH constructed a second test facility, a hemi-anechoic chamber (HAC).[6] The HAC is a more versatile test chamber, allowing for a wider variety of testing than the ATC. NIOSH utilizes the HAC for noise source identification (NSI) purposes as well as

Figure 1 Test apparatus in the acoustic test chamber (ATC).

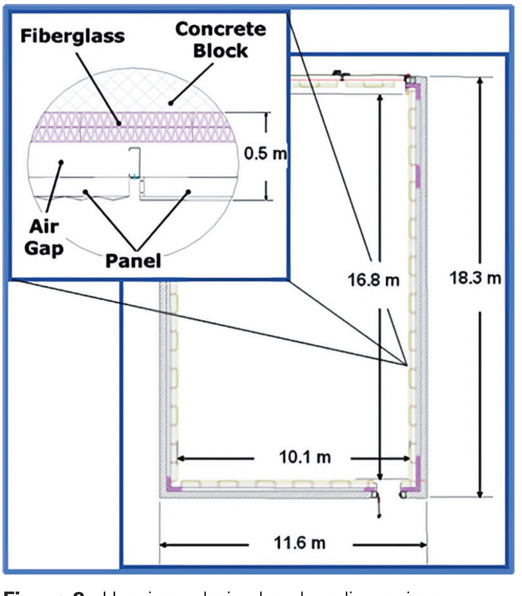

Figure 2 Hemi-anechoic chamber dimensions.

for sound power level measurements per ISO 3744 and ISO 3745 and also for sound pressure level measurements.[7,8]

The HAC was constructed within an existing building. An 18.3 m × 11.6 m × 7.6 m (60′ × 38′ × 25′) block-wall room was built to serve as the interior of the HAC (Figs. 2 and 3). The floor of the chamber is poured concrete. The HAC interior dimensions are 16.8 m × 10.1 m × 6.4 m (55′ × 33′ × 21′). At the south end of the chamber, there are two 9.6 m × 2.7 m (31.5′ × 9′) doors for equipment access and egress of large mining equipment. To save space and because testing occasionally is conducted under wet conditions, NIOSH chose to forgo standard foam acoustic wedges as acoustic treatments in the chamber. Instead, Eckel Industries-perforated V-ridged super-soft panels for a 200-Hz cutoff frequency were used for acoustic treatments. These panels also cover the large equipment access doors of the chamber and personnel doors at the north and south ends of the chamber. Additionally, there are electrical power outlets, communication lines, and a patch panel to connect microphone and other signal cables to the control room. The HAC also has a four-camera video

Figure 3 Hemi-anechoic chamber set up for sound power testing per IS0 3745.

Figure 4 Four simultaneous audiograms can be conducted in the NIOSH Hearing Loss Prevention Unit.

system that is used to monitor testing. Outside the chamber, there is a load center to provide electrical power to the equipment under test as well as 480-VDC 3-phase power.

NIOSH also operates a four-person mobile audiometric testing trailer (Fig. 4). This custom trailer is outfitted with four Benson audiometers and can provide four simultaneous audiograms. Researchers and technicians take the hearing loss prevention trailer to outreach activities across the country to conduct hearing tests and trainings on proper selection and use of hearing protection. The trailer has been to various mining and public outreach events across the United States to provide overall hearing loss prevention guidance, as well as insight into other NIOSH-developed health and safety tools and initiatives.

Figure 5 Spark 705+ dosimeter used for field testing.

ENGINEERING NOISE CONTROLS

Engineering noise controls reduce worker's noise exposure by limiting the noise reaching an employee through engineering design, i.e., they reduce equipment noise emission or block noise from reaching the worker, as with noise barriers. Effective noise control development to reduce worker's noise exposure requires a somewhat cyclical process.

The first step is to conduct noise measurements in the field (e.g., mine, quarry). Dosimetry and time-motion studies coupled with sound pressure level and frequency measurements provide valuable data early in the noise control development process (Fig. 5). The duty cycle of a DUT is delineated by task and simultaneous dosimetry and time-motion studies are conducted (Fig. 6). From these, an overall noise exposure is determined, including mean sound pressures for each duty cycle task and, most importantly, the task or activity during which the worker accumulates the most noise dose and is exposed to the highest noise level. Additional information is drawn from sound level measurements and fast Fourier transform and/or one-third octave band data collection and analysis.

LHD or haul truck log sheet						
Sample date						
Load		Haul		Dump		Notes
Start	Stop	Start	Stop	Start	Stop	

Figure 6 Example log sheet for dosimetry and time-motion studies.

Figure 7 Beamforming analysis locates two noise sources on a jumbo drill.

If field testing is not available early in noise control development, NIOSH conducts initial sound power level testing to quantify overall equipment noise emissions in one of its acoustical laboratories. These data serve as a baseline, with the long-term objective being to reduce the equipment noise emission with the application of developed engineering noise controls. The effectiveness of the noise controls can be determined by retesting post application.

