Hearing Loss in the Mining Industry:
The Evolution of NIOSH and Bureau of Mines Hearing Loss Research

R.J. Matetic
NIOSH, Pittsburgh, PA, USA

Robert F. Randolph
NIOSH, Pittsburgh, PA, USA

Peter G. Kovalchik
NIOSH, Pittsburgh, PA, USA

ABSTRACT: Noise is one of the greatest hazards to a miner's health, rivaled only by respirable dust and repetitive trauma. Hazardous noise exposures are more prevalent in mining than in any other major U.S. industrial sector, and, as a consequence, miners report more hearing problems than any other type of worker. NIOSH has made the reduction of noise-induced hearing loss a major strategic goal and is attacking the problem through improved noise controls and interventions for workers. The NIOSH strategy expands on decades of research by its U.S. Bureau of Mines predecessors that identified some of the key issues with underground and surface noise sources. The current NIOSH program expanded significantly in 2000 in response to stakeholder interest and to provide a research complement to the regulatory initiative embodied in the Health Standards for Occupational Noise Exposure published by the Mine Safety and Health Administration in that year. Since then, NIOSH has developed significant new technologies for reducing noise from continuous mining machines and roof bolting machines, which have been the main sources of noise overexposures for underground coal miners. Field studies have shown that NIOSH-developed noise controls reduce workers' noise exposures below the MSHA Permissible Exposure Level (PEL). The facilities and engineering techniques developed for the underground coal efforts are now being applied to underground metal mining, processing plants, and other mining sectors. NIOSH has also addressed the worker's role in prevention by developing the Hearing Loss Simulator, QuickFit earplug tester, and other tools workers and trainers can use to reduce the risk of noise-induced hearing loss. These worker-empowerment technologies motivate and involve miners to implement noise controls, participate in administrative exposure management, and use hearing protection effectively. As it enters its second decade of mining noise and hearing loss prevention research, NIOSH has started to evaluate the impact each of its noise controls and other interventions have had on the hearing loss problem. In addition, NIOSH will direct its resources in partnership with industry stakeholders to address every mining sector within the next ten years.

INTRODUCTION

The U.S. Bureau of Mines (USBM) and National Institute for Occupational Safety and Health (NIOSH) have a long history of identifying and addressing hazardous mining noise. In 1971, the Bureau published findings that 73% of underground coal miners were exposed to hazardous noise (Lamonica, Mundell and Muldoon 1971). A 1976 NIOSH publication showed that miners had ―measurably worse hearing than the national average" (NIOSH 1976). Unfortunately, noise and hearing loss are still a problem for today's miners. Mining has the highest prevalence of hazardous noise exposure of any major industry sector (Tak, Davis, and Calvert 2009) and mining is second only to the railroad industry in prevalence of workers reporting hearing difficulty (Tak and Calvert 2008). Noise-induced hearing loss is a special concern for miners because it is permanent and life altering. Besides hearing loss, noise-exposed workers are more likely to experience speech interference, disturbed sleep interference, excess stress, tinnitus, and decreased work performance (Kryter 1994).

The NIOSH and earlier USBM programs that addressed hazardous noise have consistently followed a doctrine guided by the hierarchy of controls (NIOSH 1996):

1. **Engineering controls** that reduce noise at the source or prevent noise from reaching the worker's location

2. **Administrative controls** that reduce worker exposure through changes in procedures or behavior to reduce their time and proximity to noise sources

3. **Hearing protection devices** that reduce the noise reaching workers' ears

Engineering controls are preferred as they are the most effective defense against noise because they do not rely as much on constant human vigilance as do administrative controls and hearing protection. However, effective and feasible engineering controls can be very challenging to develop. The NIOSH mining hearing loss research program has focused on this challenge from its early years within the U.S. Bureau of Mines to its latest accomplishments.

