Hearing Loss in the Mining Industry:
Overview of the NIOSH Hearing Loss Prevention Program at the Pittsburgh Research Laboratory

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) has recognized that Noise-Induced Hearing Loss (NIHL) is the most common occupational illness in the United States. The use of heavy equipment, the drilling of rock, and the confined work environment are some of the factors that contribute to high levels of noise exposure to workers in the mining industry. Every day 80% of the nation's miners go to work in an environment where the time weighted average (TWA) exceeds 85 dBA. Moreover, 25% of the miners are exposed to a TWA noise level that exceeds 90 dBA, the Permissible Exposure Limit (PEL). Furthermore, a NIOSH analysis of a large sample of audiograms showed that at age 50 approximately 90% of coal miners and 49% of metal/non-metal miners have a hearing impairment. By contrast, only 10% of the non-occupational-noise exposed population has a hearing impairment at age 50 (Franks, 1997) (Stephenson, 1998). Simply stated, the majority of miners have a hearing loss by the time they retire. While NIHL is the most common occupational disease in this country, this problem is especially acute among workers in the mining industry. There are several barriers to reducing NIHL in the mining industry. These include: gaps in knowledge of noise dose/source relationships, the unavailability of effective noise controls, and needs for worker education and worker empowerment. A related issue is the difficulty of communication in noisy workplaces by both hearing impaired and normal hearing workers. The Pittsburgh Research Laboratory (PRL) at NIOSH has strategically developed a hearing loss prevention program for overcoming these respective barriers in an attempt to reduce NIHL in the mining industry. This paper provides an overview of the research program being conducted at the PRL.

Hearing Loss Program Methodology

The hearing loss research program at the NIOSH-PRL, Hearing Loss Prevention Branch (HLPB) is comprised of four key programmatic areas. These areas are: 1) noise dose/source relationships; 2) availability of effective noise controls; 3) worker education and empowerment and 4) communication issues. The methodology for selection of the program areas includes the following:

Noise dose/source relationships: The mining industry does not dedicate the resources in determining where workers receive their noise exposures. Knowledge of the noise source/exposure relationship allows for effective selection and implementation of noise controls, thus reducing NIHL within the mining population.

Availability of effective noise controls: In many cases, attempts at reducing sound levels with noise controls are unsuccessful in the mining industry due to misapplication of technologies, lack of maintenance of noise controls used on equipment and/or treating noise sources that are insignificant in terms of a worker's exposure. In other cases, noise controls have not been developed due to the lack of understanding of the mechanisms of noise generation or the inability to develop controls that have suitable durability in the mining environment.

Worker empowerment and education: Workers report that they are rarely included or consulted in hearing conservation efforts. However, their involvement is crucial for the effective deployment of most exposure reduction strategies. Workers need to have better information about the noise hazards in their workplaces and how much actual exposure they are receiving from these sources. They also need to be empowered with techniques to reduce their exposure by playing a greater part in the overall hearing conservation effort. Additionally, workers typically receive inadequate education on what they can do to conserve their hearing. Common problems include training that is sporadic and uninteresting, little feedback on whether the training actually increased their knowledge or skills, and an overemphasis on hearing protection at the expense of the many other strategies workers can utilize to reduce their own exposures.

Communication issues: In mines and other noisy settings, workers report a significant problem with hearing warning signals, speech, and other sounds that are critical to working safely and efficiently. This problem is exacerbated by the masking nature of background noise, the high prevalence of hearing impairment, and the over reliance on simple hearing protection to reduce exposures.

The hearing loss program at the PRL is reducing NIHL in the mining industry by addressing the above key programmatic areas.
All programmatic areas are providing research results in a combined effort to reduce NIHL in the mining industry. Figure 1 demonstrates how each programmatic area contributes to the overall goal of the hearing loss program.

Figure 1. Programmatic areas and their association with the hearing loss prevention program.

The following section describes the purpose and approach of each programmatic area, along with recent results contributing to the overall goal of the hearing loss program, which is reducing NIHL in the mining industry.

