NOISE EXPOSURE IN LONGWALL MINING AND ENGINEERING CONTROLS RESEARCH

E. R. Bauer, D. J. Podobinski, E. R. Reeves
National Institute for Occupational Safety and Health
Office of Mine Safety and Health Research
Pittsburgh Research Laboratory
Pittsburgh, PA

J. S. Vipperman
Department of Mechanical Engineering
University of Pittsburgh
Pittsburgh, PA

ABSTRACT

Prolonged exposure to noise can cause permanent damage to the auditory nerve and/or its sensory components, known as noise induced hearing loss (NIHL). It is the most common occupational disease in the United States today. The Pittsburgh Research Laboratory (PRL) of the National Institute for Occupational Safety and Health (NIOSH) is addressing NIHL in the mining industry through several research efforts. This paper presents a general review of NIHL, the status of NIHL in mining, the results of the longwall noise surveys, and a review of the longwall engineering controls research efforts.

INTRODUCTION

Noise is often regarded as a nuisance rather than as an occupational hazard. However, overexposure to noise can cause serious hearing loss. In 1996, NIOSH reported that occupational hearing loss was the most common occupational disease in the United States, with 30 million workers exposed to excessive noise levels [NIOSH, 1996]. The problem is particularly severe in the mining industry, with studies indicating that 70% to 90% of miners have a NIHL great enough to be classified as a hearing disability [NIOSH, 1976; Franks, 1996]. This alarming prevalence of severe hearing loss among miners is demonstrated in Figure 1. The general trend among the three groups is an increase in hearing loss with increasing age. As an example, by age 50, 70% of coal miners and nearly 60% of non-coal miners have a hearing loss of more than 25 dB, compared to only 10% for non-exposed males.

Since the passage of the Federal Coal Mine Health and Safety Act of 1969, there has been some progress in controlling mining noise. Machinery manufacturers have incorporated design changes to reduce noise levels. At the same time, many of these gains have been offset by the use of larger, more powerful, equipment. Thus, the number of miners overexposed to noise, as defined by federal regulations, still exceeds the number of miners overexposed to all other health hazards. Data from over 60,000 Mine Safety and Health Administration (MSHA) noise surveys show that the noise exposure of selected occupations has decreased since the 1970s, although the percentage of miners overexposed in relation to current MSHA noise regulations remains high [Seiler et al., 1994]. MSHA found that the percentage of coal miners with noise exposures exceeding federal regulations, unadjusted for the use of hearing protection, were 26.5% and 21.6% for surface and underground mining, respectively. Table 1 lists recently published data from MSHA noise surveys of exposures in the mining industry [Federal Register, 1999] and indicates that more than 25% of the samples collected in coal mines exceeded the Permissible Exposure Level (PEL) (an eight hour Time Weighted Average (TWA_8) of 90 dBA) and nearly 77% exceeded the action level (a TWA_8 of 85 dBA) for enrollment in a hearing conservation program. On a percentage basis, a smaller percent of samples, taken in metal/nonmetal mines, exceeded the PEL and action level. These data are corroborated by data collected in the National Occupational Health Survey of Mining (NOHSM) during the 1980s [Greskevitch et al., 1996]. Based on this survey, the projected number of mine workers potentially overexposed to noise was approximately 200,000 workers, or 73% of the workforce.

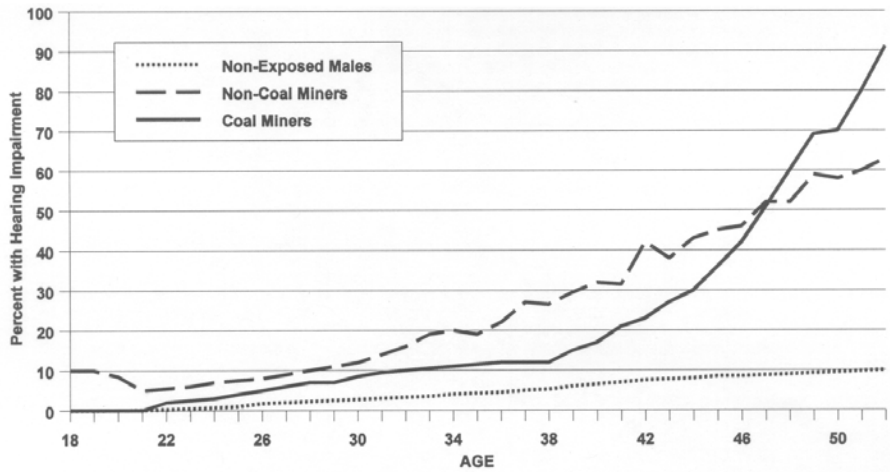

Figure 1
Hearing impairment in coal miners, non-coal miners, and non-exposed males (from Franks, 1996)

Industry segment	TWA_8 sound level, dBA	90-dBA threshold		80-dBA threshold	
		Number of samples	Percent of samples	Number of samples	Percent of samples
Coal[1]	90 (PEL)	1075	25.3	------------	------------
	85 (Action Level)	--------------	--------------	3268	76.9
Metal/ Nonmetal[2]	90 (PEL)	7360	17.4	------------	------------
	85 (Action Level)	--------------	--------------	28,250	66.9

[1]Collected from March 1991 through December 1995.
[2]Collected from March 1991 through December 1994.

Table 1
MSHA noise samples exceeding specified TWA_8 sound levels

In response to the continuing problem of NIHL among mine workers, NIOSH has begun a number of research efforts designed to reduce NIHL among mine workers. These efforts include education and training, effective use of personal protective equipment, noise source and worker dose monitoring, and engineering controls research.

