ASSESSMENT OF EQUIPMENT OPERATORS' NOISE EXPOSURE IN WESTERN UNDERGROUND GOLD AND SILVER MINES

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ABSTRACT

An assessment of U.S. western hard-rock miners' noise exposures was conducted as part of a multi-year National Institute for Occupational Safety and Health (NIOSH) survey of noise exposures in each sector of the mining industry. Noise from selected mining equipment and operator noise exposures were measured, analyzed, and tabulated for dissemination to the participating sites and are being used to direct NIOSH research and interventions to address the greatest noise hazards. Eighty-two noise dosimeter measurements were obtained, along with time-motion studies as the miners operated hard-rock mining machines. Ninety-six percent of the operators had daily noise doses that exceeded the Mine Safety and Health Administration's permissible exposure level. The average gold miner dosages while operating the following equipment were: haul trucks - 261%, load-haul-dumps (LHDs) - 235%, single boom drills - 221%, bolters - 214%, and dual boom drills - 163%. The worst exposure level was a silver miner with a daily dose of 873%. Time-motion data showed that this miner's exposure accumulated most rapidly while operating a jack-leg drill. These results will be used to help prioritize noise control development by NIOSH and other partners.

INTRODUCTION

Hearing loss and overexposure to noise continues to be a problem throughout the mining industry. Studies indicate that 70 to 90 percent of all miners have a noise-induced hearing loss (NIHL) severe enough to be classified as a hearing disability by the time they reach retirement age (1). To address this problem, as part of an ongoing strategic plan, the National Institute for Occupational Safety and Health (NIOSH) has been conducting a series of long-term noise surveillance and evaluation studies for the entire mining industry. Operator noise exposures were measured and tabulated for dissemination to the mine sites and analyzed to direct future noise control development.

This report contains the description of studies conducted at U.S. western hard-rock mines to determine the levels of miners' noise exposure. Eighty-two noise dosimeter measurements were obtained from hard-rock mining machine operators. Time-motion studies were performed as the operators used bolting machines, LHDs, haul trucks, and drills. Ninety-six percent of the operators had daily noise doses that exceeded the Mining Safety and Health Administration's permissible exposure level (PEL). The only participants with exposures below the PEL were two bolter operators and one dual boom drill operator.

APPROACH TO QUANTIFY NOISE EXPOSURE

To evaluate the operators' noise exposure, a sample population of each piece of equipment was monitored and the data analyzed using the following two research methods.

1. Noise dosimetry was used to measure the machine operators' total noise exposure during the course of their work day.
2. Time-motion studies were used to identify work tasks and/or machines causing the higher doses that are in need of engineering noise controls or administrative controls.

To complete these analyses, NIOSH researchers conducted noise surveys at eight underground metal mines located in the western U.S. to identify and quantify the noise exposure of hard-rock underground machine operators.

NOISE DOSIMETRY MEASUREMENTS

The operators' noise exposure was measured using a Quest Q-400[1] noise dosimeter. The dosimeter microphone was clipped to the midpoint of the operator's shoulder with the diaphragm pointing up and worn for a full shift. The Quest Q-400 (2) is a single-microphone, dual-channel device that allows for independent user-configurable dose evaluation settings on each of the two channels. The two channels, referred to as dosimeter 1 and dosimeter 2, collect sound level measurements simultaneously. Dosimeter 1 was set according to the MSHA PEL (3), and dosimeter 2 was set for wide-range data collection to measure and record all sound levels (Table 1). The MSHA PEL settings were used for consistency with the majority of noise dosimetry data reported for the U.S. mining industry. The wide-range data was collected for future analysis as part of a NIOSH equipment operators' noise exposure database.

Table 1. Dosimeter settings.