Hearing Loss Programmatic Areas

Develop and maintain a noise source/mine worker exposure database for prioritizing noise control technologies

Purpose: The purpose of this programmatic area is to build a database that contains up-to-date comprehensive profiles of the noise exposures to the mining population as a function of equipment and activity-specific measures, i.e., to define the noise source/worker dose relationship. It combines the efforts of past research studies with current worker noise exposure characterization studies and equipment/activity related noise data. This study is a crucial component in NIOSH's and the mining industry's efforts to develop engineering and administrative noise controls because it will define miners' noise exposures, the source of the exposures, and the characteristics of those sources. Once this information is available, efforts can then be focused on the development and application of appropriate control measures to reduce mine worker's exposures and NIHL in the mining industry.

Approach: A cross-sectional field study of the noise exposure of mine workers is being conducted; the study includes a variety of mining methods, equipment, a range of geographic locations, and different mine sizes. Surface and underground coal mines, coal preparation plants, metal/nonmetal mines, stone mines, and sand & gravel operations are included in the study. To establish representative noise exposure profiles for the various mining occupations, comprehensive and extensive noise exposure measurements are being completed (figure 2). Full-shift time-resolved dosimetry, task observations, and equipment/area noise profiles are being used to define the noise source/worker dose relationships. The basic idea is to establish typical exposure patterns for the different mining occupations through repeated sampling with the dosimetric instrumentation, then through observational data, relate exposures to sources. Finally, sound level measurements including frequency analyses will be used to characterize the specific noise sources responsible for worker noise exposures.

Results: To date, 37 site specific surveys have been completed that included eight underground coal mines, eleven surface coal mines, nine coal preparation plants, three surface stone mines, three underground stone mines, one underground silver/lead mine, one coal load out river facility, and one sand & gravel operation. In the coal mining sector, approximately 40% of the workers surveyed had exposures above the MSHA (Mine Safety and Health Administration) PEL (Permissible

Exposure Limit) of 100% or a time-weighted average of 90 dBA over an 8-hour period (TWA_8), resulting from operating equipment such as continuous mining machines, roof bolting machines, longwall shearers and stage loaders, and working in the dragline house and in and around preparation plant equipment. In the stone and sand and gravel industries, fewer than 10% of all workers surveyed experienced noise exposures above the MSHA PEL of 100%.

The MSHA rule (30 CFR 62) mandates the mine operator assure that no miner is exposed during any work shift to noise that exceeds the PEL (based on a 90-dB criterion level, 5-dB exchange rate, A-weighting and slow response). If during any work shift a miner's noise exposure exceeds the PEL, the mine operator must use all feasible engineering and administrative controls to the reduce the miner's noise exposure to the PEL, and enroll the miner in a hearing conservation program.

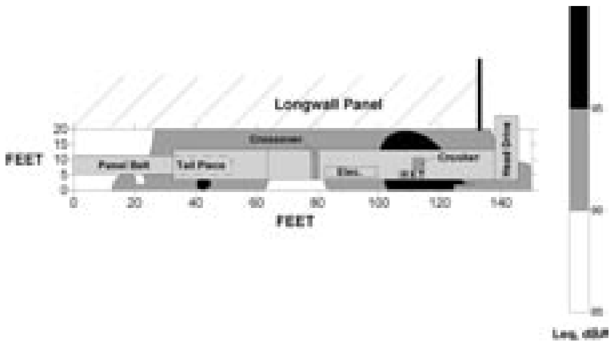

Figure 2. Contour plot of sound levels around a longwall stage loader.

Development and Assessment of Noise Controls

Purpose: The strategy for the noise control research program area is a long-term implementation plan where appropriate engineering controls are selected and targeted to reduce excessive exposure to noise and prevent additional cases of NIHL in the mining population. The quiet-by-design approach for noise control is emphasized, but low-cost retrofit of equipment with noise control measures is also a component.