USBM HEARING LOSS RESEARCH PRIOR TO 1996

Noise control and hearing loss prevention first became a high priority for the U.S. Bureau of Mines in the 1970s, following the enactment of the Federal Coal Mine Health and Safety Act of 1969. This act contained noise standards based on the 1969 amendment to the 1936 Walsh-Healey Public Contracts Act. The Bureau conducted a series of projects during the 1970s and 1980s to characterize the noise problem and develop noise controls and other recommended solutions (Aljoe 1985). During this period, the work was conducted by a small (3-5 person) research team augmented by external research contracts. The team also developed research facilities that included a reverberation chamber and an anechoic chamber at the Bureau's Pittsburgh Research Center. The Bureau research was successful in identifying a number of potential noise control solutions that were summarized in a published handbook (Bartholomae and Parker 1983). Unfortunately, the Bureau-developed solutions were not widely adopted.

NIOSH TRANSITION AND THE MSHA NOISE RULE

In 1996, the health and safety functions of the U.S. Bureau of Mines were transferred to NIOSH and reorganized under the Office of Mine Safety and Health Research. The noise control and hearing loss program remained within what became the NIOSH Pittsburgh Research Laboratory (PRL). The program began to establish closer ties with other hearing loss researchers within NIOSH, primarily those at the Division of Applied Research and Technology (DART) in Cincinnati Ohio. DART produced two important reference documents that helped set the tone for future development of the hearing loss research program in mining. The first was ―Preventing Occupational Hearing Loss—A Practical Guide" (NIOSH 1996), which outlined principles and strategies for solving noise problems, notably re-asserting the primacy of engineering noise controls. The second was ―Criteria for a Recommended Standard: Occupational Noise Exposure", which included a Recommended Exposure Limit (REL) of an 8-hour time-weighted-average sound level of 85 dB(A) with a 3-dB exchange rate (NIOSH 1998). The NIOSH REL was based upon population hearing loss risk studies and the underlying physics of sound and physiological responses to noise exposure. The REL remains NIOSH's recommendation for exposure limits and current research is investigating enhancements to address impulse noise and exposure durations significantly longer than 8 hours.

During the late 1990s, NIOSH researchers provided input to the MSHA rulemaking process that would culminate in a new noise rule. For instance, NIOSH provided MSHA with an analysis of audiometric tests for over 60,000 miners which showed that by the age of 60, 70-90% of miners had hearing impairment compared to 12% of the individuals who reach that age without significant noise exposure (Franks 1996, 1997).

MSHA's Health Standards for Occupational Noise Exposure were codified in 30 CFR 62 in 1999 with enforcement beginning in 2000. The new standard, commonly called the ―Noise Rule", gave regulatory primacy to engineering and administrative controls. It did this by requiring that mine operators use all technologically achievable engineering and administrative controls to avoid overexposures, and that hearing protectors would no longer be permitted in place of the feasible controls. Feasibility of a control was now determined by an evaluation process that ended with listing the control on a Program Information Bulletin containing ―Technologically and Administratively Achievable Noise Controls" (MSHA 2008).

NIOSH HEARING LOSS PREVENTION INITIATIVE

NIOSH identified a need for noise control and hearing loss prevention research for miners that would complement the regulatory effort embodied in the MSHA Noise Rule. The NIOSH Associate Director of Mine Safety and Health Research at the time, R. Larry Grayson, reiterated the primacy of engineering controls in the NIOSH approach (Grayson 1999) and the Institute began building a greatly enhanced research capability. Along the way, NIOSH increased the number and expertise of personnel working on noise and hearing loss issues, expanded the research facilities and resources for them to use, and extended the program's scope with a multi-stage process that would be more likely to generate useful end products for the mining industry.

Expanded Human Resources

Prior to 1999, the USBM and NIOSH hearing loss research program employed just 3-5 researchers. In most years, this team worked within a group that primarily addressed dust control and respiratory hazards. After 1999, hearing loss research was elevated to a full branch level (the second level of organization in the NIOSH structure) and began growing though a plan of internal transfers and recruitment. The Hearing Loss Prevention Branch now maintains a staff of 16-24 (with fluctuations due to temporary student personnel and project cycles). Reflecting the emphasis on noise controls, the branch consists of researchers primarily from various engineering disciplines, but also employs audiologists, behavioral scientists, and staff with other health-related credentials, along with several technicians.