Dosimeter Number	Parameter	Settings	Designation
1	Weighting Threshold Level Exchange Rate Criterion Level Response Upper Limit	A 90 dB 5 dB 90 dB Slow 140 dB	MSHA Permissible Exposure Limit (PEL)
2	Weighting Threshold Level Exchange Rate Criterion Level Response Upper Limit	A 40 dB 3 dB 85 dB Slow 140 dB	Wide Range (L_{eq})

TIME-MOTION STUDY

To determine when and where the miners were receiving most of their noise dose, time-motion studies were performed. Researchers recorded equipment position (at the face, in the drift), status (running (low idle, high idle), drilling, loading, tramming (moving)), and the mining task duration. The internal clocks in the dosimeters and the clocks used by the time-motion study observers were time-synchronized so that exposures and observations could be directly associated in further analysis. The correlation of dosimeter and time-

[1]Reference to specific brand names does not imply endorsement by the National Institute for Occupational Safety and Health.

motion studies can be used to identify the machines, tasks, locations, and other factors that are most responsible for a worker's noise exposure. Once the factors are identified, appropriate risk reduction interventions can be selected and prioritized. The options include some combination of new or retrofit noise controls, improved maintenance of existing controls, adoption of administrative controls, and use of hearing protection devices - only after all feasible engineering and administrative controls have been implemented.

GOLD MINE FINDINGS

The results of the gold mine dosimetry data are shown in Tables 2 through 6. These tables show the average work shift and time-weighted average full shift noise dose and equivalent TWA_8 dB(A) - calculated to a standard 8-hour shift, for operators of selected machines at the mine sites. The TWA_8 dB(A) is used so that all work-shifts regardless of length can be easily compared. The standard deviation of the daily doses and the percentage of operators over the PEL are also shown in the tables. Figures 1 through 5 are cumulative dose vs. time plot examples of one corresponding operator's work shift, with some defined mining activities with selected dB(A) and dose levels. Note: the Y-axis scales vary between figures 1-5.

Twenty-one bolter operators were fitted with dosimeters and time-motion studied; the results are summarized in Table 2.

Table 2. Bolter operators' average work shift, TWA_8 dB(A), and daily dose, range of doses, standard deviation of doses, and percentage of overexposed operators.

Average Duration of Work (Hr:min)	Average TWA_8 dB(A)	Dose
11:23	95	Average: 214%
Range of Doses (N = 21)		26% - 551%
Standard Deviation (Dose)		130%
Overexposed Operators: 90%		

Figure 1 is a cumulative dose plot of a representative bolter operator dose for the observation shift and pinpoints some of the major dose contributors. The operator's daily dose for the observation shift was 289% or a TWA_8 of 98 dB(A). The operator attained the permissible exposure limit of 100% dose at approximately 1:30 PM (5.5 hours into his shift) and went on to almost triple his dose by the end of the shift. Time-motion studies show that the task with the highest noise exposure for the bolter operators was tramming, which contributed over 74% of the cumulated dose on average (4).

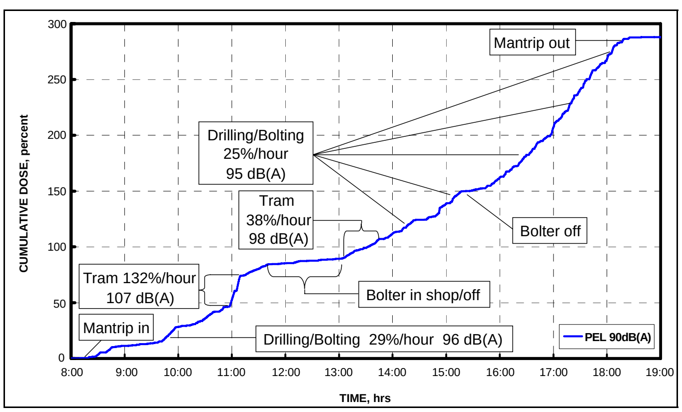

Figure 1. Cumulative dose plot of a bolter operator's work shift [08:10 to 18:20].

Seventeen haul truck operators were fitted with dosimeters and time-motion studied. The results are summarized in Table 3.