Once the baseline noise levels have been quantified, either in the field or laboratory, the source of the noise must be determined. Noise source identification is best conducted in an acoustically controlled environment a laboratory provides but, when necessary, can be conducted in the field. NIOSH employs beamforming analysis to localize noise sources. An example of beamforming analysis of a jumbo drill shows noise sources along the drill string, one near the drill bit end and another near the drifter (drilling mechanism) end (Fig. 7). NIOSH also conducts Source-Path-Contribution (SPC) analysis to localize noise sources. Here, prospective noise sources are selected and tested to determine their contribution to the sound level at the equipment operator's location (Fig 8).

Once significant noise sources are determined, then prospective noise controls are developed to address those sources. The process then repeats with field testing to confirm a reduction in operator's noise exposure and sound levels with dosimetry and time-motion studies or in the laboratory with sound power and sound pressure testing. Refinements of the prospective noise controls follow, with the objective of repeating these cycles until the operator's noise exposure is reduced by 3 dB, a 50% reduction in exposure given a 3-dB exchange rate, or the operator's noise exposure is reduced to below 90 dB, the MSHA Permissible Exposure Level (PEL) criterion.

Over the years, NIOSH has collaborated with equipment manufacturers in developing and demonstrating commercially available engineering noise controls to reduce equipment noise emissions and, in turn, operator's noise

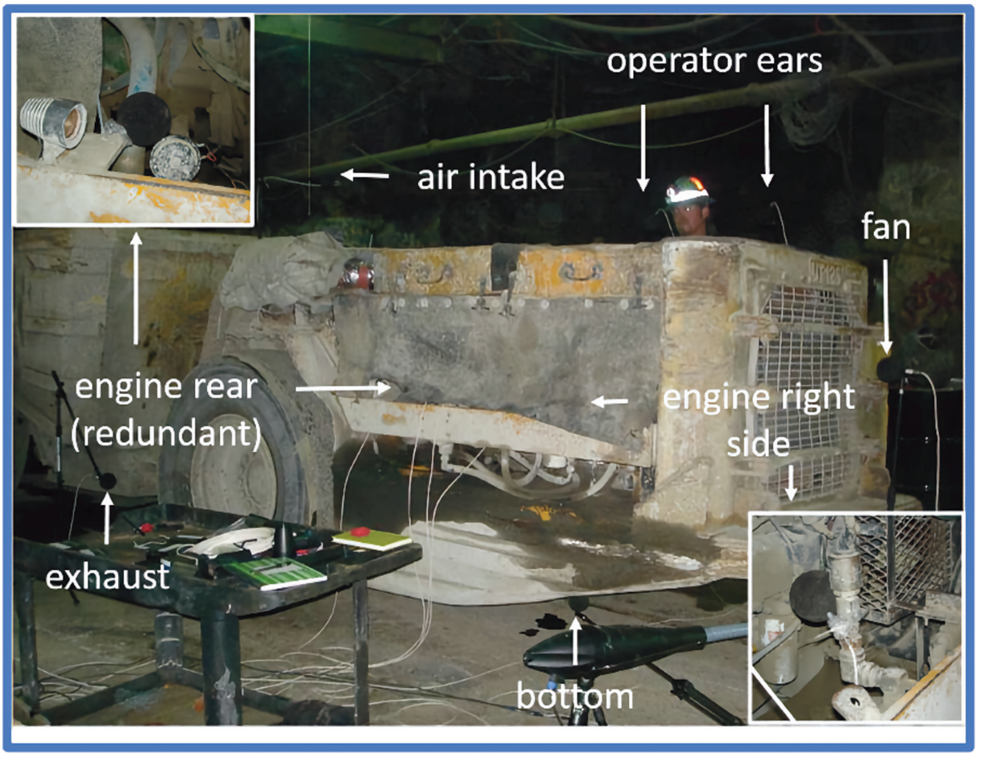

Figure 8 SPC testing on an underground haul truck. Prospective noise sources and operator location shown.

Figure 9 Continuous mining machine prior to sound power testing in the ATC.