Approach (Assessment of Controls): The noise control research program has two parts: The first is to determine the availability of effective noise controls. In many cases attempts at reducing sound levels with noise controls are unsuccessful due to misapplication of technologies, lack of maintenance of noise controls or focusing on the noise source that is insignificant towards reducing the workers' exposure. Noise surveys are conducted on available noise controls at mine sites and are assessed for effectiveness. The methodology for the assessment of engineering noise controls can be broken down into five areas:

1) identification of machines with installed engineering noise controls; 2) development of a test plan dependent upon the type of machine and the type of engineering noise control installed; 3) evaluation of the installed control or controls utilizing sound level, sound intensity and dosimetric measurements; 4) analysis of the experimental results to determine the effect of the controls on the sound level at the equipment operator's ear and/or the operator's noise exposure and 5) dissemination of the information via reports, presentations, peer-reviewed publications, or handbooks.

Results: Findings to date show that engineering noise controls that work on the surface may not work as well as expected underground; properly installed barriers provide effective noise reduction; improperly placed absorptive material has little to no effect on sound levels; and a noise problem should be verified before a solution is attempted.

Approach (Development of Controls): The second part of the noise control research program is the development of noise controls. In many cases, noise controls have not been developed due to the lack of understanding on how the noise is generated or the inability to develop a noise control that is durable in the mining environment. The methodology for the development of noise controls conducted at NIOSH is broken down into seven areas, which include:

1) identification and rank order of dominant noise sources utilizing sound power, sound level and sound intensity measurements in a laboratory setting (controlled environment); 2) process and analyze laboratory data to determine the areas of the machine that are dominant contributors to radiated noise; 3) propose and evaluate noise controls that address the dominant noise sources based on their potential to reduce noise, cost, functionality, ease of implementation, durability and worker acceptance; 4) coordinate with equipment manufacturers and users during the process of data collection and analysis to assess the feasibility of the controls prior to selecting the best noise control concepts; 5) design, implement and laboratory test the proposed noise controls to design functional noise controls based on the highest rated noise control concepts; 6) implement and test noise controls (before and after installation) in a mining environment utilizing sound level and dosimetric measurements to determine sound level and exposure reduction over a period of time (3-month intervals for a 1-yr period). In addition, inspect the condition of the controls over the 1-yr period for worker acceptance and durability and 7) disseminate results of the research via appropriate conferences, meetings, peer-reviewed journal articles and other publications.

Results (Development of controls): The current focus by NIOSH is developing engineering noise controls for continuous mining machines, roof bolting machines, and surface drills. The Continuous mining machine is first among all the equipment in underground coal whose operators exceed 100% noise dosage. NIOSH has addressed this issue by developing a chain conveyor with coated flights as a noise control for reducing the sound power of continuous mining machines (figure 3). The coating has been shown to be very durable. A total reduction of 7dB A-weighted at the operator position has been achieved with the coating. The control is currently being manufactured by Joy Manufacturing. Joy Manufacturing represents the largest producer of continuous mining machines in the U.S and the coated flight chain conveyor noise control is currently in use in several mines.

Figure 3. Coated flight bars on a continuous mining machine in an underground coal mine.

Roof bolting machine operators are the third most likely to be overexposed to noise and rank second when considering only the equipment used in underground coal mining. NIOSH has confirmed that during wet drilling, sound power level emissions are less than similar tests conducted under vacuum conditions of the roof bolting machine. This is primarily due to attenuating the sound power emission at frequencies of 1 kHz or greater. Wet drilling also facilitates the additional benefit of increased performance such as higher penetration rates and extended bit life. Roof bolting machines equipped for wet drilling are currently available from Fletcher Mining Equipment, the leading manufacturer of roof bolting machines in the U.S. NIOSH has also confirmed that mist sound power level emissions during mist drilling are less than similar tests conducted under vacuum conditions. Again, there is the reduction of the noise emissions at 1 kHz and above as well as the increase in performance. Depending on the compressive strength of the drill media, laboratory and field testing suggest sound level reductions of 2-7 dB A-weighted at the operator's position. Mist systems developed by Joy Mining Machinery for roof bolting machines are currently in use in several underground coal mines.