Figure 2 is a cumulative dose plot of a representative haul truck operator's dose for the observation shift and pinpoints some of the major dose contributors. The operator's dose for the observation shift was 455%, or a TWA_8 of 101 dB(A). The operator attained the permissible exposure limit of 100% dose at approximately 11:00 AM, less than 2 hours into his shift. Time-motion studies show that the task with the highest noise exposure for the haul truck operators was tramming while loaded, which contributed over 86% of the cumulated dose on average (4).

Table 3. Haul truck operators' average work shift, TWA_8 dB(A), and daily dose, range of doses, standard deviation of doses, and percentage of overexposed operators.

Average Duration of Work (Hr:min)	Average TWA_8 dB(A)	Dose
10:51	97	Average: 261%
Range of Doses (N = 17)		114% - 575%
Standard Deviation (Dose)		129%
Overexposed Operators: 100 %		

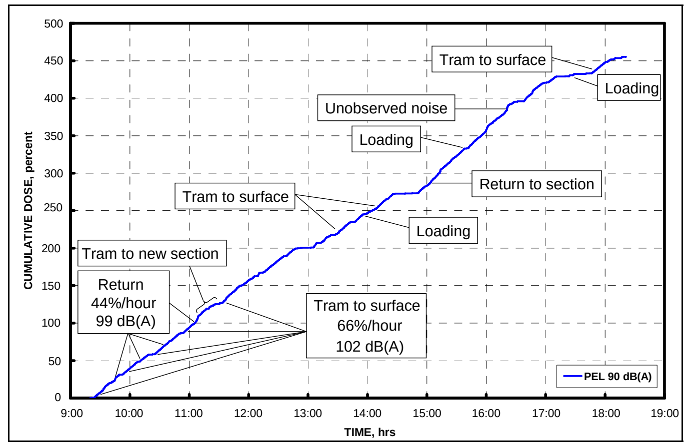

Figure 2. Cumulative dose plot of a haul truck operator's work shift [09:20 to 18:08].

Fourteen LHD operators were fitted with dosimeters and time-motion studied. The results are summarized in Table 4.

Table 4. LHD operators' average work shift, TWA_8 dB(A), and daily dose, range of doses, standard deviation of doses, and percentage of overexposed operators.

Average Duration of Work (Hr:min)	Average TWA_8 dB(A)	Dose
11:02	96	Average: 235%
Range of Doses (N = 14)		111% - 438%
Standard Deviation (Dose)		107%
Overexposed Operators: 100 %		

Figure 3 is a cumulative dose plot of a representative LHD operator's dose for the observation shift and pinpoints some of the major dose contributors. The operator's dose for the observation shift was 167% or a TWA_8 of 94 dB(A). The operator attained the permissible exposure limit of 100% dose at approximately 3:30 PM, about 6.5 hours into his shift. When the operator was able to turn the motor off between loading the haul trucks the cumulative dose was less than tramming or loading over the same time period. Time-motion studies show that the task with the highest noise exposure for the LHD operators was loading haul trucks, which contributed over 67% of the cumulated dose on average (4).

Nine single-boom drill operators were fitted with dosimeters and time-motion studied. The results are summarized in Table 5.

Figure 4 is a cumulative dose plot of a representative single-boom drill operator's dose for the observation shift and pinpoints some of the major dose contributors. The operator's dose for the observation shift was 162%, or a TWA_8 of 94 dB(A) in just over five hours of work. The operator attained the permissible exposure limit of 100% dose at approximately 2:00 PM, after about three hours and twenty-five minutes of work. Time-motion studies show that the task with the highest noise exposure was drilling with motor at high idle, which contributed over 58% of the cumulated dose on average (4).