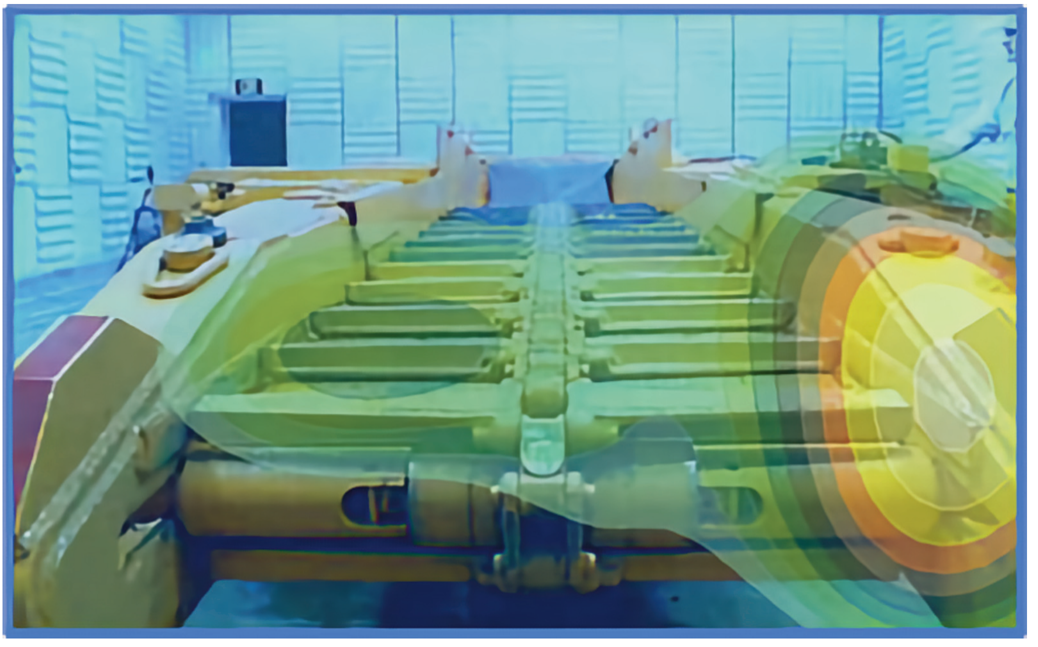

Figure 10 Beamforming analysis confirms that the conveyor chain is a significant noise source on a CMM.

exposure. A continuous mining machine (CMM) is used in underground coal mines to break up the coal into manageable sized pieces (Fig. 9). The coal is then moved away for processing via shuttle car and/or conveyors. CMMs themselves have conveyors to move the coal away from the coal cutting drum to the rear of the machine. Beamforming analysis confirmed that the conveying chain was a significant source of CMM emitted noise (Figs. 10 and 11).[9] The conveyor flight bars impact and scrape along the conveyor deck, generating noise. Also, the conveyor deck swings right and left, loosening the chain tension, emitting higher noise levels than when the chain is in the centered position. NIOSH worked with a collaborating manufacturer to develop and test several engineering noise controls to reduce CMM conveyor chain noise. These include a urethane-coated flight

Figure 11 Standard conveyor chain.

Figure 12 Urethane-coated flight bar chain.

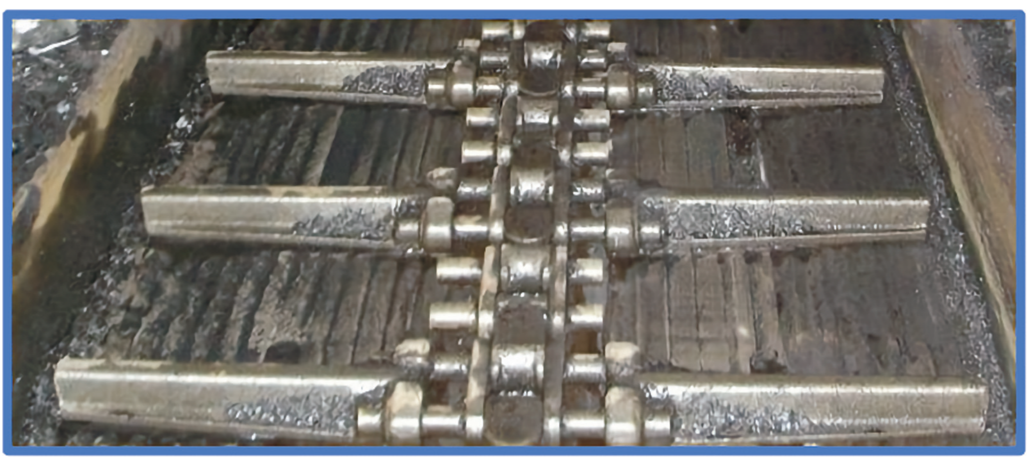

Figure 13 Dual sprocket chain.

bar chain to reduce impact and scraping noise along the conveyor deck (Fig. 12), and a dual sprocket chain to help maintain chain tension when the conveyor deck is moved right or left (Fig. 13).[10] This work culminated with the development of a commercially available urethane-coated dual sprocket conveyor chain (Fig. 14).

A roof bolting machine is used in coal mines to drill holes and install roof bolts into the top (roof) of the mine to maintain roof support and prevent catastrophic roof falls. The machine operator works near the drilling and bolting mechanism, and beamforming analysis confirmed that the drill steel was a significant source of noise emission (Fig. 15). During drilling, the cutting of the rock by the drill bit mechanically excites the drill steel, causing it to vibrate and radiate noise. The solution was to develop a drill bit isolator to break the metal-to-metal link between the drill bit and the drill steel (Fig. 16).[11] While drilling with the bit isolator, the drill steel vibrates less and radiates less noise. Underground testing of the drill bit isolator showed noise levels at the

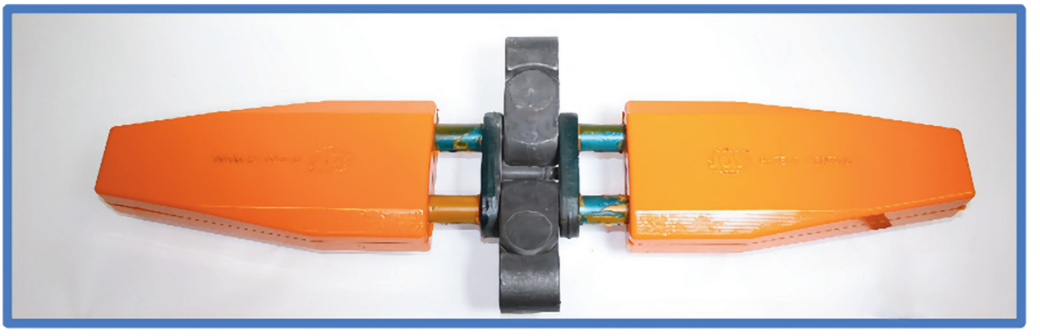

Figure 14 Urethane-coated dual sprocket flight bar.