Expanded Physical Resources

To deliver research outcomes with greater efficiency and productivity, NIOSH needed to expand and improve their laboratories and instrumentation. The existing reverberation laboratory received a full structural overhaul and upgraded instrumentation (Peterson and Bartholomae 2003). The 1300 cubic meter chamber, now known as the Acoustic Test Chamber (ATC), has been accredited by the National Institute of Standards and Technology's National Voluntary Laboratory Accreditation Program (NVLAP) for precision-grade sound power measurements according to ISO 3741. In 2005, to complement the capabilities of the reverberant ATC, NIOSH constructed a new 1200 cubic meter hemi-anechoic chamber (HAC) that can be used for noise source identification and other studies requiring an environment free of acoustic reflections (Figure 1).

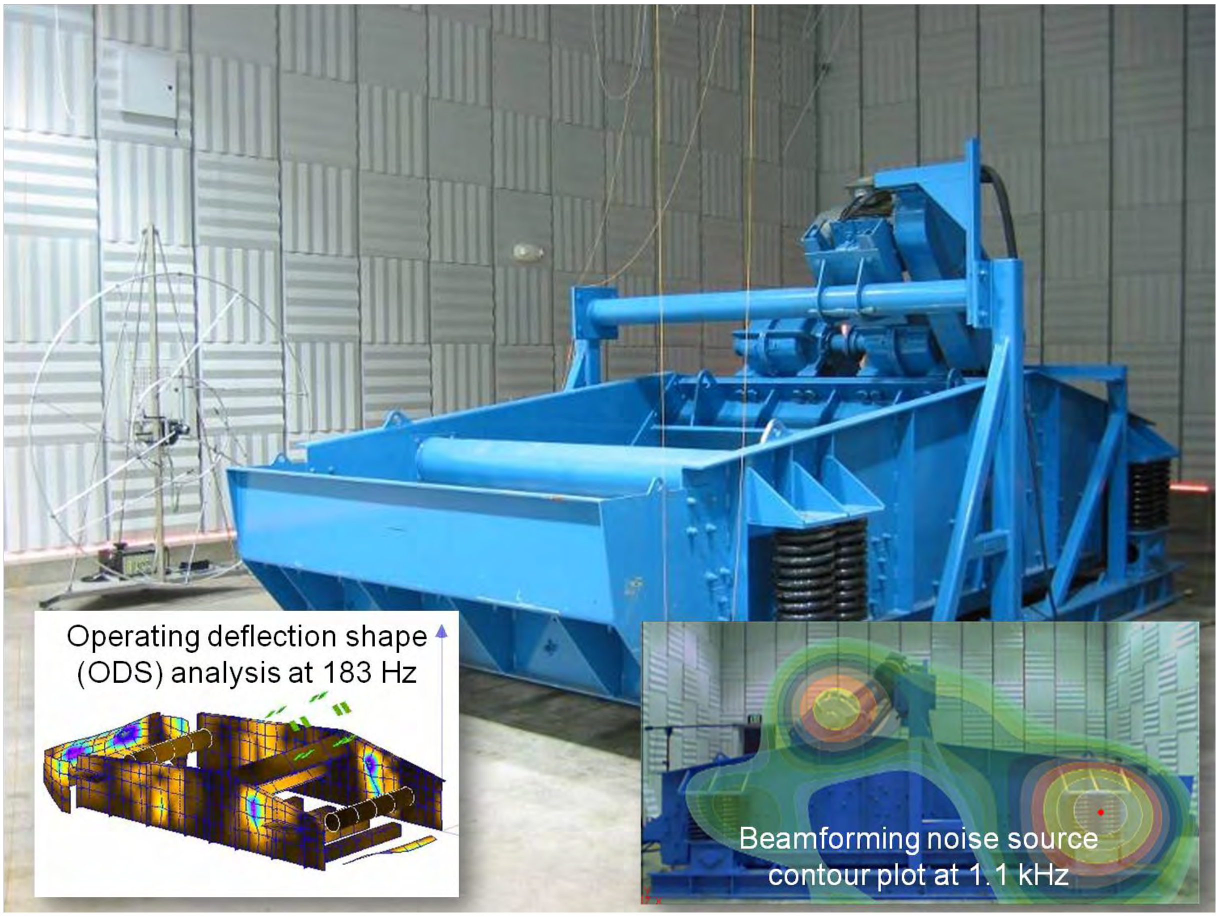

Figure 1. Vibrating screen assembly inside the NIOSH hemi-anechoic chamber next to microphone phased array used for noise source identification via the beamforming technique. Insets show results of operating deflection shape analysis and beamforming analysis.

For hearing protection and audibility studies, the research program constructed an Auditory Research Laboratory (ARL) in 1999. This laboratory consists of two test chambers, one that has reverberant surfaces for diffuse sound testing and another with sound-absorbing surfaces for conducting hearing tests and assessing directional audibility. The ARL has received NVLAP accreditation for testing the attenuation of hearing protectors. The program also acquired and equipped a mobile laboratory, the Hearing Loss Prevention Unit, which is a 32-foot trailer containing a 4-person sound-insulated booth that can be used for hearing tests and hearing protector evaluations. The trailer also has a space for training and worker counseling.

Expanded Strategic Plan

Recognizing that a more comprehensive program would be needed to make hearing loss solutions available to miners and the mining industry, the NIOSH mining hearing loss program developed a strategic plan in 2004 that consisted of four major components:

1. Develop and maintain a noise source/mine worker exposure database for prioritizing noise control technologies