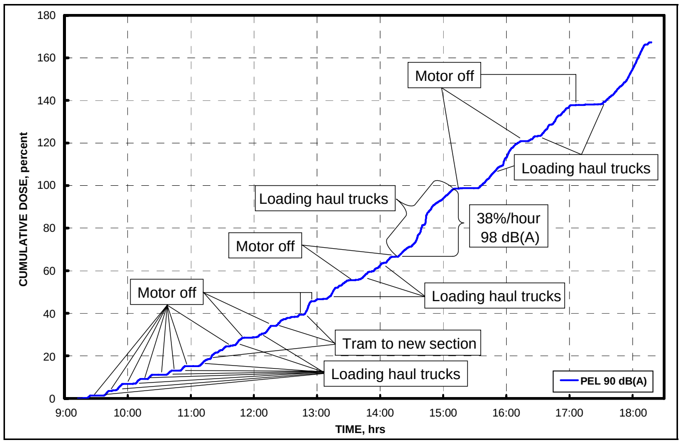

Figure 3. Cumulative dose plot of a LHD operator's work shift [09:10 to 18:18].

Table 5. Single-boom drill operators' average work shift, TWA_8 dB(A), and daily dose, range of doses, standard deviation of doses, and percentage of overexposed operators.

Average Duration of Work (Hr:min)	Average TWA_8 dB(A)	Dose
12:23	96	Average: 221%
Range of Doses (N = 9)		100% - 467%
Standard Deviation (Dose)		120%
Overexposed Operators: 100 %		

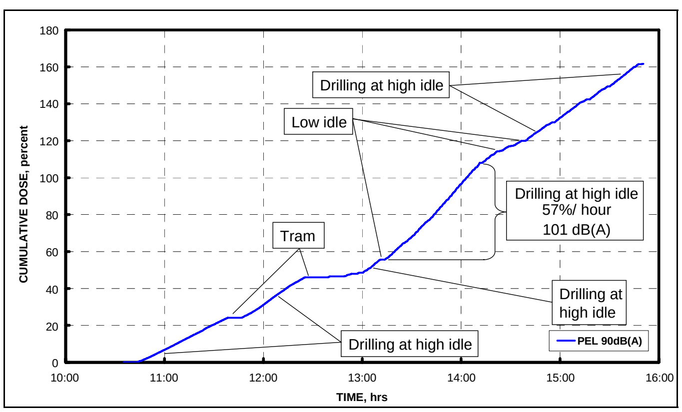

Figure 4. Cumulative dose plot of a single-boom drill operator's work shift [10:35 to 15:48].

Seven dual-boom drill operators were fitted with dosimeters and time-motion studied. The results are summarized in Table 6.

Table 6. Dual-boom drill average operators' average work shift, TWA_8 dB, daily dose, range of doses, standard deviation of doses, and percentage of overexposed operators.

Average Duration of Work (Hr:min)	Average TWA_8 dB(A)	Dose
10:23	93	Average: 165%
Range of Doses (N = 7)		67% - 402%
Standard Deviation (Dose)		111%
Overexposed Operators: 86%		

Figure 5 is a cumulative dose plot of a representative dual-boom drill operator's dose for the observation shift and pinpoints some of the major dose contributors. The operator's dose for the observation shift was 167%, or a TWA_8 of 94 dB(A). The operator attained the permissible exposure limit of 100% dose at approximately 2:30 PM. Time-motion studies show that the task with the highest noise exposure was drilling with motor at high idle, which contributed over 89% of the cumulated dose on average (4).

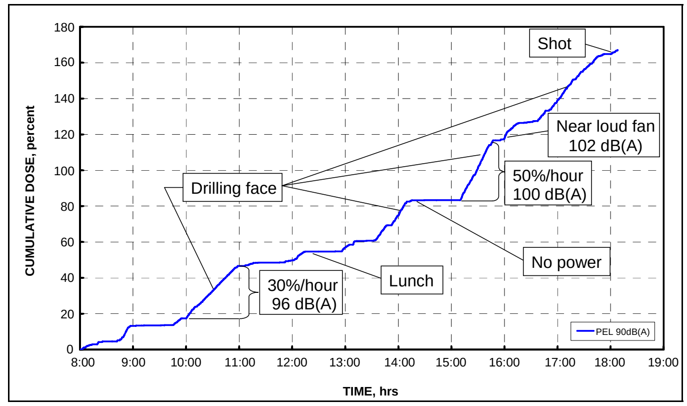

Figure 5. Cumulative dose plot of a dual-boom drill operator's work shift [8:00 to 18:10].