Additionally, NIOSH has confirmed that surface drill operators at mine and construction sites experience overexposure to noise. NIOSH has addressed this issue by developing a partial cab as a noise control for reducing the noise generated from surface drills (figure 4). Laboratory test results of the partial cab's configuration and material content design showed an 8 to 15 dB A-weighted sound level attenuation. Preliminary test results of the proto-type partial cab, fabricated and attached to a production air rotary drill rig, indicate sound level attenuations of 8 dB A-weighted. Future partial cab modification designs based on field applications expect to improve sound level attenuations to 10 dB or greater at the operator's control panel.

Figure 4. Partial cab installed on an air-rotary drilling rig.

To test and develop noise controls, the NIOSH-PRL has several key facilities available for researchers to conduct laboratory testing of the controls. These facilities consist of the following:

Mining Equipment Test Facility – This facility provides full-scale surface testing of mining equipment in an essentially free field environment prior to taking equipment underground for testing in the actual mine environment. The building complex consists of an open high-bay facility that is more that 4200 square meters in a free field area.

Reverberation Room – This room was designed for sound power testing of large mining equipment in conformance with ISO standard 3741. The room is18.31 meters long by 10.38 meters wide by 6.72 meters high, which yields an interior volume of 1277 cubic meters and a surface area of 766 square meters, the largest such facility in North America (figure 5). The reverberation room is equipped with a sound measurement system which includes an array of 15 microphones that are suspended from the ceiling of the reverberation room and an instrumentation system for calculating sound power levels.

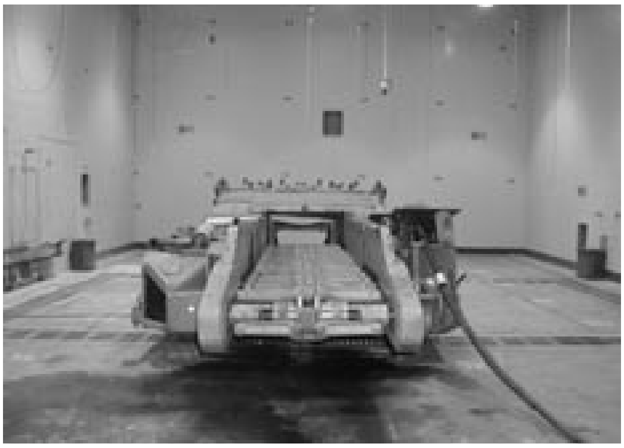

Figure 5. Continuous mining machine in the reverberation room at the NIOSH-PRL.

Worker Empowerment and Education

Purpose: The worker empowerment program area at NIOSH is supporting workers as key players in the overall strategy to reduce NIHL. Almost every approach to hearing loss prevention has some human component. Engineering noise controls usually rely on workers to properly implement, use, and maintain them. Administrative controls are effective only if workers follow their dictates. Hearing protectors only work if they are worn correctly whenever the worker is exposed to hazardous noise.

The worker empowerment program provides outputs that will have a direct effect on the overexposure problem as well as internal inputs and outputs to the other programs. The direct outputs take the form of "Research to Practice" (r2p) products. These are products based on technical, engineering, and scientific work that have been translated into a form that can be directly used by workers. For instance, workers are unlikely to read through lengthy technical reports about noise dosimetry, but they would be much more likely to use simplified guidelines about how to identify and avoid major noise sources.

Initially, this program has concentrated on first motivating workers and managers to prevent hearing loss. Once motivation levels are raised, the next step is to address specific prevention behaviors. The first prevention behavior addressed in this program is effective use of hearing protectors. Even when hearing protectors are required, actual usage rates are low. For instance, Landen (2004) reported that 47.6% of a sample of sand and gravel miners never wore hearing protectors.

Even when hearing protectors are worn, the actual levels of protection tend to be far below the rated performance (Berger, Franks, and Lindgren, 1994). The solution is a combination of improved motivation to perform the task correctly, and improved ability for performing the task.

