

REDUCING NOISE-INDUCED HEARING LOSS IN LONGWALL COAL MINE WORKERS: NIOSH'S APPROACH

ERIC R. BAUER, ELLSWORTH R. SPENCER, ADAM K. SMITH, ROBERTA L. HUDAK

National Institute for Occupational Safety and Health
Pittsburgh Research Laboratory
Hearing Loss Prevention Branch
Pittsburgh, PA

ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) is conducting research with the objective of preventing hearing loss in the mining industry. Longwall mining is one sector that has received considerable attention. Studies involving the monitoring of worker noise exposures, characterizing equipment sound levels and dominant noise sources, evaluating engineering noise controls, analyzing hearing protection device (HPD) effectiveness, and testing of improved sound level monitoring techniques specifically for longwall mining systems, are being conducted. The research efforts revealed that stageloader operators are the most exposed longwall workers, with the discharge end being the noisiest location along the stageloader. In addition, the studies have shown that using stationary dosimeters, coupled with observational data of the cutting cycle and worker habits, has the potential for improved monitoring of the effectiveness of engineering noise controls. To address the ineffective use of soft foam earplugs, a simplified 3-step method was developed for inserting soft foam earplugs. Results indicate a 9 dB greater attenuation after training subjects on the 3-step method. Finally, muff type HPDs are being evaluated for effects of speech intelligibility in noise. The combined results of these studies illustrates that much can and has been done to prevent noise-induced hearing loss (NIHL) in the mining industry, especially with respect to longwall mining workers. This paper presents an overview of ongoing studies, a progress report of results, and the implications for reducing worker noise exposures and preventing NIHL in longwall mining workers.

INTRODUCTION

Noise, which is any unwanted or undesirable sound, occurs throughout the mining industry. Exposure to high sound levels, i.e. hazardous noise levels, over time can result in damage to the hair cells of the cochlea [NIOSH, 1998]. The eventual result is a permanent shift in hearing thresholds, known as noise-induced hearing loss (NIHL). NIHL is the most common occupational illness in the United States today, with 30 million workers exposed to excessive noise levels or toxicants that are potentially hazardous to their hearing [NIOSH, 1996a]. The problem is particularly severe in all areas of mining (surface, processing plants, and underground) where large, noisy equipment predominates and where many workers are located in close proximity of this equipment. A NIOSH analysis of NIHL in miners presented a snapshot of the extent of NIHL in the mining industry (Figure 1) [NIOSH, 1996b]. This analysis of several

thousand audiograms indicate the number of miners with hearing impairments (defined as an average hearing threshold level of 25 dB or greater for the frequencies 1000, 2000, 3000, and 4000 Hz) increased with age until age 50, at which time 49% of the metal/nonmetal and 90% of the coal miners had a hearing impairment [NIOSH, 1996b and 1997].

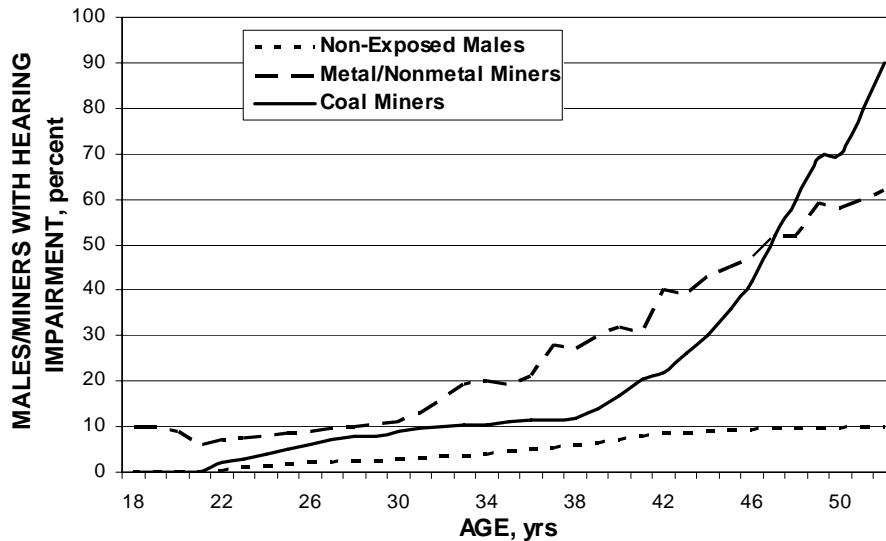


Figure 1 Hearing impairment in coal miners, metal/nonmetal miners, and non-exposed males [NIOSH, 1996b and 1997].

Despite the extensive work with engineering controls in the 1970s and 1980s, NIHL continued to be a problem in the mining industry [Federal Register, 1996]. To address the issue, the Mine Safety and Health Administration (MSHA) published Health Standards for Occupational Noise Exposure [Federal Register, 1999]. Requirements of the new standard included:

- The adoption of an Occupational Safety and Health Administration (OSHA)-like Hearing Conservation Program (HCP);
- Enrollment in the HCP for workers exposed above an Action Level of 85 dB(A) eight-hour time weighted average (TWA_8);
- Reduce worker exposures to or below A Permissible Exposure Level (PEL) of 90 dB(A) TWA_8 or equivalently a dose of 100%;
- No reduction in noise exposure due to the use of personal hearing protection; and
- A requirement that mine operators use all feasible engineering and administrative controls to reduce noise exposures.