2. Develop engineering noise control technologies applicable to surface and underground mining equipment
3. Empower workers to acquire and pursue more effective hearing conservation actions
4. Improve the reliability of communication in noisy workplaces

The plan continued to emphasize the primacy of engineering controls (component 2) while augmenting it with data for identifying research needs (component 1) and providing tools to workers so they could more readily adopt solutions to reduce their exposure (component 3). The communications aspect (component 4) was included to address audibility issues that might involve hearing protector design and use.

The components of the strategic plan have undergone periodic review and revision, and a revised set of goals are under development for a new strategic plan for all of NIOSH's mining research programs. The revised goals will continue to emphasize engineering solutions enhanced by effectiveness evaluations and improved transfer of technologies to the workplace.

NOISE CONTROL DEVELOPMENT AND DISSEMINATION PROCESS

NIOSH develops noise controls through a process designed to yield effective and practical solutions. To date, 14 different noise controls have been successfully developed through the process. Typically, the process involves the following steps:

1. Use risk data and stakeholder input to identify candidate machines or technologies for control development
2. Perform field measurements and task observations to identify which tasks and operator locations are associated with the most noise exposure
3. Perform noise source identification to determine which machine components are generating the most noise
4. Develop noise control solutions based on noise control engineering principles
5. Validate whether the designs attain the expected noise reduction through computer modeling and laboratory testing
6. Field test the control in a working mine to assess exposure reduction, practicality, and durability
7. Promote adoption of the control

The first two machines that were addressed through this process are the continuous mining machine (CMM) and the roof bolting machine (RBM). These machines were selected based on MSHA exposure data which shows they are the two underground coal mining machines associated with the largest percentages of noise overexposures.