Approach: This program uses the behavioral sciences to effect change. The theoretical basis incorporates aspects of major health promotion motivation theories such as Pender's (1987) Health Promotion Model and Ajzen's (1991) Theory of Planned Behavior. Using these theories, communication products are designed to emphasize both the likelihood of and severity of noise-induced hearing loss. The program also incorporates concepts from the Transtheoretical Stages of Change model (Prochaska & DiClemente, 1992) to tailor the design of different types of communication interventions. For instance, workers who do not yet recognize a problem need different types of information than those who are actively seeking a solution.

Results*:* The NIOSH Hearing Loss Simulator is a motivational tool developed to show both the likelihood and severity of hearing loss. The Simulator is a software program that allows users to see and hear the effects of hazardous noise exposure. A display and on-screen controls allow the user to select different sound levels and durations, then instantly hear the effect on pre-recorded speech sounds with or without background noise (figure 6). The simulated noise-induced hearing loss follows the empirically-supported models in ANSI S3.44 (2001). As a prototype communication product, the Simulator was evaluated with groups of miners and mine technical support personnel. The initial version was readily adaptable to different media to address different trainee and user populations (Randolph, Kohler, and Byrne, 2002).

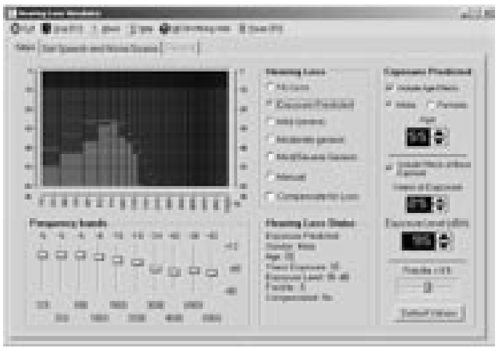

Figure 6. NIOSH-PRL hearing loss simulator.

The problem of improper wearing of hearing protectors was addressed through a simplified earplug technique. Called the “Roll-Pull-Hold” technique, it emphasizes the three critical actions that must be performed to obtain a high level of protection from earplugs. The existing instructions printed on earplug packaging or contained in training videos are complex and verbose, and the essential message is easily missed. In particular, the second step of earplug insertion is typically labeled as “Insert” with little emphasis on the technique of pulling the outer ear upward to straighten the ear canal. Since the label “Insert” is obvious to the point of uselessness, this step was relabeled “Pull” to highlight the often forgotten upward pull technique. This technique was evaluated with miners who received different forms of the Roll-Pull-Hold training along with hearing tests

Results: Evaluations of the Hearing Loss Simulator showed positive reactions to it as an appealing training product. More importantly, trainees showed positive changes in the specific attitudes and beliefs targeted by the Simulator. The differences in pre- and post-training responses indicated that all of the changes were in the desired direction, except for responses about hearing loss and age. The Simulator has now been released to the public, and is available as a download from www.cdc.gov/niosh and on CD-ROM on request to rrandolph@cdc.gov.

The simplified Roll-Pull-Hold technique also yielded significant prevention results. Initial testing showed that, while 96% of the tested miners correctly performed the Roll step, only 54% correctly performed the Pull step and 49% performed the Hold step. When all three steps were performed correctly, measured protection rose by over nine decibels (figure 7). Information about the Roll-Pull-Hold technique, including a 30-second video, can be accessed on the NIOSH website at www.cdc.gov/niosh/mining/topics/hearing/earplug.html.

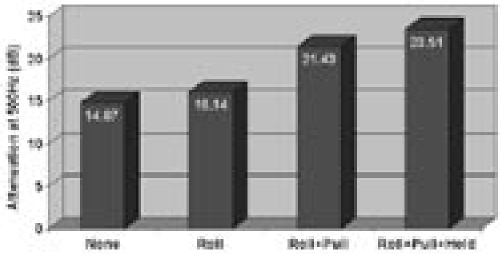

Figure 7. Evaluation of roll-pull-hold technique.