Longwall mining and longwall section workers are not immune to noise. A compilation of MSHA noise survey data for fiscal year 1990 revealed that approximately 40% of the total samples taken for longwall occupations exceeded the Permissible Exposure Level (PEL) of 100% [Gigliotti et al., 1991]. Ongoing NIOSH exposure measurements revealed noise doses up to 786% for longwall coal mining system workers in job classifications that included shearer operator, jacksetter (shieldman), longwall foreman,

and headgate (stageloader) operator [Bauer et al., 2001]. Bauer also reported that the sound levels around the longwall ranged from 81 dB(A) to 102 dB(A) and showed that the stageloader operator was among the most frequently overexposed longwall coal mining system worker, with recorded dose levels ranging from 142% to 386%.

In an attempt to reduce NIHL in the mining industry, NIOSH has been conducting noise research in the mining industry. The research efforts have included surveys designed to monitor worker dose; measure equipment noise levels; understand the noise source/dose relationship; laboratory studies to analyze hearing loss; hearing protection device (HPD) effectiveness and speech intelligibility in noise; improved and consistent insertion of soft foam plugs; and in-mine testing of improved sound level monitoring techniques. These studies have been completed in underground coal mines including longwall mining sections, or have generated results that are directly applicable to longwall mining. This paper presents the results of these research efforts designed to minimize and eventually eliminate NIHL in the mining industry including longwall mining. The results are applicable to the 52 longwalls in 46 operating underground coal mines in the U.S. [Coal Age, 2006] and the estimated 1500 to 3000 workers that routinely work on, or occasionally visit, longwall mining sections.

RESEARCH PROGRAM

Preventing NIHL among mine workers has proven to be a difficult task. MSHA has addressed the problem by publishing and enforcing new standards for occupational noise exposure that require mine operators to adopt an OSHA-like hearing conservation program and does not allow adjusting a miner's noise exposure measurement for the use of personal hearing protection. The new standards require the use all feasible engineering and administrative controls for noise exposure reduction. MSHA has also been conducting acoustical field investigations at mine sites, in response to issued citations, to assist mine operators to lower miners' noise exposures. Mining companies have been active in this endeavor through the testing, evaluation, and implementation of engineering noise controls as well as reducing worker exposures through the use of administrative noise controls. NIOSH, at the Pittsburgh Research Laboratory, has adopted a multi-faceted approach with research efforts addressing:

1. Exposure source/dose measurement and tracking;
2. Engineering noise controls;
3. Worker empowerment and education; and
4. Communication in noise and personal protective equipment (PPE) (Figure 2).

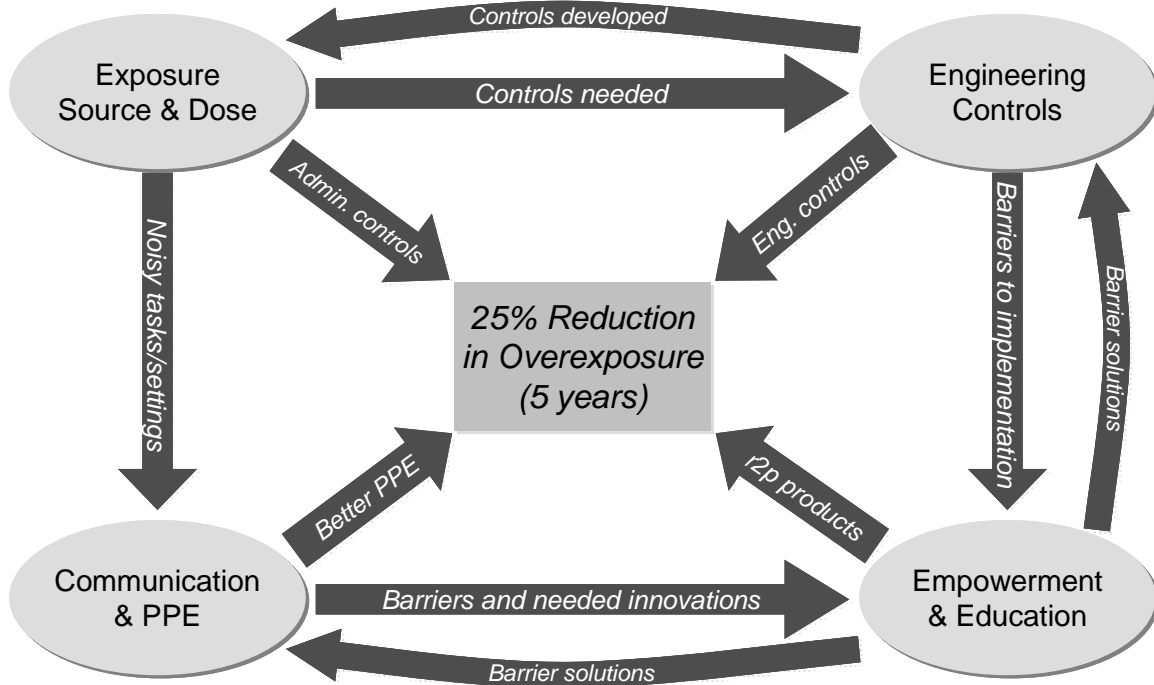


Figure 2 NIOSH/PRL Hearing Loss Program and Goals.

SCOPE OF RESEARCH

The worker-dose monitoring, equipment noise profiles, noise source/dose relationship determination, and alternative monitoring research efforts were conducted on the longwall sections in underground bituminous coal mines. These efforts involved using personal dosimeters for monitoring longwall worker dose, sound level meters and/or dosimeters to measure longwall equipment noise, and task observations of workers and equipment operating parameters to identify the source(s) of worker noise exposure.