CMM controls

In NIOSH field observations of continuous mining machine operators, 86% were exposed to noise exceeding the MSHA PEL (Bauer, Babich, and Vipperman 2006). Noise source identification in the NIOSH laboratories identified the conveying system as the dominant noise source (Kovalchik, Johnson, Burdisso, Duda, and Durr, 2002). One of the noise controls developed for the conveying system was the coated flight bar (Figure 2). Several engineering revisions of this control were developed and tested in the NIOSH laboratories and then field tested in a working coal mine (Smith, Spencer, Alcorn, and Kovalchik 2006). The coated flight bar alone reduces operator exposures by 7 dB

(Smith 2008). Additional reductions based on NIOSH designs and engineering include a dual-sprocket chain, a noise-controlled scrubber fan, vibration-isolated tail roller, and an isolated take-up system.

Figure 2. NIOSH-developed coated flight bars on a continuous mining machine conveying system.

RBM controls

A similar process was followed for the roof bolting machine. NIOSH researchers conducted field observations to assess overall exposure of roof bolter operators and found that 81 percent had exposures exceeding the MSHA PEL (Bauer, et al. 2006). The bolting task associated with the most exposures was drilling prior to inserting the bolt. The noise control team then performed noise source identification in the PRL Hemi-anechoic Chamber that showed that the drill/roof and drill/chuck interfaces were responsible for most of the radiated noise (Yantek, Peterson, and Smith, 2007). They then developed and field tested a suite of controls that includes a collapsible drill steel enclosure (Peterson 2008) (Figure 3), and isolators for the drill bit and chuck (Kovalchik, Smith, Matetic, and Peterson 2009).

Figure 3. NIOSH-developed collapsible drill steel enclosure to control noise on roof bolting machines.

Behavioral Interventions
The NIOSH mining hearing loss research program has also addressed the human side of prevention with a series of behavioral and training interventions. A hearing loss simulator was developed as a way to demonstrate the impact of noise exposure on hearing (Randolph, Reinke, and Unger 2008). The simulator can be used to show that the use of an effective noise control over time can preserve a significant amount of hearing. Although hearing protectors are the last item on the hierarchy of controls, they are still widely needed where feasible and effective noise controls do not yet exist. The NIOSH research program developed a QuickFit device (Figure 4) to help hearing protector users perform a rapid check of earplug attenuation (Randolph 2008).

Figure 4. Testing earplug fit with the NIOSH QuickFit device.

Future Directions

Additional noise control efforts on vibrating screens used in coal preparation plans are reaching completion following the same process as the work on the CMM and RBM (Yantek, Jurovcik, and Bauer 2006). The research team is now wrapping up work on the underground coal sector with a new project on longwall mining machines. Another new project will start the process of addressing other mining sectors by developing noise controls for load-haul-dump machines and haul trucks used in underground metal mines. A third new project will evaluate the research program's success at reaching its noise reduction and hearing loss prevention goals, and will develop technology transfer approaches to make noise control advances accessible to every mine where they can be used.

SUMMARY AND CONCLUSIONS

Hazardous noise and hearing loss are long-standing problems in the mining industry that can most effectively be solved through solutions that reduce noise at the source. The U.S. Bureau of Mines and NIOSH research programs have consistently addressed noise sources through an emphasis on engineering controls. This emphasis was augmented after 1999 by an expanded research program that added field evaluations to prove the effectiveness of controls and a behavioral component to motivate more widespread adoption. To date, the NIOSH program has produced 14 effective mining noise control technologies and several behavioral, training, and management tools. Future developments will expand the program's impact by extending noise control development beyond underground coal to every other mining sector.

REFERENCES

Aljoe, W.W. 1985. *The Bureau of Mines Noise-Control Research Program—A 10 Year Review*, IC 9004 US Bureau of Mines.

Bartholomae, R.C., and Parker R.P. 1983. *Mining Machinery Noise Control Guidelines*.Report No. I 28.16/2:M66/8. Pittsburgh, PA: Bureau of Mines, United States Department of the Interior.

Bauer, E.R., Babich, D.R., and Vipperman, J.S. 2006. *Equipment Noise and Worker Exposure in the Coal Mining Industry.* Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2007-105, IC 9492.