Results of the gold mine studies showed that all but three of the sixty-eight operators' daily dose exceeded the MSHA's PEL. The averaged daily noise dosages were as follows: 1) 261% for haul truck operators, 2) 235% for LHD operators, 3) 221% for single-boom drill operators, 4) 214% for bolter operators and 5) 163% for dual-boom drill operators.

Some of the high PELs are attributable to the studied workers having work shifts longer than eight hours. For example, a worker exposed to a constant 95 dB(A) during the shift will have a PEL of 200% (TWA_8 of 95 dB(A)) at eight hours and then a PEL of 250% (TWA_8 of 97 dB(A)) at ten hours. The high standard deviation for the operator's dose for a specific machine type can also be attributed to normal variations in the work process, including the following:

- monitoring of different operators.
- operators' degree of expertise.
- condition of the mine's terrain (angled drift, heaved floor, or debris on the floor).
- presence of or the proximity of noisy equipment.
- quantity of work done.
- turning off equipment vs. idling equipment when not in use.
- exceeding vs. following the manufacturer-recommended drilling parameters for thrust, torque, and rotational speed.

SILVER MINE FINDINGS

The workers selected for dose monitoring at the silver mine included miners, nippers, truck drivers, and service mechanics. The noise dosimeters were worn for full (10-hr) shifts. Since only fourteen workers were studied at this silver mine and the number of workers in each job category was too small for computing reliable population statistics, the TWA_8 dB(A) and daily dose for each individual are shown in one table. Table 7 summarizes the results of the dosimeter measurements. These doses indicate that only one nipper (miner helper) and both service mechanics were below the citable MSHA dose of 132% (2 dB above the PEL's TWA_8 of 90 dB(A)). The remaining workers experienced doses significantly higher than the PEL (5). Figures 6 through 9 are cumulative dose vs. time plot examples of one corresponding operator's work shift, with some defined mining activities with selected dB(A) and dose levels. Note: the Y-axis scales vary between Figures 6-9.

Table 7. Silver mine workers' TWA_8 dB(A) and daily dose.

Occupation	TWA_8 dB(A)	Dose
Miner	106	873%
Miner	105	829%
Miner	104	687%
Miner	102	552%
Miner	96	239%
Miner	96	218%
Nipper (helper)	101	431%
Nipper (helper)	93	154%
Nipper (helper)	91	115%
Truck Driver	101	437%
Truck Driver	100	428%
Truck Driver	100	409%
Service Mechanic	91	117%
Service Mechanic	91	112%

MINERS

A total of six miners wore a dosimeter for a full shift. One of the miners working in a ramp in one of the mine's stopes was time-motion studied for a full shift. This was done to correlate dose with activities, tasks, locations, and equipment. This miner was responsible for all aspects of stope/ramp development including: 1) operating a jackleg drill to drill bolt holes and to install rock bolts, 2) drilling the blast holes in the face with a dual-boom drill (jumbo), and 3) mucking the face with a loader. The miner also spent considerable time moving equipment and supplies around the face area. During the observation shift, the miner used the jackleg drill to support the rib and roof with chain link fencing, operated the dual-boom drill, and loaded explosives in the blast holes in preparation for shooting the face. The miner only operated the loader to move supplies and assist in installing the chain link fencing to support the roof and ribs.

Figure 6 is a cumulative dose plot of the miner's dose for the observation shift and pinpoints some of the major dose contributors. The total dose for the observation shift was 829%, or a TWA_8 of 105 dB(A). The miner attained 100% dose approximately two hours after the start of the shift and 132% (MSHA citable dose) approximately fifteen minutes later. The major contributor to the total dose was operation of the jackleg drill to drill bolt holes and the installation of rock bolts to hold the chain link fencing for rib and roof control.