Figure 15 Beamforming analysis confirms that the drill steel is a significant noise source on a roof bolting machine.

operator's location were reduced by 3 dB when compared to baseline drilling.[12]

Additional engineering noise controls that NIOSH has developed include the following:

- Partial cabs for surface water well drills.
- Collapsible drill steel enclosure for roof bolting machines.
- Drilling chuck isolator for roof bolting machines.

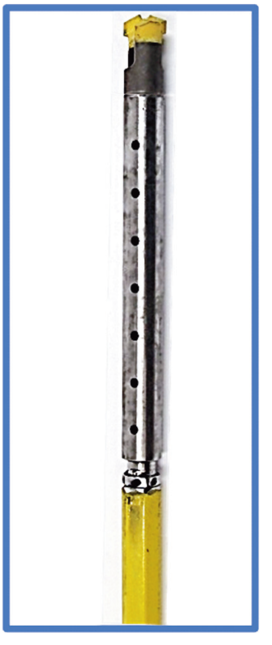

Figure 16 The drill bit isolator reduces noise radiation from the drill steel.

- Enclosures for longwall shearer systems.
- Enclosures for vibrating screens shaker mechanisms.
- Modified cooling fan systems for underground haul trucks and load–haul–dumps.
- Drill string centralizers for jumbo drills.
- A patent for longwall shearer modeling for noise radiation.

ADMINISTRATIVE NOISE CONTROLS

Administrative noise controls reduce worker's noise exposure, not by reducing the noise but by limiting the time a worker is exposed to noise. An example of these controls includes job

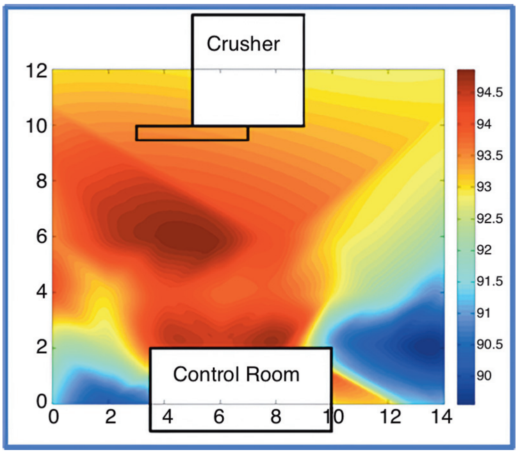

Figure 17 Noise contour maps are a useful tool to warn workers of high noise areas.

rotation, where workers share job classifications by rotating between lower noise and higher noise jobs. Here, the objective is to ensure that neither worker is overexposed to noise. Other examples of administrative noise controls are limiting access to high noise areas, providing quiet areas, and conducting work tasks remotely if possible.

Tools for the development of administrative noise controls include the analysis of noise contour maps (Fig. 17) in which high noise areas are documented and presented in an easily discernable format, warning workers to avoid these areas whenever possible. These maps could be coupled with additional warnings, for example, signage, flashing lights, and barriers for worker's hearing safety. Additionally, color contour maps are useful to illustrate area

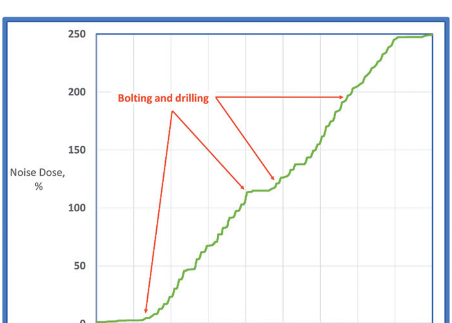

Figure 18 Dosimetry and time-motion studies can indicate high noise tasks.

noise levels before and after installation of engineering noise controls or to compare worker area noise levels over time. Dosimetry and time-motion studies can also be used to assist in the development of administrative controls. Cumulative noise dose plots can show what equipment operators are doing while accumulating noise dose (Fig 18). In this example, a roof bolting machine operator accumulates the bulk of their noise dose when bolting and drilling. To reduce the operator's noise dose, the worker could share the bolting and drilling with an employee who works in a less noisy job.