Franks, J.R. 1996. Analysis of audiograms for a large cohort of noise-exposed miners. Cincinnati, OH, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Biomedical and Behavioral Science. Unpublished.

Franks, J.R. 1997. Prevalence of hearing loss for noise-exposed metal/nonmetal miners. Cincinnati, OH, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Biomedical and Behavioral Science. Unpublished.

Grayson, R.L. 1999. Effective prevention of hearing loss in miners. *Holmes Safety Association Bulletin*, January issue, pp. 3-5.

Kovalchik, P.G., Johnson, M., Burdisso, R., Duda, F., and Durr. M. 2002. Noise Control for Continuous Miners, Proceedings from the 10th International Meeting on Low Frequency Noise and Vibration and its Control, York, England.

Kovalchik, P.G., Smith, A.K., Matetic, R.J., and Peterson, J.S. 2009. Noise Controls for Roof Bolting Machines. *Min. Eng.* 61(1):74-78.

Kryter, K.D. 1994. *The Handbook of Hearing and the Effects of Noise.* San Diego, CA: Academic Press.
Lamonica, J. A., Mundell, R. L. and Muldoon T. L. 1971. *Noise in Underground Coal Mines.* BuMines RI 7550.

MSHA. 2008. *Technologically Achievable, Administratively Achievable, and Promising Noise Controls*, Department of Labor, Mine Safety and Health Administration, Program Information Bulletin P08-12 (30 CFR Part 62), http://www.msha.gov/ regs/complian/pib/2008/pib08-12.pdf.

NIOSH. 1976. *Survey of Hearing Loss in the Coal Mining Industry.* Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76–172.

NIOSH. 1996. *Preventing Occupational Hearing Loss—A Practical Guide*. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 96-110

NIOSH. 1998. *Criteria for a Recommended Standard: Occupational Noise Exposure. Revised Criteria.* Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-126.

Peterson, J.S. 2008, *Collapsible Drill Steel Enclosure for Reducing Roof Bolting Machine Drilling Noise.* U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH). Technology News 532.

Peterson, J.S., and Bartholomae,R.C. 2003. Design and instrumentation of a large reverberation chamber. NOISE-CON 2003. Ames, IA: Institute of Noise Control Engineering of the USA.

Randolph, R.F, Reinke, D.C., and Unger, R.L. 2008. *NIOSH Hearing Loss Simulator Instruction and Training Guide.* Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2008-119.

Randolph, R.F. 2008. *QuickFit Earplug Test Device.* Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2009-112. Technology News 534.

Smith, A.K. 2008. *Engineering Controls for Reducing Continuous Mining Machine Noise*. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH). Technology News 531.

Smith, A.K., Spencer, E.R., Alcorn L.A., and Kovalchik, P.G. 2006. Underground Evaluation of Coated Flight Bars for a Continuous Mining Machine. Inter-Noise 2006. The 35th International Congress and Exposition on Noise Control Engineering, 3-6 December 2006, Honolulu, Hawaii. West Lafayette, IN: International Institute of Noise Control Engineering.

Tak, S, Davis, R.D., and Calvert, G.M. 2009. Exposure to hazardous workplace noise and use of hearing protection devices among US workers—NHANES, 1999–2004. *American Journal of Industrial Medicine* 52:358–371.

Tak, S., and Calvert, G.M. 2008. Hearing difficulty attributable to employment by industry and occupation: An analysis of the National Health Interview Survey—United States, 1997 to 2003. *Journal of Occupational and Environmental Medicine* 50:46–56.

Yantek, D.S., Jurovcik, P., and Bauer, E.R. 2006. Noise and Vibration Reduction of a Vibrating Screen. *Trans. Soc. Min. Metal Explor.* 318:201-213.

Yantek, D.S., Peterson, J.S., and Smith. A.K. 2007. Application of a Microphone Phased Array to Identify Noise Sources on a Roof Bolting Machine. NOISE-CON 2007. Reno. NV: Institute of Noise Control Engineering of the USA