FUNDAMENTALS OF NOISE INDUCED HEARING LOSS

Noise is any unwanted or undesirable sound. NIHL has been around for centuries, and first received attention with the advent of steam power during the industrial revolution. In fact, it was initially dubbed "boilermaker's disease" because of the hearing loss experienced by workers fabricating steam boilers [U.S. Dept. of Health and Human Services, 1998]. NIHL can be temporary or permanent depending on the level and frequency characteristics of the noise, the duration of exposure, and the susceptibility of the individual. Temporary hearing loss can last a matter of hours to several days or weeks. A permanent noise-induced hearing loss is not reversible and cannot be corrected by conventional medical or surgical procedures [Michael and Byrne, 2000]. Permanent NIHL is caused by exposure to sound levels or durations that damage the hair cells of the cochlea located in the inner ear (Figure 2). Hearing acuity is generally affected first in the frequency range from 3000 to 6000 Hertz (Hz). People with NIHL do not generally experience pain or even realize that serious hearing damage has occurred. They may hear a continuous ringing in their ears, called tinnitus. A noise-induced hearing loss becomes particularly noticeable when verbal communication is attempted in noisy or reverberant areas.

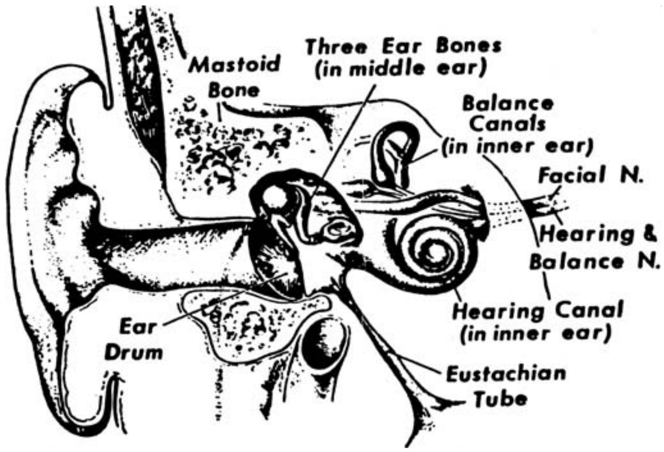

Figure 2
Diagram of human ear (Cochlea is listed as Hearing Canal)

HISTORY OF NOISE REGULATIONS IN MINING

Regulation of noise in mining is covered in Title 30 of the Code of Federal Regulations (30 CFR). The Federal Coal Mine Health and Safety Act of 1969 established requirements for protecting coal miners from excessive noise and, subsequently, the Federal Mine Safety and Health Act of 1977 broadened the scope to include all miners, regardless of mineral type [30 CFR, 1977]. The regulations allowed a PEL of 90 dBA TWA over eight hours. Exposure below the criterion of 90 dBA was unregulated, while continuous exposure to levels greater than 115 dBA was not permitted.

Despite the extensive work done to reduce noise overexposure in the 1970s and 1980s, NIHL in mine workers is still a problem. Therefore, MSHA has published new Noise Health Standards for Mining [Federal Register, 1999]. The new rule-making efforts were adopted in September 1999 and became effective in September 2000. They include a PEL of 90 dBA TWA_8, and a new action level for workers exposed to a dosage over 50% of the PEL (which is 85 dBA TWA_8). Moreover, the new rule establishes the primacy of engineering and administrative noise controls, and eliminates credit for the use of personal hearing protection. Additional criteria include a dual hearing protection level of 105 dBA TWA_8 and a stipulation that no miner is exposed to sound levels exceeding 115 dBA. Specific details of the new regulations are listed in Table 2.

Type	TWA_8, dBA	Dose	Sound Levels Integrated, dBA	Exchange rate, dB	Weighting	Response
Action level	**85**	**50%**	**80 to 130**	**5**	**A**	**Slow**
Permissible exposure level	**90**	**100%**	**90 to 140**	**5**	**A**	**Slow**

Table 2
Details of Part 62 of 30 CFR - Occupational noise exposure measurements

CROSS-SECTIONAL SURVEY OF NOISE EXPOSURE

NIOSH is obtaining multishift worker noise exposure and equipment noise levels to develop a comprehensive profile of the noise exposures to the mining population as a function of equipment- and activity-specific measures. This study is a component of the effort to develop noise controls. It will define the sources of miners' exposures and the characteristics of those sources. This information will enhance ongoing efforts focusing on the development and application of appropriate engineering and administrative control measures to reduce exposures for mine workers. Data collection is being performed at underground and surface coal and metal/nonmetal mines and in coal processing plants. It is necessary to survey all segments of the mining industry because workers across the industry continue to have a significant risk of hearing impairment, as described by MSHA data published in the Federal Register [1999].

At each mine site, the data collected include worker noise dose, equipment noise, and other worker, mine, and equipment-specific information; utilizing the same procedure at all mines. Mine workers wear Quest Model Q 400 time-resolved dosimeters with the microphones pinned on the top, middle of the shoulder. Workers are observed to determine the correlation between tasks performed, noise dose received, and the noise source responsible for that incremental contribution to the overall exposure. Noise profiling of longwall and continuous miner section equipment, consisting of A-Weighted Equivalent Continuous Sound Levels (Leq) measurements on a uniform grid pattern (usually 3.28 ft (1 m) square), is conducted using Quest Model 2900 Integrating and Logging Sound Level Meters (Figure 3). In general, Leq noise levels were recorded using tripod-mounted SLMs, with microphones at 5-5.5 ft (1.5-1.7 m) from the mine floor (approximate ear height). Where possible, measurements were made completely around the equipment and at a distance away until the Leq level dropped below 90 dBA. Table 3 lists the dosimeter and SLM settings.