The hearing protection and audibility consideration research efforts are conducted in NIOSH PRL's Auditory Research Laboratory (ARL), which is accredited by the National Voluntary Laboratory Accreditation Program (NVLAP). These efforts involve investigating speech intelligibility concerns that arise when noise-exposed miners are required to wear hearing protection. Laboratory evaluation of the acoustical characteristics of various muff-type hearing protective devices, with an emphasis on optimizing the balance between under-/over-protection, effectiveness, and communication ability, will be conducted on individuals with normal hearing using the Modified Rhyme Test [ANSI S3.2-1989, R1999]. Results of these evaluations will allow recommendations to be made for accommodating noise-exposed miners so that they can perform their jobs safely while still being protected against noise-induced hearing loss. Finally, the Roll-Pull-Hold (RPH) method of soft foam earplug insertion was evaluated at numerous mine sites and hundreds of mine workers in the NIOSH Mobile Hearing Loss Prevention Unit to determine if the RPH technique had an effect on earplug attenuation performance.

RESEARCH RESULTS

WORKER EXPOSURE MONITORING

Longwall section workers wore dosimeters for a full shift to provide noise exposure data (Table 1) [Babich and Bauer, 2006]. The wide range of exposure data for each occupation is a result of many factors including: work habits; worker location; age of equipment; equipment operation; and downtime. In addition, Table 1 combines data from a number of mines, thus the exposures are the result of different equipment as well. Exposure data can be used to reduce NIHL in a number of ways. First, exposure data alert mine operators as to which workers are being overexposed and thus which occupations need to be addressed concerning exposure reduction efforts. In the case of longwall section workers, analysis of data suggests that exposure reduction efforts should be directed at essentially all occupations because all experienced exposures in excess of the MSHA PEL. Secondly, when exposure information is combined with worker observations, administrative noise controls can be implemented more effectively.

Occupation	No. of Recorded Doses	Range of MSHA PEL Dose, %
Tail Shearer Operator	19	22 to 786
Headgate (Stageloader) Operator	18	36 to 386
Head Shearer Operator	20	33 to 266
Longwall Foreman	16	23 to 203
Relief Shearer Operator	2	22 to 193
Shieldman	44	13 to 192
Mechanic/Electrician	24	5 to 156

Table 1 MSHA PEL dose for longwall section workers

EQUIPMENT/AREA NOISE MEASUREMENTS

Sound levels were recorded around the longwall equipment including the shearer, Armored Face Conveyor (AFC), shields, stageloader and belt, and hydraulic pump unit. Table 2 lists the results of the sound levels recorded using a Type 2 sound level meter (SLM) on 3- to 6-ft spacing and at a distance of approximately 3 to 6 ft from the equipment or less depending on clearance between the mine ribs and equipment. The SLM was programmed to monitor the A-weighted Equivalent Continuous Sound Pressure Level (Leq), in decibels (dB), which is the average sound level for a measurement period based on a 3-dB exchange rate. The 3-dB exchange rate is the method most firmly supported by scientific evidence for predicting hearing impairment as a function of noise level and duration [NIOSH 1998]. Table 2 illustrates that measured sound levels of longwall equipment can vary significantly and at times can be considered “hazardous noise levels”.

Equipment	Range Leq, dB(A)
Stageloader and Section Belt	82 to 103
Hydraulic Pump Unit	74 to 103
Shearer	85 to 100
Face (Shields/AFC)	80 to 96

Table 2 Sound level measurements for longwall section equipment

To illustrate the sound level measurements, several examples of longwall section equipment are included. An illustration of the sound levels around a shearer as it cuts from the head to the tail is shown in Figure 3. Sound levels above 95 dB(A) were recorded adjacent to the shearer. In response to exposure reduction, this illustration reveals that if the head drum shearer operator remains positioned 10 ft or more outby (towards the head and stageloader) the head drum, the sound levels are less than 90 dB(A). This is a location where the sound levels are “safer” thus for an eight-hour shift and if the head shearer operator has no other exposure sources, his dose would be less than the MSHA PEL of 100%. The tail drum shearer operator needs to be positioned as far toward the head as possible, or at least at the middle of the shearer, to minimize noise exposure. Even at the midpoint of the shearer where noise levels are between 90 and 95 dB(A), the operator is likely to be overexposed. Operator repositioning should only be employed until appropriate engineering controls can be implemented to reduce the noise levels generated by the shearer.