HEARING PROTECTION

It is recognized that hearing protection devices (HPDs) have several drawbacks, including unreliable attenuation unless worn correctly, discomfort for some users, and attenuation that blocks desired sounds along with noise. Specifically, miners have expressed concerns that wearing HPDs inhibits their ability to communicate with coworkers and reduces the audibility of alarms and other auditory warnings. Decreased audibility is not only a communication nuisance but can also contribute to unsafe working conditions. For miners who exhibit hearing loss, the degradation in audibility while wearing hearing protection can be even greater. An in-depth study of the use and effectiveness of electronic, output-limiting HPDs was conducted. This focused on HPDs with output-limiting technology that either compressed the incoming signal or used a low-pass filter model to limit the output of the device. When the input exceeded a predefined limit, the HPD would limit the output and in turn act as a standard earmuff. Both fixture-based and human subject data were collected regarding the ability to perceive speech in a background of various mining noises. The culmination of the research indicated that the use of output-limiting HPDs could be beneficial for mobile workers who experience a variety of noise levels throughout their workday. The devices are the most effective at improving speech intelligibility when they are set to a lower output level and primarily for workers who are not in a constant, somewhat steady noise.[13]

Poorly fit hearing protectors pose another barrier to prevent NIHL among workers. HPDs marketed in the United States are tested in laboratories to determine their Noise Reduction Rating (NRR) using an experimenter-fit protocol. This rating is intended to represent the amount of noise protection that the protector can provide. However, the attenuation values obtained at worksites are often much less than those achieved in the laboratory.[14] With incorrect HPD fit, as often occurs with untrained users, little or no protection from noise may be obtained. NIOSH has developed two tools to aid users of HPDs in achieving adequate fit. The Roll-Pull-Hold method and QuickFit earplug fit tester are NIOSH products aimed at alleviating two specific issues with fitting earplugs.

It can be difficult to understand and remember the instructional wording and small print that is often found on the packaging of soft foam earplugs. Additionally, the directions for earplug insertion can be inconsistent between manufacturers or the packaging may be discarded before the directions are read and comprehended. NIOSH has developed and published the Roll-Pull-Hold method to simplify the insertion of soft foam earplugs by standardizing the instructions to focus on three words essential to the insertion task (Fig. 19). By breaking the instructions into three simple steps, each linked to a single word, users of foam earplugs can remember the insertion procedure without referring to the packaging, and in turn achieve a better plug fit.

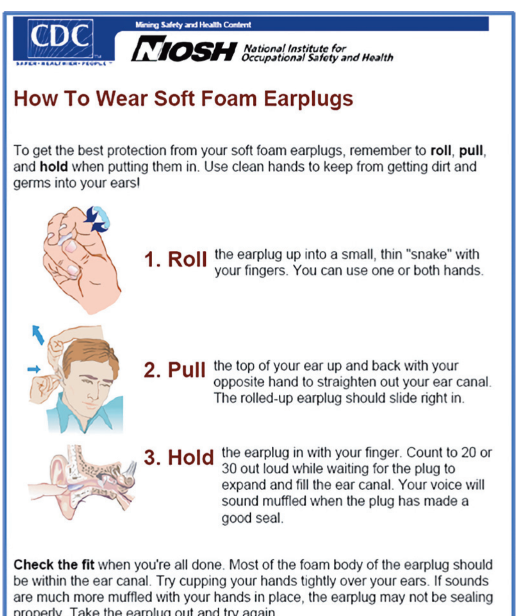

Figure 19 Simplified instructions facilitate better hearing protection.

Figure 20 The QuickFit is a simple method to test ear plug insertion effectiveness.

The NIOSH QuickFit is a highly simplified variation of laboratory fit evaluations such as the procedure specified in ANSI S12.6[15] (Fig. 20). The electrical components are derived by using off-the-shelf MP3 player components, with a few other parts, housed in the shell of a standard earmuff-style hearing protector. In contrast to most other fit-test systems, only one critical test frequency is used with the QuickFit, which saves time and allows for a simple three-step procedure that can be done at the worksite. QuickFitWeb is an online application that uses the same test tones as the handheld device, except that the sounds are played through computer speakers. This application, available to those with access to the internet via a computer or mobile device, allows for testing of earmuff-style protectors as well as plugs. The web version eliminates the need for the handheld device but does not allow for testing earplug fit separately for left and right ears.

The QuickFit does not replace more complex systems that provide users with a personal attenuation rating (PAR). Instead, the QuickFit tests only one frequency one-third octave band in a “go” or “no-go” paradigm designed to determine whether a user has achieved at least 15 dB of attenuation with earplugs. This simplified method of fit testing proves more time-effective for use at busy worksites and is simple enough for workers to use with a short, one-time training session. The QuickFit tests can be completed for both ears in less than 5 minutes.

HEARING LOSS PREVENTION TOOLS AND WORKER EMPOWERMENT

A variety of tools and guidance documents have been developed to assist workers with protecting their hearing. Workers in mining and other noisy occupations tend to believe that hearing loss is inevitable due to their high levels of noise exposure and the natural processes of aging. Without understanding the consequences of noise exposure on hearing, a worker has no reason to take any actions for protection against noise exposure. The NIOSH Hearing Loss Simulator was developed to motivate miners to protect their ears from NIHL (Figs. 21 and 22). It is a software training and communication tool that allows for self-experience of the impact of NIHL. The purpose of this tool is to motivate workers to protect their own hearing by allowing them to experience the potential hearing loss they may incur with conditions very similar to their “real life” work environment. A user of the Hearing Loss Simulator can adjust various parameters to estimate the hearing loss one would experience given a specific level of noise exposure over a specific number of years. The effects are shown visually on a frequency band control panel while the user listens to