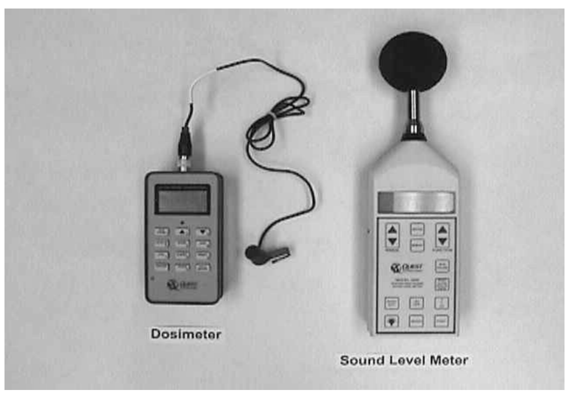

Figure 3
Dosimeter and Sound Level Meter used in study

Longwall Noise Surveys

Noise surveys were conducted on three longwall faces. The first survey was completed at a mine in southern West Virginia operating in the Lower Cedar Grove coalbed. A second study was conducted in Colorado, in a mine operating in the Wadge coalbed. The final study was completed in a longwall mine in northern West Virginia operating in the Pittsburgh coalbed. In addition, in each of the mines, noise surveys were completed on the continuous miner (CM) sections during gate road development. A summary of equipment noise profiling (Leq) and worker dose monitoring at each site follows.

Type	Instrument	Parameters	
		MSHA PEL	Wide Range
Worker Dose	**Quest Q-400 Dosimeter**	**Weighting - A Threshold Level - 90 dB Exchange Rate - 5 dB Criterion Level - 90 dB Response - Slow Upper Limit - 140 dB**	**Weighting - A Threshold Level - 40 dB Exchange Rate - 3 dB Criterion Level - 85 dB Response - Slow Upper Limit - 140 dB**
		Parameters	
Equip. Profiling	**Quest 2900 Sound Level Meter**	**Weighting - A Exchange Rate - 3 dB Response - Slow Range - Variable (60 - 140 dB) Memory - On Measurement - Leq, dBA**	

Table 3
Noise monitoring parameters

Southern West Virginia Mine
The longwall at this mine was operating in the Lower Cedar Grove coalbed, which was 55-70 in (1.4-1.8 m) thick. Mining height averaged 72-84 in (183-213 cm), including 12-20 in (30.5-51 cm) of rock, for reject averaging 40%. Equipment noise profiling (Table 4) and full shift (10hr) worker noise dosimetry was conducted (Table 5). At this mine, only the headgate operator and headgate shearer operator were task-observed; an example plot is shown in Figure 4 and illustrates some of the tasks responsible for the headgate operator's dose.

Equipment	Range of noise (Leq), in dBA	Location of Highest Leq Noise Level
Stageloader	**84 – 98**	**head drive, crusher, gear boxes**
Hydraulic pump car	**85 – 98**	**motors and hyd. pumps**
Shearer (Headgate) Shearer (Tailgate)	**96 98**	**ND[1] ND**
Panline	**81 – 87**	**near head drive**
Dinner hole	**<60**	**None**

[1]ND - Not determined

Table 4
Results of equipment profiling on longwall in southern West Virginia mine

Location	Workers Monitored	Results of Dose Monitoring		Tons
		No. of Shifts	Range of PEL Dose, %	
LW[1]	Head Shearer Operator Tail Shearer Operator Headgate Operator Jacksetter Electrician Foreman	3 3 3 6 3 3	185-266 290-786 142-179 81-188 76-126 61-203	6600-8140
CM[2]	CM Operator CM Helper Roof Bolter, Right Roof Bolter, Left Shuttle Car Operator Scoop Operator Brattice Man Electrician Foreman	3 3 3 2 6 3 2 3 3	222-323 201-347 142-247 133-234 70-165 24-44 37-53 36-92 39-114	990-1135

[1]LW – Longwall; [2]CM – Continuous Mining

Table 5
Summary of dosimeter measurements in southern West Virginia mine

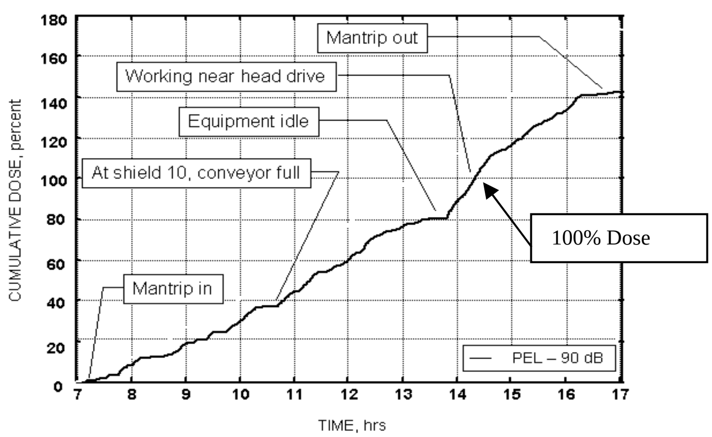

Figure 4
Cumulative dose plot for headgate operator from southern West Virginia mine

Colorado Mine
This mine was operating in the Wadge coalbed, which averaged 8.25 to 9.5 ft (2.5 to 2.9 m) thick. In most instances there was very little inseam rock. Leq noise level values were recorded for the longwall equipment (Figure 5) and all longwall workers wore a noise dosimeter for three full (10 hr) shifts. Table 6 summarizes the equipment noise levels and Table 7 summarizes the results of the dosimeter measurements.