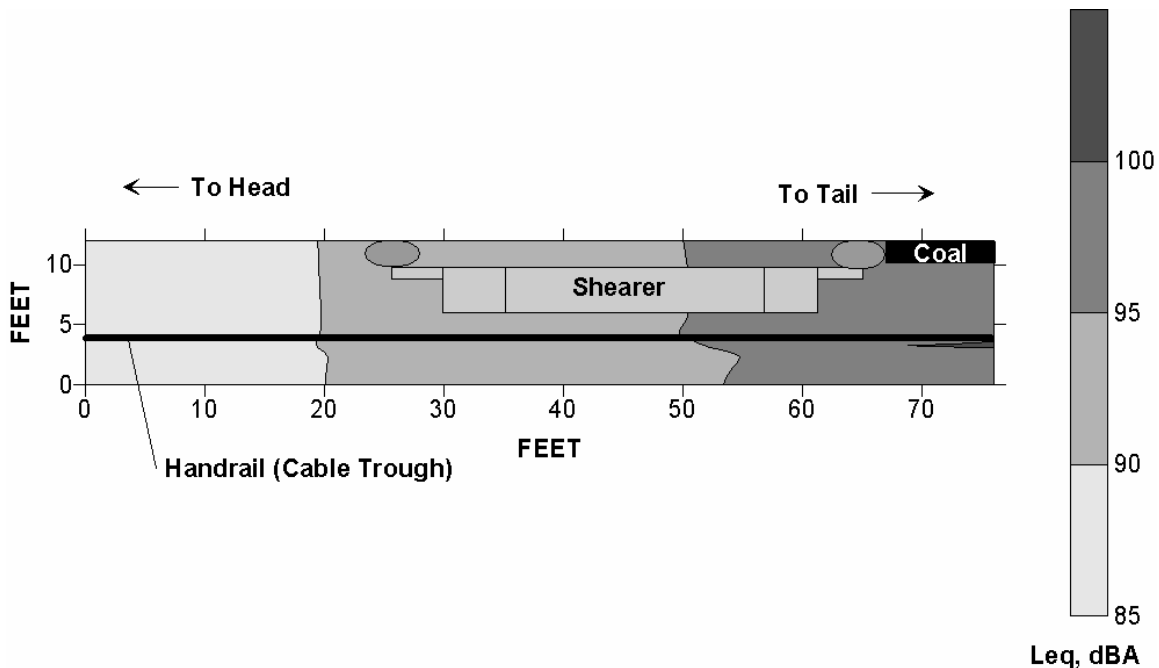


Figure 3 Sound profile plot for longwall shearer [Babich and Bauer, 2006]

Figure 4 is a sound profile plot for a longwall stageloader. Sound levels above 95 dB(A) were recorded adjacent to the stageloader and below 85 dB(A) along the belt at distances greater than 15 ft from the tailpiece. Exposure reduction can be accomplished by either quieting the noisy areas (crusher and tailpiece) with engineering noise controls, or through administrative controls that require the stageloader operator to avoid the two noisiest areas (crusher and tailpiece areas). Positioning the controls and computer monitor on the monorail along the belt and away from the tailpiece can also limit the stageloader operator's exposure.

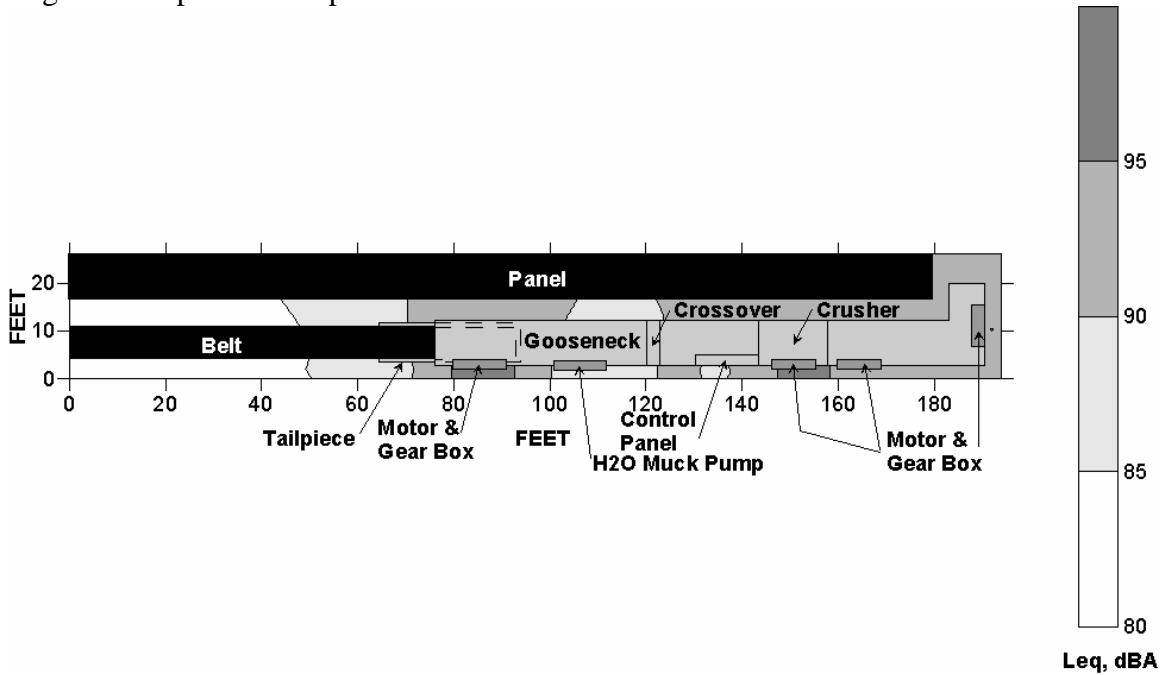


Figure 4 Sound profile plot for a longwall stageloader

Finally, even though exposure durations are low, overexposure may be possible if sufficient time is spent near the hydraulic pump car assembly. Sound levels exceeding 95 dB(A) can be present as illustrated in Figure 5. All mine workers should limit their time near the longwall hydraulics to walking past the area at the start and end of each shift. When required to walk past or work near the longwall hydraulics, workers should wear appropriate hearing protection and perform as much maintenance as possible when the system is off.