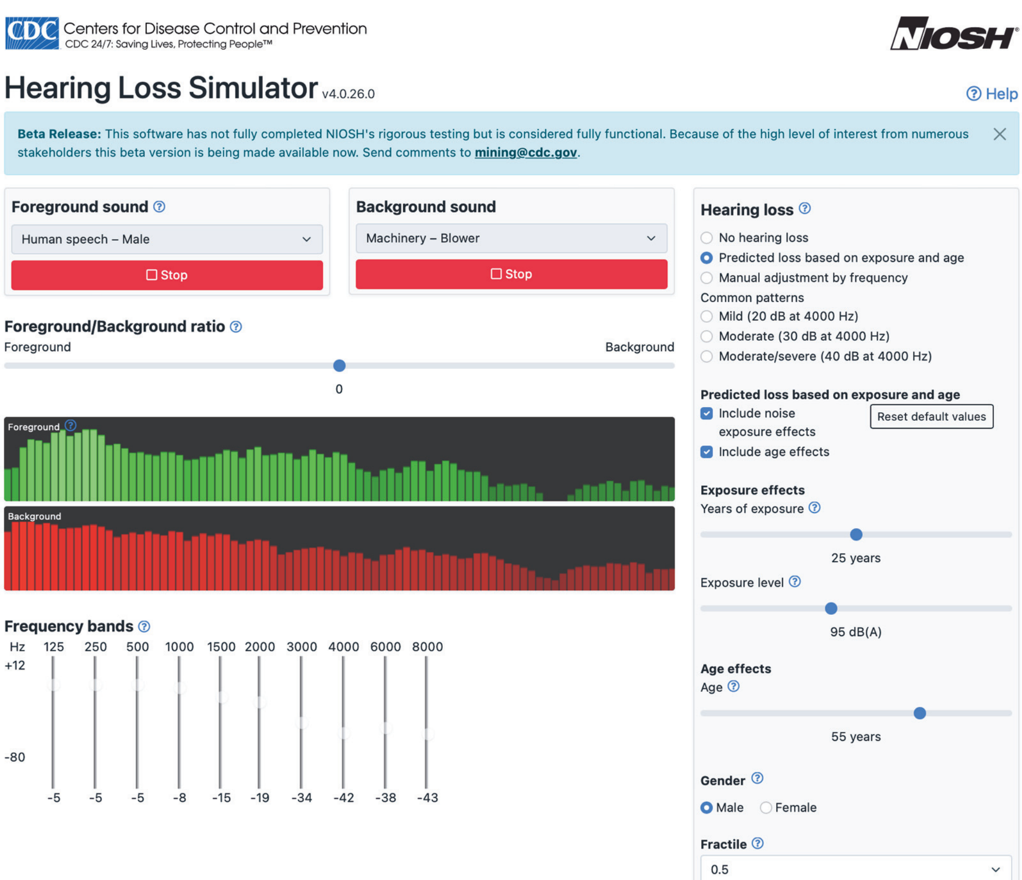

Figure 21 The NIOSH Hearing Loss Simulator is a great tool to educate workers on the effects of hearing loss.

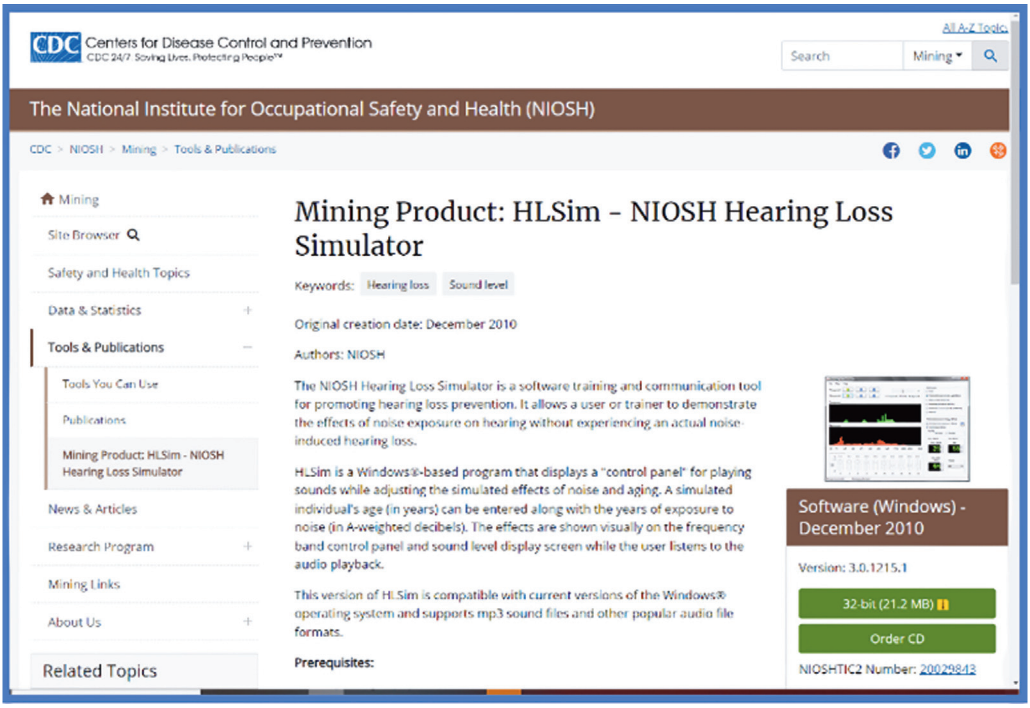

Figure 22 The Hearing Loss Simulator is a free download available from the CDC NIOSH web page.

audio playback. Additionally, frequency band sliders are available that allow users to manually input hearing thresholds, from an audiogram, for example, so that a specific hearing loss can be demonstrated. The Simulator gains realism by basing its approximation of the NIHL experience on models derived from hearing-impaired populations. The software performs calculations based on the ANSI standard S3.44, "Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment.[16] This tool has continually been one of the most visited websites and requested tools from NIOSH in the past decade.