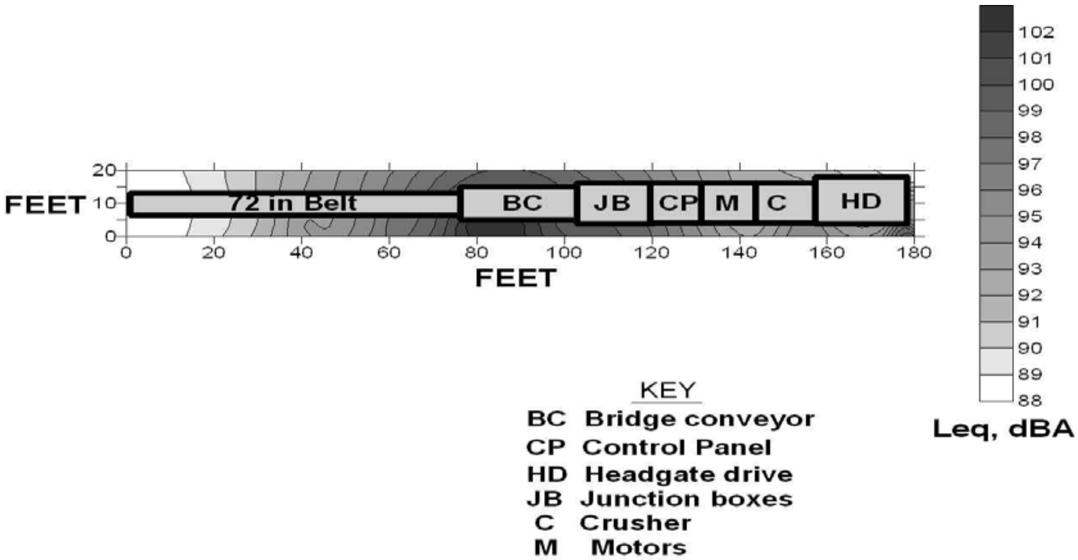

Figure 5
Noise levels measured along the stageloader and panel belt in Colorado mine

Equipment	Range of noise (Leq), in dBA	Location of Highest Leq Noise Level
Stageloader	**89 – 102**	**bridge conveyor**
Longwall hydraulics	**82 – 98**	**motors and hyd. pumps**
Shearer	**85 – 90**	**ND[1]**
Panline	**85 – 91**	**near head drive**
Head drive	**89 – 96**	**ND**
Tail drive	**92 – 94**	**ND**
Dinner hole	**63 – 68**	**None**

[1]ND - Not determined

Table 6
Results of equipment profiling on longwall in Colorado mine

Northern West Virginia Mine
This mine was operating in the Pittsburgh coalbed. Mining height averaged 82-86 in (208-218 cm), composed of 5 to 6 ft (1.5 to 1.8 m) of coal, overlain by 2 to 24 in (5 to 61 cm) of draw rock, followed by 1 to 24 in (2.54 to 61 cm) of top coal. In most instances, this resulted in a rock content of approximately 30%. Equipment noise profiling (Figure 6) and worker dose monitoring (9 hr, full shift) were conducted. Table 8 presents the results of the equipment noise profiling and Table 9 summarizes the results of the dosimeter measurements. Task observations were conducted on the headgate (Figure 7) and tailgate shearer operators only.

Location	Workers Monitored	Results of Dose Monitoring		Tons
		No. of Shifts	Range of PEL Dose, %	
LW	**Shearer Operators[1]**	**6**	**164-355**	**14318-22610**
	Headgate Operator	**3**	**233-386**	
	Faceman	**9**	**64-192**	
	Mechanic	**6**	**64-156**	
CM	**CM Operator**	**4**	**48-197**	**1070-1692**
	CM Helper	**4**	**44-132**	
	Roof Bolter, Right	**4**	**77-213**	
	Roof Bolter, Left	**4**	**57-230**	
	Roof Bolter Helper	**3**	**222-355**	
	Shuttle Car Operator	**7**	**23-109**	
	Scoop Operator	**4**	**150-210**	
	Utility Man	**2**	**19-168**	
	Mechanic	**3**	**34-162**	
	Foreman	**4**	**131-232**	

[1]Shearer operators switched from head to tail position when shearer direction changed.

Table 7
Summary of dosimeter measurements in Colorado mine

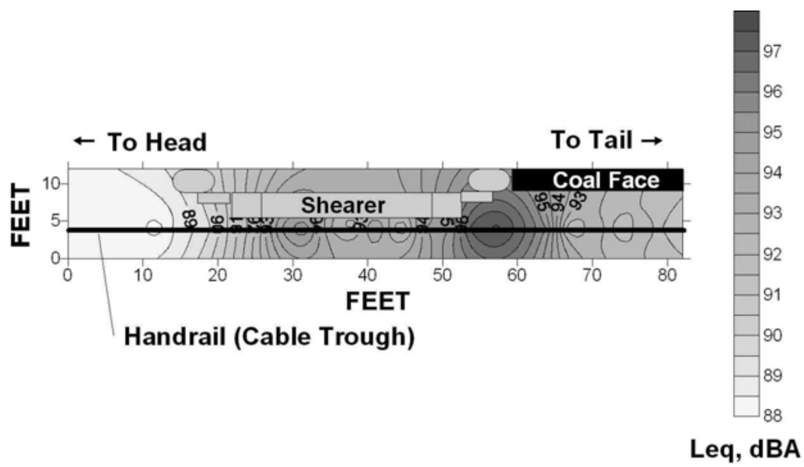

Figure 6
Leq noise levels around shearer while cutting from head to tail in northern West Virginia mine

Comparative Analysis of Mine Sites
A comparison of the noise surveys at the three mines indicates the following:
- Noise levels of similar equipment found in each mine was relatively consistent, although the range of Leq noise levels varied.
- Worker exposures were also similar from one mine to the other.
- Worker dose varied widely from shift-to-shift indicating that single shift dose measurement is not sufficient for determining compliance.
- Little correlation was found between production and equipment noise levels and worker dose.