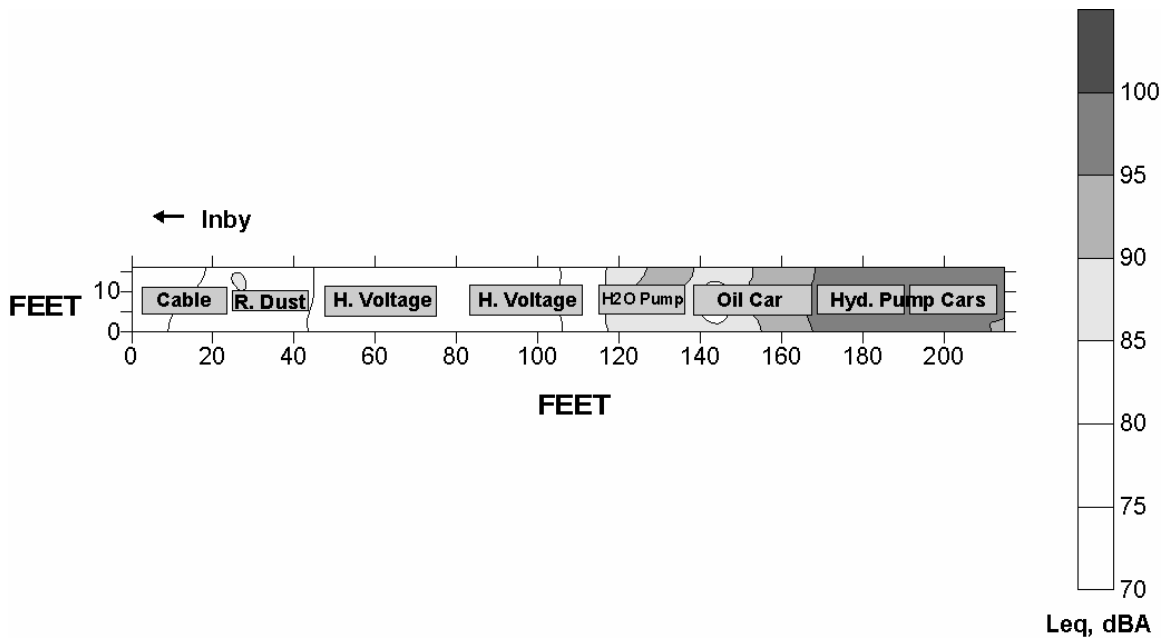


Figure 5 Sound profile plot for longwall hydraulics

NOISE SOURCE/DOSE RELATIONSHIP

A combination of dosimetry and task observations was used to attempt to estimate the noise source/dose relationship. By observing the tasks and locations of longwall workers, then matching the observations to the accumulated dose, the tasks and/or locations most responsible for a workers dose can be determined. For instance, a stageloader operator was observed, his dose measured, then combined into a cumulative dose plot as shown in Figure 6. The plot illustrates that the stageloader operator experienced a generally uniform dose accumulation throughout the shift with occasional periods of low dose as shown by the flat slopes of the cumulative dose line. These low dose periods occurred when the worker was along the face and when the stageloader was idle. Other observations have shown less dose accumulation occurred when the worker was at the controls (located down the belt away from the stageloader) and when along the belt in general. Knowledge of the dose accumulation and worker tasks and/or locations can help mine operators to implement exposure reduction efforts where they will be most effective. For instance, from 1:50 pm to 2:20 pm when the stageloader operator was near the head drive, he received approximately 35% of his total shift dose. By limiting or eliminating the time working near the head drive the stageloader operator could have reduced his final shift dose to approximately 105%. With a few more judiciously selected administrative controls (worker repositioning to lower noise areas), the stageloader operator could easily reduce his shift dose to below the MSHA PEL of 100%.

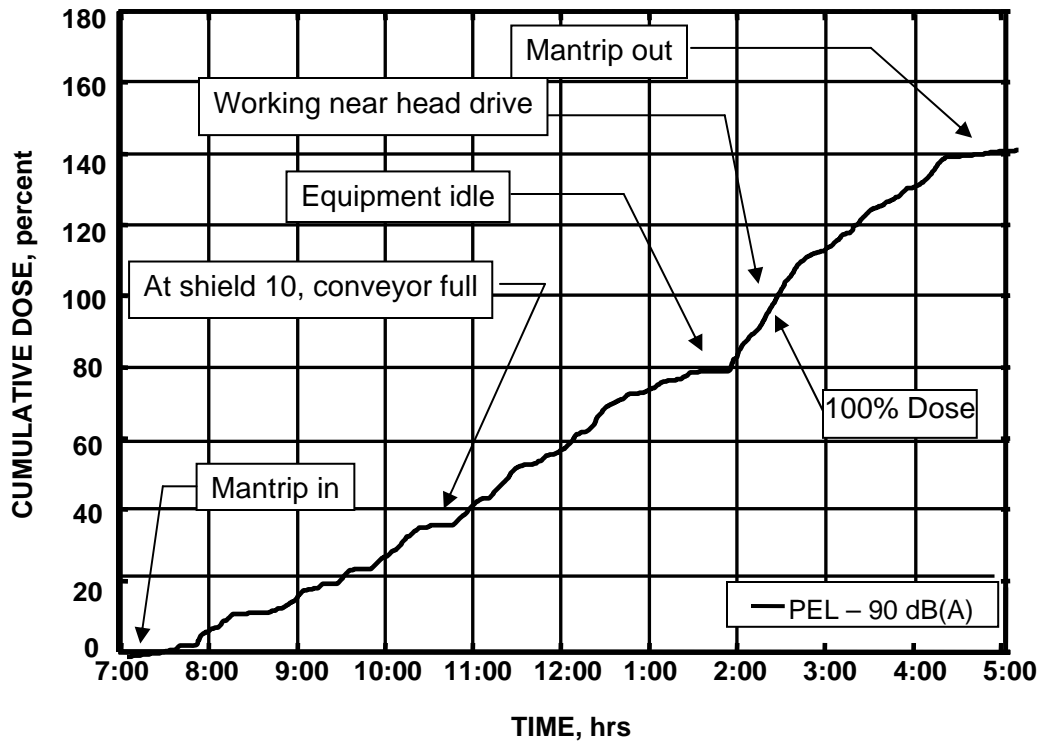


Figure 6 Cumulative dose plot and task observations for a stageloader operator [Bauer, et al, 2001]