Audiometric testing is the standard monitoring method in hearing conservation programs. Yet, audiograms remain misunderstood by most workers, leading to confusion and indifference regarding their hearing status and necessary steps for hearing protection. NIOSH developed the "Inquiring Ears Want to Know" fact sheet to increase worker's knowledge about their own hearing status (Fig. 23). This one-page (front and back) flyer is designed to augment the verbal information provided to workers after an audiometric test with written information and visual images for a greater retention of the most salient points. An explanation of test results is provided, along with tips for preventing future hearing loss, a list of non–noise-related causes of hearing loss, as well as a reminder of the Roll-Pull-Hold method for earplug insertion. The document is appropriate for all noise-exposed workers through simple wording and vivid images intended to convey complex messages. A Spanish translation is also available to accommodate the growing Spanish-speaking segment of the workforce.

The "CAP the Noise" campaign was developed to strengthen the knowledge of employers and workers about the hierarchy of noise controls (Figs. 24 and 25). Often, reliance is placed on the use of hearing protection when workers are over-exposed to noise. However, hearing protection use is fraught with difficulty and reliant on skill by the user. NIOSH developed the "CAP the Noise" flyer and sticker to

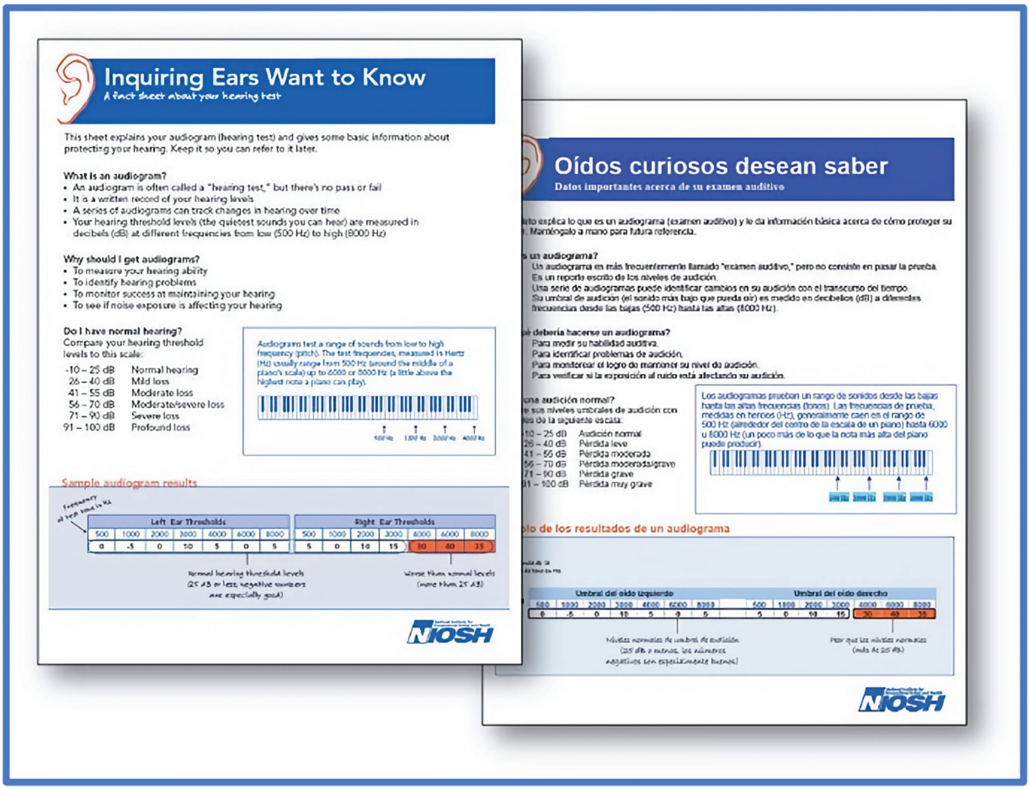

Figure 23 The "Inquiring Ears Want to Know" fact sheet provides plain language explanations of audiometric testing results. A Spanish version is also available.

remind workers that controlling the noise at the source is the most effective means of reducing noise exposure. If equipment noise is still too high, the worker is reminded that they can protect their hearing by avoiding the noise through administrative controls and lastly using hearing protection.

Another outreach tool aimed at improving workers' self-empowerment to reduce noise exposure is the "NOW HEAR THIS!" fact sheet (Fig. 26). This fact sheet is aimed at providing easy-to-implement, inexpensive, or free solutions to occupational noise overexposure. This, along with the other facts sheets, is made available at no cost on the NIOSH Mining website and is provided at the various conferences, meetings, and other outreach initiatives attended by NIOSH researchers.