Equipment	Range of noise (Leq), in dBA	Location of Highest Leq Noise Level
Stageloader	86 – 100	crusher, motor, and gear box at tail piece
Hydraulic pump car	78 – 99	motors and hyd. Pumps
Shearer (head to tail) Shearer (tail to head)	88 - 99 86 – 96	adjacent to tail drum adjacent to head drum
Panline (full)	78 – 80	near head drive
Section belt	83 – 96	roller with worn out bearings
Dinner hole	<70 – 90	when located next to stageloader

Table 8
Results of equipment profiling on longwall in northern West Virginia mine

Location	Workers Monitored	Results of Dose Monitoring		Tons
		No. of Shifts	Range of PEL Dose, %	
LW	Head Shear Operator Tail Shear Operator Shieldman Mechanic Foreman	3 3 10 4 3	125-179 124-240 49-138 37-99 102-123	3145-5550
CM	CM Operator LM Operator Roof Bolter, Right Roof Bolter, Left Roof Bolter, Center Shuttle Car Operator Utility Man Mechanic Foreman	3 3 3 3 3 6 1 3 2	88-127 58-81 169-275 128-185 18-33 9-34 297 8-68 17-36	186-325

Table 9
Summary of dosimeter measurements in northern West Virginia mine.

NOISE SOURCE LOCATION USING SOUND INTENSITY TECHNIQUES

Prior to expending time or money on solving a noise problem, the number, strength, and location of the major noise source(s) should be determined. Only after source identification and quantification, can cost-effective engineering and/or administrative noise control solutions be implemented. The preferred way to reduce worker noise exposure is to contain or control the noise at its source. This is referred to as engineering noise control. When properly installed and maintained, this type of control requires no further action on the part of the worker to reduce his/her noise exposure. For this reason, the primacy of engineering controls was emphasized in the enactment of Part 62 of 30 CFR [Federal Register, 1999].

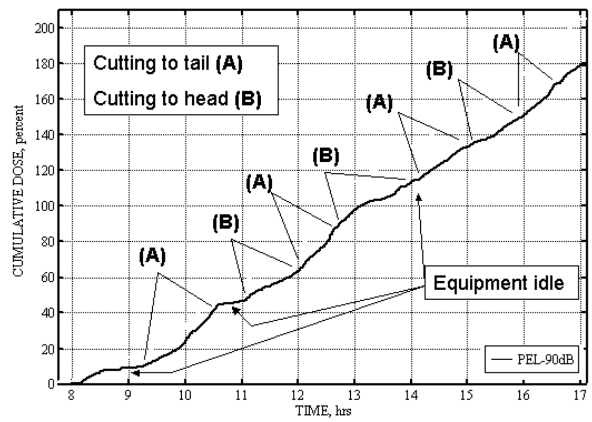

Figure 7
Cumulative dose plot for head shearer operator in northern West Virginia mine

When implemented properly, engineering controls can be a cost effective proposition. A systematic approach to noise control can ensure control efforts are targeted to necessary areas. Systematic approaches to resolving noise control problems are outlined in many texts. A suggested sample approach is:

- (i) Define the problem - Operation of various mining equipment often causes the worker exposure to exceed the PEL.
- (ii) Establish the goal and scope of the program. - For example, the goal may be to reduce worker exposure to below the action level requiring enrollment into a hearing conservation program.
- (iii) Qualitatively identify source(s), path(s) and receiver(s) - These are the steps currently being addressed by many in the mining industry.
- (iv) Draw an acoustical free body diagram that identifies all noise sources, air-borne and structure-borne paths to the receiver.
- (v) Quantitatively rank the sources and paths with analysis tools.
- (vi) Determine the merits of source-path-receiver controls.
- (vii) Identify direct and reverberant field contributions.
- (viii) Isolate flanking paths and their significance.
- (ix) Identify and rank structure-borne and air-borne paths.
- (x) Give careful consideration to all possible controls.
- (xi) Select combination of controls that is most effective for the budget.
- (xii) Apply controls and evaluate results, then compare with expected results.

Why Sound Intensity?

Sound intensity measurement is a technique for identifying and ranking noise sources (Steps 3 and 5 above). Sound level meters (SLMs) and dosimeters, currently in widespread use within the industry, use one microphone to measure sound pressure. Sound pressure, being a scalar quantity and having magnitude only, does not provide the source location. Sound intensity analyzers utilize two microphones in close proximity to one another (Figure A1). The additional microphone provides directional information, making sound intensity a vector, having both magnitude and direction. This directional aspect of the sound intensity measurement enables one to say, for example, “The noise generated by this machine originates in the lower right hand corner ” as opposed to simply saying “This machine is noisy.” This additional information allows manufacturers, equipment rebuilders and maintenance personnel to focus on and treat the actual noise source rather than try to enclose the entire machine in an attempt to reduce its overall noise level.

Longwall Engineering Controls Research

Background

Dosimetry information has identified the area adjacent to the longwall stageloader as one of the higher noise areas in the underground mining environment. The size, complexity and mobility of the stageloader, and the height of the coal seam, preclude the use of operator enclosures or most other means to isolate the equipment noise from the workers in the immediate area. Sound intensity measurement techniques were used to locate and identify the specific source(s) of noise within the stageloader assembly. Pinpointing the noise source would minimize the engineering control effort.

Many equipment manufacturers assemble and test run the equipment prior to shipment to the mine because it is difficult to modify large underground mining equipment once installed and operational. This allows for easier identification of potential problems and for making the necessary modifications before it is installed in an operating underground mine. The manufacturer and end user of this particular stageloader allowed us to conduct a sound intensity survey of the unit while it was being operated in the manufacturer's shop. Results of the survey were shared openly among all parties involved.