ALTERNATIVE MONITORING METHODS

A study was conducted to evaluate an alternative monitoring method for identifying the noise sources that are major contributors to the noise exposure of longwall coal mining system workers and to evaluate the effectiveness of engineering noise controls to reduce the noise source sound levels and exposure of the workers. The measurement system used to analyze the noise sources included stationary dosimeters in a documented repeatable pattern (locations along the stageloader) and a time-motion study of the cutting cycle and stageloader operator's work cycle [Spencer et al., 2007]. These measurements were conducted on the stageloader only. No attempt was made to use this measurement system to monitor sound levels on the face (shearer, pan line, shields, or tailgate). This would have required a much larger effort than budgetary and personnel constraints would have allowed.

To locate the stationary dosimeters, the stageloader was divided into a number of separate measurement segments or areas as shown in Figure 7. The dosimeter locations were marked and recorded with reference numbers. The 12 pre-programmed dosimeters were attached to magnetic stands then placed at the predetermined locations [Spencer et al., 2006]. While the dosimeters recorded noise information, researchers conducted the time-motion study of the operator's work cycle and shearer cutting cycle for the desired number of complete passes (a pass consisted of the shearer cutting down to the tailgate and back), or cutting cycles of the longwall mining system [Spencer et al., 2007].

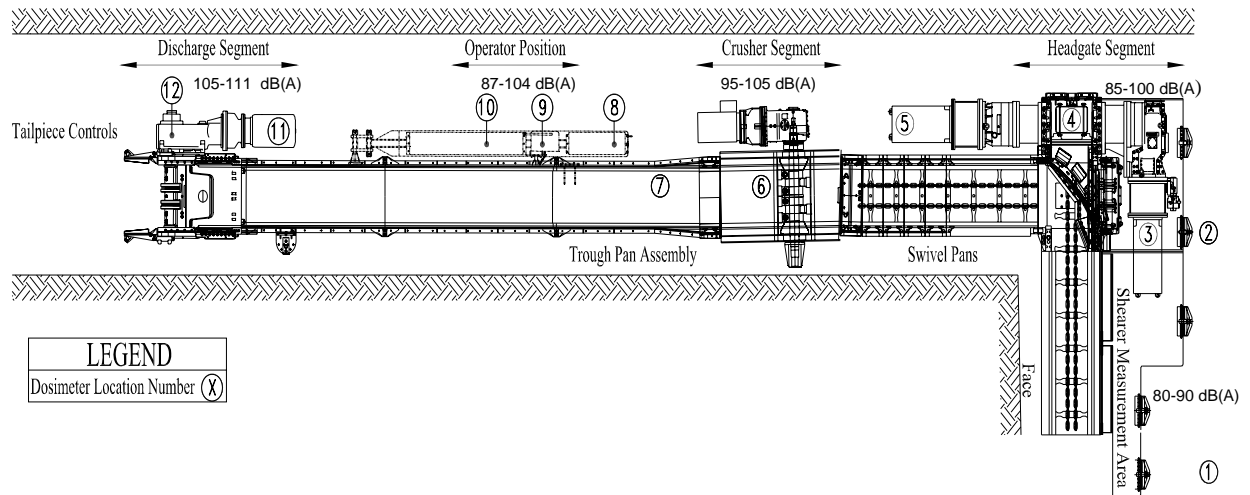


Figure 7 Segments of the longwall headgate mining system and location of stationary dosimeters (not to scale) [Spencer et al., 2007]

The underground measurements revealed that the highest Leq sound levels occur at the stageloader discharge segment and tailpiece controls, ranging from 105 to 111 dB(A). They remained at about these same levels throughout the test. The studies suggest that the use of stationary dosimeters and time-motion studies are a promising method for analyzing the effectiveness of engineering noise controls for reducing longwall worker noise exposures.

HEARING PROTECTION AND AUDIBILITY CONSIDERATION

A research effort is underway in PRL's Auditory Research Laboratory to evaluate active hearing protection devices for effects on speech intelligibility in industrial noise environments, particular mining. In addition to protection from noise-induced hearing loss, many workers require good speech intelligibility for the safe performance of their jobs. Unfortunately, hearing protectors cannot selectively attenuate the noise while leaving the speech unaffected. The study is exploring the differences (if any) between speech intelligibility measures and signal perception obtained with active cancellation earmuffs, electronic amplitude sensitive earmuffs, and conventional passive-attenuation earmuffs. Results of these evaluations assist where recommendations must be made for accommodating noise-exposed miners, including longwall section workers, so that they can perform their jobs safely while still being protected against noise-induced hearing loss.