Communication and Hearing Protectors

Purpose: Hearing protectors are indispensable in situations where noise cannot be sufficiently reduced though engineering and administrative controls. However, conventional hearing protectors have significant drawbacks that present challenges to their usefulness. For instance, while conventional hearing protectors attenuate undesirable noise, they can also reduce the audibility of speech, warning signals, and other useful sounds (Suter, 1989). Comfort, usability, and interference with the wearer’s other tasks also present significant barriers to consistent hearing protector use. This program area is addressing these hearing protector drawbacks through a combination of improved selection methods and evaluation of novel technologies.

Workers receive information through a variety of sounds, some of which are relatively common and generic, while others are very task-specific. Spoken communication is the most common type of information-bearing sound in both occupational and non-occupational settings, so most of the hearing protector audibility research has focused on speech recognition. Workers in mines and other industrial settings also need to be able to hear backup alarms and other warning signals that may be rare outside of the workplace. Equipment operators report that they listen for subtle changes in the sounds from their machines to monitor their performance and predict mechanical problems. In all of these cases, the goal is to preserve audibility of essential information-bearing sounds while reducing exposure to noise. While there are standard methods of rating the attenuation of hearing protectors (e.g., ANSI, 1997), there is no standard for rating the effect on speech intelligibility or audibility of warnings.

The benefit from this program area comes in the form of improved hearing protector technologies, and better selection processes for choosing the protectors that are available. Choosing appropriate hearing protectors is a significant problem. Hundreds of different varieties of hearing protectors are currently available. The current NIOSH Compendium of Hearing Protectors (online at www.cdc.gov/niosh/topics/noise/hpcomp.html) contained 369 earmuffs, earplugs, canal caps, and other devices.

Approach: In this program area, HPD’s are subjected to laboratory evaluations to assess their audibility performance as well as any novel features they have. Basic attenuation performance is assessed according to ANSI 12.6 and other existing standards. Audibility is assessed through experiments in the PRL Auditory Research Laboratory using recordings of speech sounds as well as a wide variety of mining and industrial sounds presented to volunteer human subjects. When the intelligibility and audibility experiments are completed, the data will be used to develop an improved hearing protector selection tool. This tool will complement the existing NIOSH Compendium of Hearing Protectors by providing situation-specific hearing protector recommendations.

Results: This research program is relatively new, and most of the studies hae just started. Special evaluations can be conducted to evaluate special features incorporated into hearing protectors. For instance, one new hearing protector system incorporated exposure-measuring microphones into the protectors. The readings produced by these microphones were compared to standard dosimeter microphones worn on a worker’s shoulders and a “gold standard” high-precision microphone located at the center-of-head position. The study on the new hearing protectors that also measure noise exposure found that the system’s microphones could provide a useful estimate of the dose received. The system showed some discrepancies from both the standard dosimeter microphones and a center-of-head microphone, but these differences tended to be in a conservative direction. That is, where errors existed, the system indicated higher sound levels than the comparison microphones.

Summary

NIOSH has strategically developed a hearing loss prevention program for overcoming respective hearing loss barriers in an attempt to reduce NIHL in the mining industry. Thru the utilization of a well-balanced research approach, consisting of four key programmatic areas, research is being conducted and findings are being implemented and disseminated to the mining industry. The long-term impact of these and other successful interventions will be followed through long term evaluations to confirm that workers are being exposed to less noise and that fewer of them will develop a hearing loss.

It should also be noted that NIOSH has been working under a Coal Noise Partnership with the United Mine Workers of America, Bituminous Coal Operators Association, National Mining Association, Mine Safety and Health Administration and several mining equipment manufacturers and suppliers. The partnership is providing opportunities for collaborative research with key stakeholders (mine operators, labor officials, equipment manufacturers, regulatory officials, etc.) related to the hearing loss prevention program at the Pittsburgh Laboratory (PRL). The partnership is providing a significant impact in accomplishing the goals of the hearing loss prevention program.

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