Measurement Technique

The stageloader assembly was divided into areas that were consistent with the manufacturer’s nomenclature. This particular stageloader was divided into the discharge zone - the horizontal section located directly over the belt tailpiece; and the gooseneck zone - the area between the crusher and the discharge zone. Initially, because of uncertainty that sound intensity measurements could effectively locate the source(s) of the equipment noise, no measurements were made in the area between the crusher and the headgate drive.

Each zone to be measured was then placed in an imaginary “box.” The purpose of the box was to provide planar measurement surfaces that completely enclose the device under test and allow for evaluating all sound coming from within a particular volume. All sides of the box are referred to as surfaces. Each surface is then broken down into segments. For these measurements, each segment was 18 in by 18 in (0.45 m by 0.45 m). These dimensions were chosen by considering the frequency range of interest, the overall size of the stageloader, and the guidelines for determining the minimum number of measurement points required to produce valid results using the fixed-point measurement technique [ANSI, 1992].

Measurements are then made normal (at 90^0) to the surface and averaged over fifteen seconds at the center of each segment using a B&K 2260 Noise Investigator. To insure a consistent spacing between the probe and the measurement surface, a 3.9 in (10 cm) long plastic spacer was attached to the microphone probe. The selected spacer rod did not allow vibrations to be transferred to the microphone probe, and was diametrically small enough to not affect the measurement.

Sound Intensity Measurement Results

The results of the sound intensity measurements taken on the side of the stageloader gooseneck zone are shown in Figure 8. Measurements were made at each of the grid intersections. The information was processed by the B&K 2260 Noise Investigator, and plotted using Microsoft Excel. Figure 8a illustrates an apparent source of high intensity located in the lower right hand corner of the gooseneck assembly. It can also be seen that the intensity lessens as the distance from the alleged source increases, indicating that it was not an errant data point causing the high reading.

This area corresponds to the lower deck of the gooseneck immediately adjacent to the crusher assembly. Upon disassembly prior to shipment to the mine site, the manufacturer found an area of interference in this lower deck region that resulted in the flight bars contacting the conveyor deckplate. This problem was addressed prior to shipment.

Because the measurement technique appeared to effectively locate noise sources, we were asked to repeat the measurements after implementation of engineering controls. The controls selected by the manufacturer were implemented in two phases: first, additional panels were installed onto the side of the stageloader in areas that were easy to access; and next, the void created by the addition of these panels was filled with sand. Both of these control ideas attempted to dampen the noise generated by the operation of the stageloader by increasing the mass of the structure. The results of these measurements are shown in Figures 8b and 8c respectively.

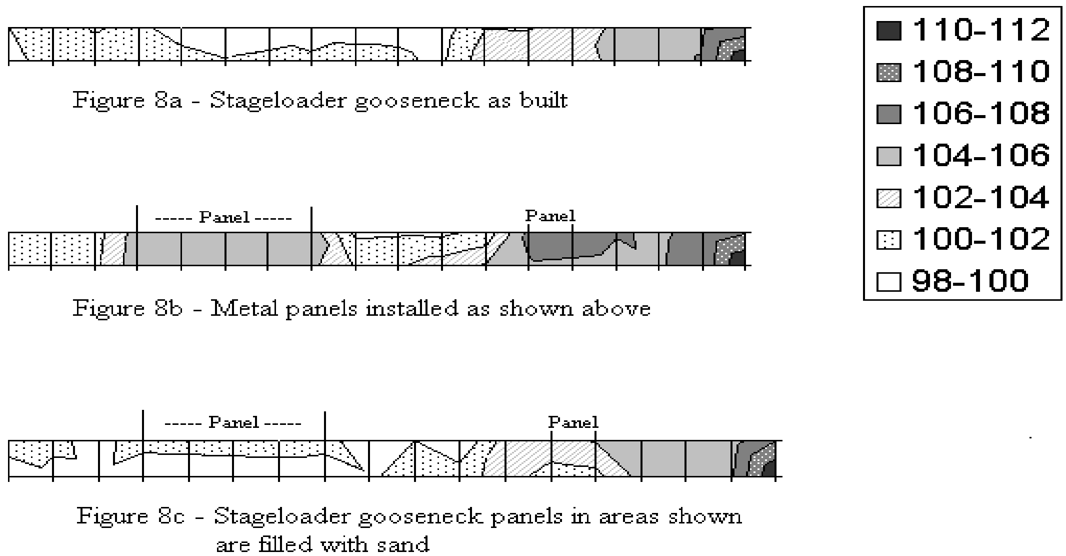

Figure 8a - Stageloader gooseneck as built

Figure 8b - Metal panels installed as shown above

Figure 8c - Stageloader gooseneck panels in areas shown are filled with sand

Figure 8
Sound intensity measurements of gooseneck assembly

Sound Power Measurements
The addition of sand resulted in a decrease in localized sound intensity, as shown in Figure 8c. However, an increased area of higher sound intensity occurred, making it difficult to tell if the treatment was effective in reducing the overall noise level of the equipment. Sound power (watts), which is the total sound energy radiated by the source per unit of time, can be used to evaluate noise level reductions.

Several recognized national standards are available to compute sound power from sound intensity measurements. The method specified in ISO 9614-1 is shown here for illustrative purposes. The sound power level of the device under test is:

$$L_w = 10 \times \log\left(\frac{\sum I_{ni} S_i}{P_o}\right) \text{ dB,}$$

where: I_{ni} = the sound intensity measured at the i^{th} segment, in watts/square meter;
S_i = the area of the i^{th} segment, in square meters; and
P_0 = the sound power reference or 1 picowatt (10^{-12} watts).