SOFT FOAM EARPLUG INSERTION STUDIES

The recommended steps for reducing worker noise exposure include the implementation of all feasible engineering noise controls (removing the noise) or administrative noise controls (removing the worker). During the process of implementing these controls, if the noise levels remain above 90 dB(A), hearing protection devices (HPDs) provide what is perceived as an inexpensive way to prevent hearing loss both on and off the job. They are worn to reduce the level of sound entering the ear, not to eliminate the sound completely. For HPDs to be effective, they must be worn correctly and fit properly. Even if a worker does wear hearing protection, they often do not wear it correctly (Figure 8).

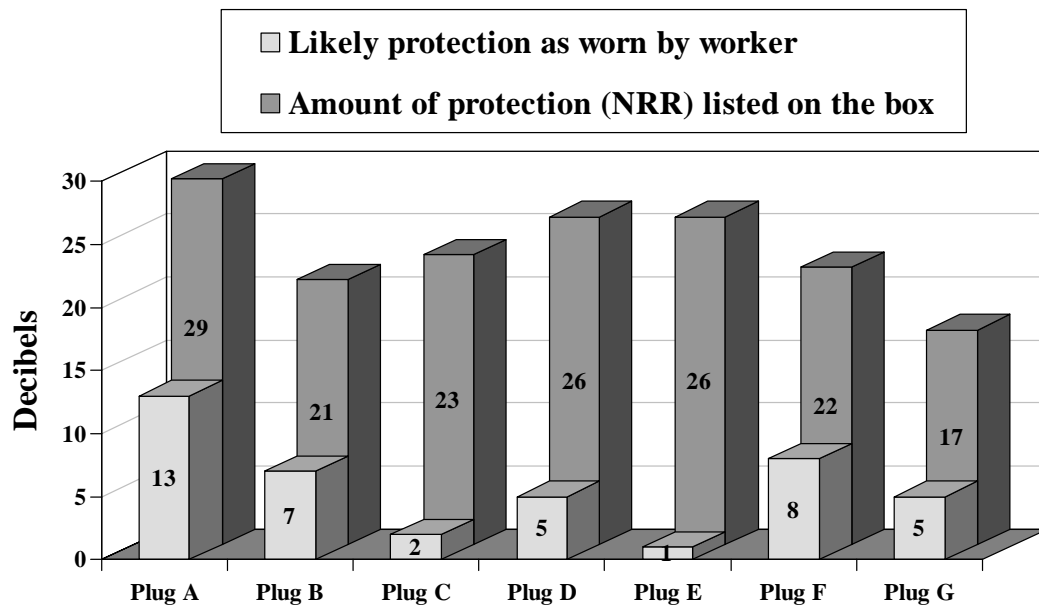


Figure 8 Mean real-world field test results vs. labeled noise reduction rating (NRR) values for seven different earplugs [Berger et al., 1996]

In response, NIOSH developed a 3-step method for inserting soft foam earplugs. The goal of this research effort was to improve the worker's ability to insert a plug correctly, and ultimately reduce hearing loss if the plug is worn correctly and consistently when exposed to noise at or above 85 dB(A). The Roll-Pull-Hold (RPH) Hearing Protection Method instructs workers how to insert earplugs effectively (Figure 9). This insertion method, with simplified instructions, allows the employee to practice inserting earplugs, while obtaining training and feedback on their insertion technique. Subjects who followed the RPH steps correctly achieved 9 dB higher attenuation than the subjects who did not perform the steps correctly. The effectiveness of insertion was evaluated by pre- and post-insertion audiometric examinations. The worker was ultimately informed that soft foam earplugs can be worn consistently and correctly to prevent hearing loss.

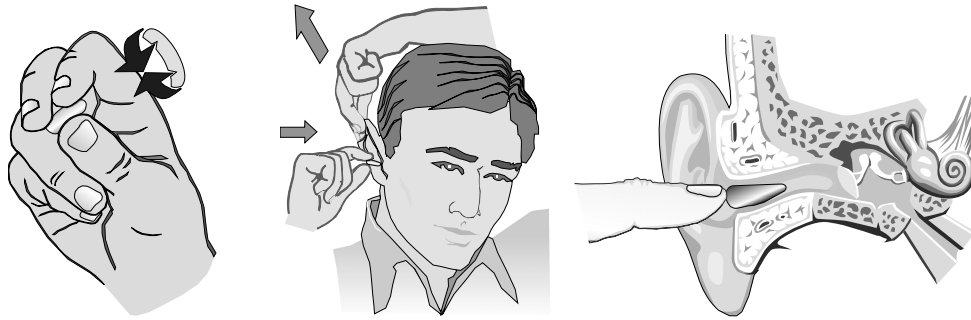


Figure 9 Roll-Pull-Hold hearing protection method [NIOSH, 2007]

IMPLICATIONS FOR PREVENTING NIHL

The combination of research efforts being conducted by NIOSH are designed to reduce the incidence of NIHL in mining, including longwall section workers. Information gained from full-shift worker exposure monitoring alerts mine management as to which workers are being overexposed and which occupations should be addressed concerning exposure reduction efforts. When exposure information is combined with worker observations, the noise source/dose relationship can be defined. This information allows mine operators to implement effective administrative noise controls. Equipment and area sound level measurements can be used to generate sound profile plots. These plots can alert mine operators and workers concerning the “noisy” areas that should be avoided and where engineering noise controls are most needed.

The alternative monitoring method, although still in the development stage, may prove to be an effective way to determine the noise sources responsible for longwall worker exposures. It may also prove to be an improved monitoring method for analyzing the effectiveness of engineering noise controls on longwall and other mining equipment.