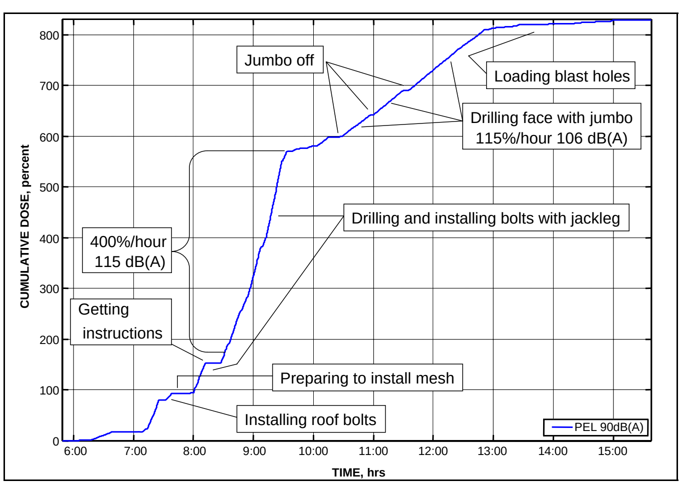

Figure 6. Cumulative dose plot of a silver miner's work shift [5:45 to 15:45].

NIPPER

Three nippers or miner helpers were monitored, with one being time-motion studied for approximately half a shift. The nipper's main tasks are to assist the miners. This includes operation of all stope equipment, especially the loader and supply tractor. During the observation period the nipper was building a muck wall in one mine stope. The nipper accomplished this task by moving muck from the muck bay near a ramp in another location and hauling it down into the stope with a 2-yd loader. As illustrated in Figure 7, the nipper received approximately 95% of the total dose during the 140 minutes of loader operation.

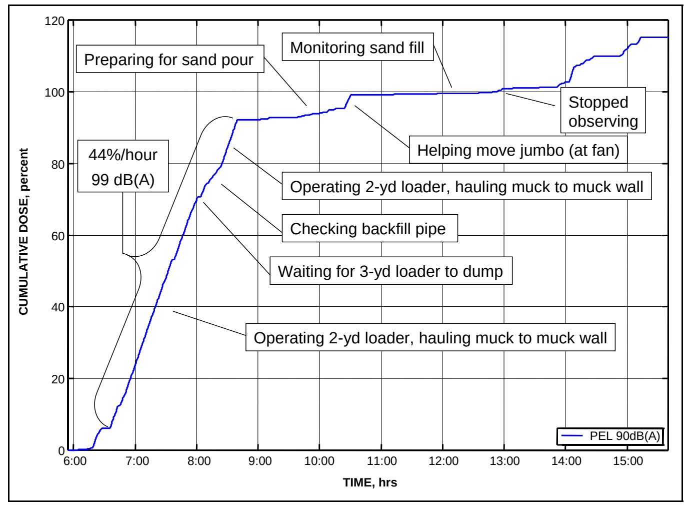

Figure 7. Cumulative dose plot of a nipper's work shift [5:55 to 15:55].

SERVICE MECHANIC

The service mechanic was monitored for just two shifts, but was observed for most of one of the shifts. The work tasks included driving the service car to each of the stopes and servicing (greasing and adding diesel fuel and hydraulic oil) the dual-boom drills (jumbos) and loaders. The time spent servicing each piece of equipment varied, and during the observation shift ranged from a low of six minutes to a high of eighteen minutes. The average service time was approximately twelve minutes which in many cases occurred in the vicinity of an overhead auxiliary fan. Figure 8 is the cumulative dose plot for the service mechanic's dose during the shift he was observed. The daily dose of 117% and a TWA_8 of 91 dB(A) were below the citable MSHA dose, but still above the PEL. The major contributors of the total dose as indicated on Figure 7 were the noise generated by the service tractor while tramming from one stope to another and servicing equipment near the auxiliary fans.