Sound power measurements are typically used to quantify the total energy being emitted by a noise source. In this example, we used the sound power emitted by one surface to compare the before-and-after results of the application of an engineering control. The relationship of sound power emitted by the noise source and the sound pressure that impinges on the ear of the worker is analogous to the situation shown in Figure 9. For a constant electrical input to the heater, the power given off by the heater (analogous to sound power) is constant. The temperature perceived by the individual (analogous to sound pressure) depends on both the environment (size of room, number of windows and doors, and whether they are opened or closed), and the distance from the heat source. In general, if you can lower the amount of power generated by the source, the temperature (or sound pressure) perceived by the individual will be less, if the distance and environment are constant. The effectiveness of engineering controls can be evaluated and compared by determining the sound power emitted by the source.

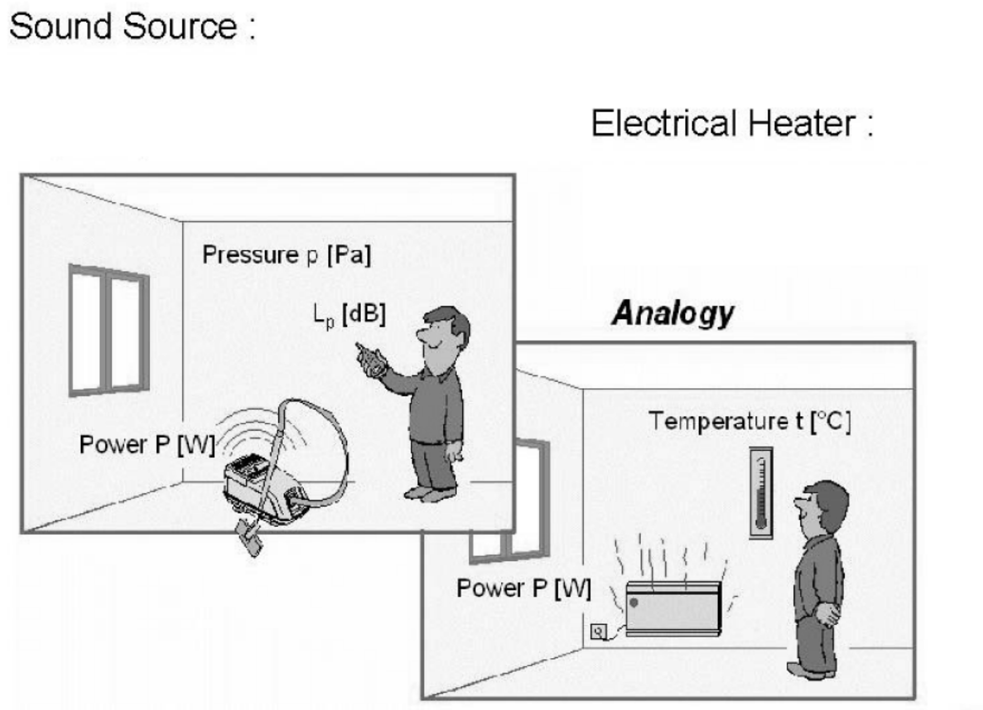

Figure 9
Analogy of sound power and thermal power [Rasmussen, 1998]

The sound power levels for these three areas are shown in Table 10.

Reference Figure	Condition	Sound Power Level, dB
8a	**Unmodified (base case)**	**111.9**
8b	**Partially paneled**	**114.0**
8c	**Filled with sand**	**111.7**

Table 10
Sound power levels for stageloader gooseneck areas – one side surface only

Future Longwall Engineering Control Efforts
The following sound intensity surveying activities are planned:

- Measure the power unit (motor, fluid coupler, gear case) to quantify the noise generated by water-cooled motors.
- Measure the effect of flight bar spacing on overall stageloader noise levels.
- Perform follow-up measurements on this particular stageloader to quantify the effects of aging and coal loading on the generated noise levels.
- Use accelerometers to measure panel vibration and modal effects both before and after a modification is made.

DISCUSSION

The result of exposure to high noise levels can be a permanent hearing loss termed Noise Induced Hearing Loss (NIHL). Studies have shown that over 70% of mine workers are at risk of overexposure to noise, and that 60 to 70% of all mine workers will have a 25 dB or greater hearing loss by age 50.

The results of the preliminary worker dose monitoring revealed that approximately 47% of the longwall workers monitored experienced noise dosages above the allowable (citable) PEL of 132% (90 + 2 dB). The workers most consistently experiencing doses above 132% include the shearer operators and headgate/stageloader operators. Other workers who occasionally are exposed to noise doses above 132% include the shieldmen/jacksetters, mechanics/electricians, and foremen. On the CM sections, face crew worker noise doses were above 132% only 39% of the time. The workers consistently above this level included the roof bolter operators, foremen, and at one mine, the CM operator and helper. In addition, significant variation exists in the full-shift doses.

The noise profiling of the longwall equipment revealed that the stageloader was generally the noisiest piece of equipment, followed by the shearer and hydraulic pump car/assembly. This equipment consistently generated noise levels greater than 90 dBA. It was found that the face conveyor (panline) and section belt developed noise levels ranging from 80 to 90 dBA. Many more pieces of equipment on the CM section generated noise levels above 90 dBA, including the roof bolter, continuous miner, feeder/breaker, auxiliary fans, scoop, miner/bolter, and loading machine. Nearly all other equipment emitted noise levels greater than 80 dBA during operation.