Finally, the hearing protector and audibility consideration research will assess the effectiveness of new technological advances in hearing protection and identify methods to improve the audibility of important sounds while wearing hearing protectors. In addition, the Roll-Pull-Hold method will promote the correct and consistent use of soft foam earplugs. The results of these research efforts will benefit the workers in that they can perform the job safely, prevent accidents, and reduce noise-induced hearing loss.

SUMMARY

The National Institute for Occupational Safety and Health is spending considerable time and effort to reduce noise-induced hearing loss in the mining industry including longwall mining. These efforts include the development of engineering noise controls, advancing the use of administrative noise controls, exposure and noise measurement, laboratory

studies to better understand hearing loss and prevention methodologies, hearing protection device effectiveness studies, and improved sound level monitoring techniques. They are intended to assist both mine operators and individual workers to recognize and avoid noise exposures, and effectively protect their hearing. Individually the research efforts are just one piece of the puzzle and will not totally eliminate NIHL. Eventually when the results of all the efforts are available to the mining industry, NIHL will be significantly and positively impacted.

To date, the most promising results have come from the worker exposure monitoring and soft foam earplug studies. The dose monitoring revealed that the stageloader operator and shearer operators are the most exposed workers and most likely to experience NIHL. The studies have also shown that stageloader operators need to stay away from the stageloader discharge area, head drive, and crusher area to minimize their exposure. In addition, the shearer operators should stay as far outby (toward the head) as possible to minimize their exposure. The soft foam earplug investigations, coupled with training in the Roll-Pull-Hold 3-step insertion method, have shown miners that with correct insertion they can obtain a 9 dB greater attenuation. The result is less likelihood of developing either a temporary threshold shift or a permanent threshold shift (NIHL). The remainder of the research efforts addressed in this paper, although still in the early stages, show considerable promise in reducing NIHL among longwall workers. Avoiding noise exposures, implementing noise controls, and using HPDs effectively will minimize, and eventually eliminate, NIHL in the mining industry.

REFERENCES

- American National Standards Institute [1999]. American National Standard Method for Measuring the Intelligibility of Speech over Communication Systems. ANSI S3.2-1989 (R1999), New York, NY.
- Babich, DR and ER Bauer [2006]. Summary of longwall and continuous miner section noise studies in underground coal mines. *Mining Engineering*, v. 58, No. 11, Nov., pp. 41-46.
- Bauer ER, DJ Podobinski, and ER Reeves [2001]. Noise exposure in longwall mining and engineering controls research. In: Proceedings of Longwall USA 2001 International Exhibition & Conference, Pittsburgh, PA, June 13-15, Intertec Publishing Corp., Overland Park, KS, pp. 51-69.
- Berger EH, JR Franks, and F Lindgren [1996]. International review of field studies of hearing protector attenuation. In: Axelsson A, H Borchgrevink, RP Hamernik, P Hellstrom, D Henderson, and RJ Salvi, eds. Scientific basis of noise-induced hearing loss. New York: Thieme Medical Publishers, Inc., pp. 361-377.
- Coal Age [2006]. U.S. Longwall Census 2006 - Coal Companies Invest in More Longwall Capacity. S. Fiscor, Editor-in-Chief, v. 111, No. 2, February, pp. 26-30.

Federal Register [1996]. Health Standards for Occupational Noise Exposure in Coal, Metal, and Nonmetal Mines: Proposed Rule. Department of Labor, Mine Safety and Health Administration, 30 CFR Parts 56, 57, 62, 70, and 71, v. 61, No. 243, Tuesday, December 17, pp. 66348-66469.

Federal Register [1999]. Health Standards for Occupational Noise Exposure: Final Rule. Department of Labor, Mine Safety and Health Administration, 30 CFR Parts 56 and 57 et al., v. 64, No. 176, September 13, pp. 49548-49634.

Gigliotti, SJ, CA Davis, G Niewiadomski, JE Tisdale, and PM Turcic [1991]. Review of Longwall Mining in the United States Relative to Health and Safety. In: Proceedings of Longwall USA International Exhibition & Conference. Overland Park, KS: Intertec Publishing Corp., pp. 51–69.

NIOSH [1996a]. Preventing occupational hearing loss – a practical guide. Edited by Franks, J, MR Stephenson, and CJ Merry. National Institute for Occupational Safety and Health, Cincinnati, OH, DHHS (NIOSH) Publication 96-110, 91 p.

NIOSH [1996b]. Analysis of audiograms for a large cohort of noise-exposed miners. Franks, JR, pp. 1-7, and cover letter to Davitt McAteer from Linda Rosenstock, August 6, 1996.

NIOSH [1997]. Prevalence of hearing loss for noise–exposed metal/nonmetal miners. Franks, JR, pp. 1-5, and cover letter to Andrea Hricko from Gregory Wagner, October 7, 1997.

NIOSH [1998]. Criteria for a Recommended Standard: Occupational Noise Exposure, Revised Criteria. DHHS (NIOSH) Pub. No. 98-126. National Institute for Occupational Safety and Health, Cincinnati, OH, p. 25.

NIOSH [2007]. How to Wear Soft Foam Earplugs.
www.cdc.gov/niosh/mining/topics/hearingloss/earplug.htm

Spencer, ER, DR Babich, LA Alcorn, and AK Smith [2007]. Identification of Noise Sources on Longwall Panels Using Multiple Time-Synchronized Dosimeters. Society for Mining, Metallurgy, and Exploration, Inc., SME Preprint 07–097, Littleton, CO, 5 pp.