SUMMARY

NIHL continues to plague the nation's mining workforce. To address this issue, NIOSH maintains a hearing loss prevention program to develop engineering and administrative noise controls to reduce miners' noise exposure. Per the hierarchy of noise controls, NIOSH has developed engineering noise controls to reduce equipment noise emissions. Several of these engineering noise controls are commercially available, such as a dual sprocket CMM conveyor chain and a drill bit isolator. Relating to administrative noise controls, NIOSH has demonstrated how time-motion and dosimetry studies can show high noise duty cycle tasks that should be avoided or shared among workers to reduce noise exposures. Noise contour maps can also be used to illustrate high noise areas to be avoided. The Roll-Pull-Hold method of ear

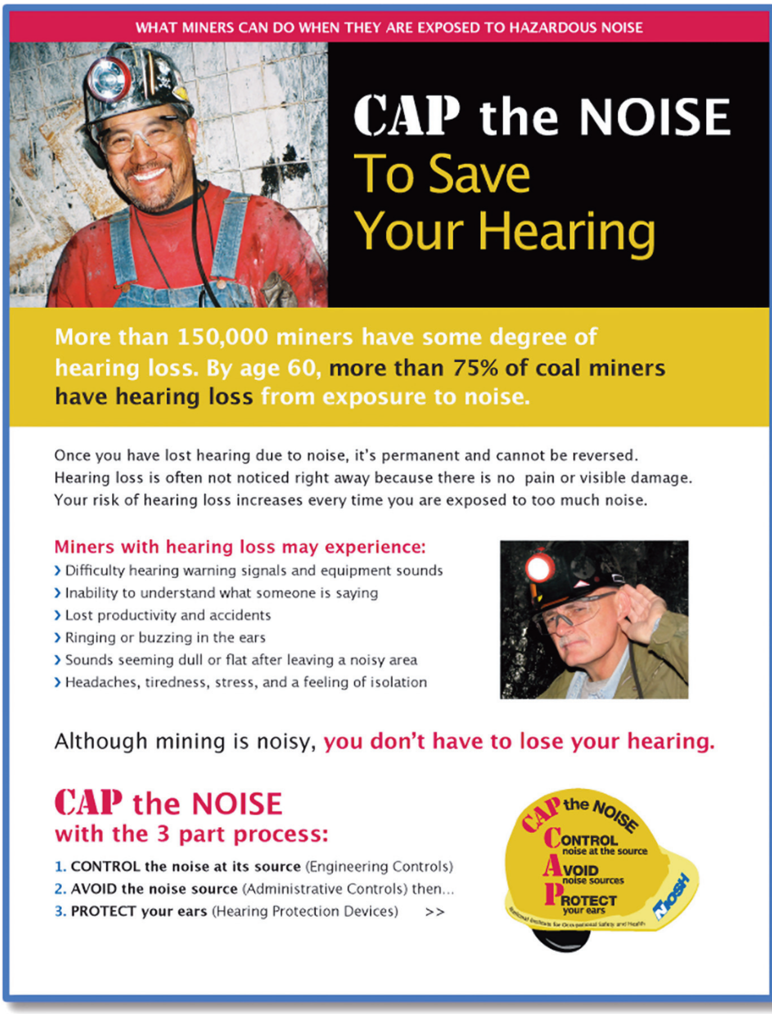

Figure 24 The "CAP the Noise" campaign serves as reminder of the hierarchy of noise controls.

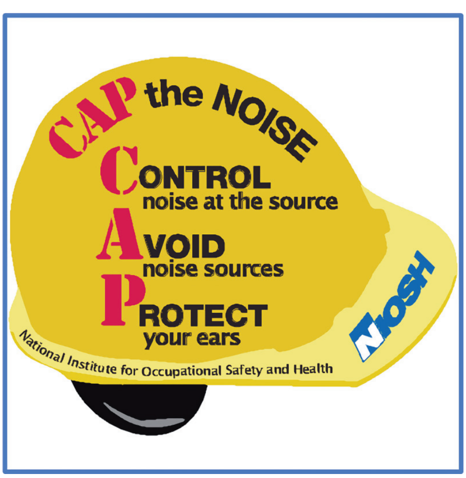

Figure 25 A hardhat sticker is also available for the "CAP the Noise" campaign.

plug fitting coupled with the Quick Fit can be used to improve and then test ear plug fit to protect workers hearing. The Hearing Loss Simulator may be used to illustrate to workers the harmful effects of hearing loss, motivating the worker to use empowerment tools like "CAP the Noise" and "NOW HEAR THIS!" to protect their own hearing. Many of these are available free to the public as downloads from the CDC NIOSH web pages.

DISCLAIMER

The findings and conclusions in this document are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH),

Figure 26 The "NOW HEAR THIS!" fact sheet illustrates self-empowerment tools for workers.

Centers for Disease Control and Prevention (CDC). Mention of any company name, product, or software does not constitute endorsement by NIOSH.

CONFLICT OF INTEREST

None declared.

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