Finally, it was demonstrated that sound intensity can be used to locate noise sources on a longwall stageloader and possibly other mining equipment. Using this technique can reveal unexpected noise sources that can then be corrected prior to field installation**.** It was also demonstrated that filling side panels with sand may decrease sound levels. Further testing is needed to verify if this can reduce noise levels if applied to the entire stageloader assembly. In addition, the motor cooling fan contributes to the overall noise level of the stageloader power unit.

REFERENCES

ANSI, 1992, Engineering Method for the Determination of Sound Power Levels of Noise Sources Using Sound Intensity, S12.12, American National Standards Institute, New York, 19 pp.

CFR 30, 1997, Code of Federal Regulations (CFR) governing noise exposure in mining, CFR 30, Subchapter O, Part 70, Subpart F: Noise Standards for Underground Coal Mines; Subchapter O, Part 71, Subpart D: Noise Standards for Surface Work Areas of Underground Coal Mines and Surface Coal Mines; Subchapter O, Part 55, Section 55.5: Metal and Nonmetal Open Pit Mines; Section 56.5: Sand, Gravel, and Crushed Stone Operations and 57.5: Metal and Nonmetal Underground Mines.

Federal Register, 1999, Health Standards for Occupational Noise Exposure; Final Rule, Department of Labor, Mine Safety and Health Administration, 30 CFR Parts 56, 57, 62, 70 and 71, **64** (176), September 13, pp. 49548-49634.

Franks, J.R., 1996, Analysis of audiograms for a large cohort of noise-exposed miners, Internal Report, National Institute for Occupational Safety and Health, Cincinnati, OH, pp. 3-8.

Greskevitch, M.K., T.S. Bajpayee, D.W. Grace, J.M. Hale, and F.J. Hearl, 1996, "Results from the National Occupational Health Survey of Mining (NOHSM)," DHHS (NIOSH) Publication No. 96-136, September, pp. 17-18.

ISO 9614-1, 1993, Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 1: Measurement at discrete points, International Organization for Standardization, Geneva, Switzerland, 24 pp.

Michael, K.L. and D.C. Byrne, 2000, Industrial Noise and Conservation of Hearing, *Chapter Nineteen in Patty's Industrial Hygiene, Fifth Edition, Volume 2*, Edited by R.L. Harris, John Wiley & Sons, Inc., pp. 15-16.

NIOSH, 1996, National Occupational Research Agenda (NORA), National Institute for Occupational Safety and Health, Publication No. 96-115, p. 14.

NIOSH, 1976, Survey of Hearing Loss in the Coal Mining Industry, National Institute for Occupational Safety and Health, Publication No. 76-172, June, 70 p.

Rasmussen, G., 1989, Intensity - Its Measurement and Uses, *Sound and Vibration*, **23** (3), March, pp. 12-21.

Seiler, J.P., M.P. Valoski, and M.A. Crivaro, 1994, Noise Exposure in U.S. Coal Mines, U.S. Dept. of Labor, Mine Safety and Health Administration, Informational Report IR 1214.

U.S. Department of Health and Human Services, 1998, Criteria for a Recommended Standard, Occupational Noise Exposure, Revised Criteria 1998, U.S. Dept. of H&HS, Public Health Service, Centers for Disease Control and Prevention, NIOSH, Cincinnati, OH, June, p. 11.

APPENDIX – Sound Intensity Theory

Sound intensity at any point in a sound field is defined as the average rate of flow of sound energy transmitted in a specified direction through a unit area normal to this direction at the point considered. Sound intensity is measured in units of watts per square meter. The letter “I” is used when referring to intensity. The mathematical formula for sound intensity is the dot product of the sound pressure and the particle velocity (p · v) (Refer to Figure A1). The sound pressure used in the calculation is the average of the two pressures measured by the two microphones (P_a, P_b). The particle velocity is determined by using the finite difference approximation developed by Euler.

$$Velocity(v) = \int \frac{1}{\rho} \frac{\partial p}{\partial r} dt,$$

where ρ is the density of air,
p is pressure, and
r is the separation distance between the microphones.

This partial derivative can be approximated by

$$v = -\frac{1}{\rho} \int \frac{(P_b - P_a)}{\Delta r} dt,$$

where P_a and P_b are readily measured.

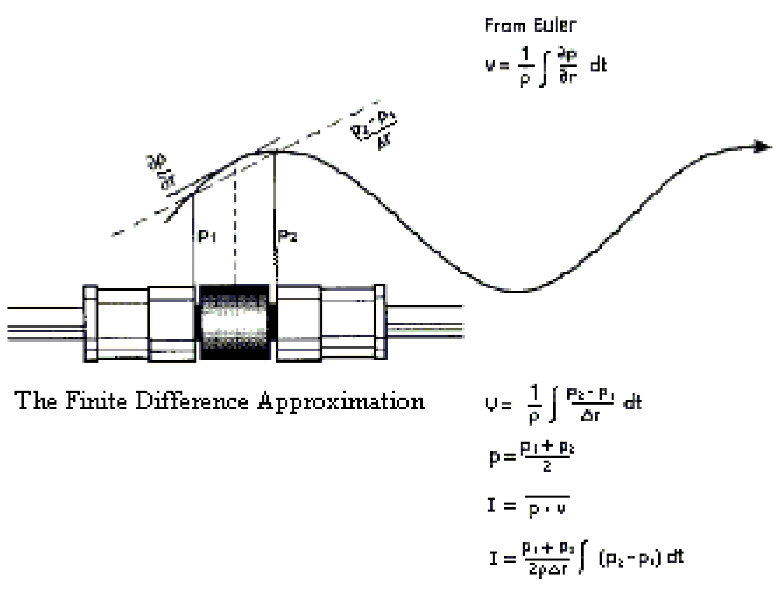

Figure A1
Microphone spacing for sound intensity measurements [Rasmussen, 1989]