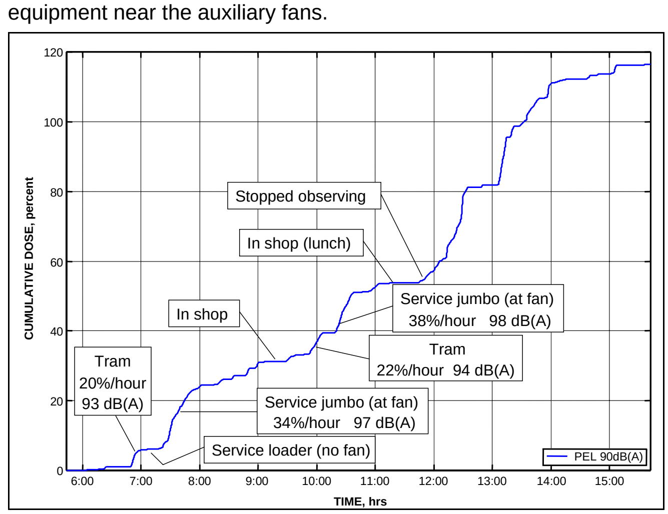

Figure 8. Cumulative dose plot of a service mechanic's work shift [5:45 to 15:45].

TRUCK DRIVERS

The truck drivers operated single-seat, open-cab muck trucks running from the muck piles to the grizzly and could not be safely time-motion studied by the researchers. However, the daily doses were highly consistent among the three, ranging from 409 to 437 percent, and a TWA_8 range of 100 to 101 dB(A) was measured for all three drivers. This high degree of consistency and the repetitive, continuous nature of the task support a conclusion that the noise was primarily from operating the truck. From the gold mine time-motion studies, the highest noise exposure rates occurred while performing the task of "tramming while loaded", which contributed over 86% of the cumulated dose on average (4). Figure 9 is the cumulative dose plot for a haul truck operator's work shift in a silver mine The operator attained the permissible exposure limit of 100% dose at approximately 8:20 AM, less than three hours into the work shift. The daily dose for this operator was 409% and a TWA_8 of 100 dB(A).

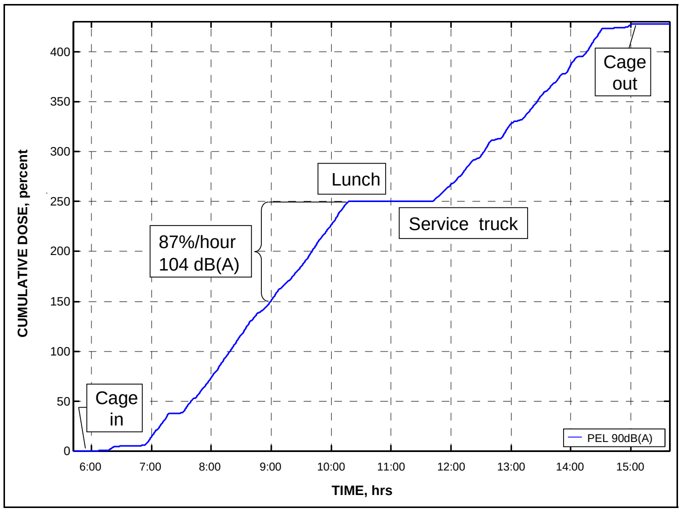

Figure 9. Cumulative dose plot of a haul truck operator's work shift [5:45 to 15:45].

SUMMARY AND DISCUSSION

This study found high levels of hazardous noise exposure to be common at the sampled U.S. western hard-rock mines, where noise generated by some of the larger hard-rock mining equipment was measured to be in excess of 113 dB(A). While the data can be used as a comparative reference, each operation is encouraged to perform a site-specific noise survey to determine its workers' noise exposure as a basis for a local hearing loss prevention program. If an individual daily noise dose is unusually high, that operator or job position should be observed to identify the causes and select appropriate exposure reduction interventions.

To address the hazardous noise exposures, appropriate interventions should be matched to the noise sources and tasks. While some pieces of equipment can be retrofitted with noise controls, other methods such as administrative noise controls and hazard awareness training can be used to reduce the miners' exposure to noise. One example from the current study illustrates this point: While a service mechanic was observed repairing equipment next to a loud auxiliary fan, he rapidly accumulated an elevated noise dose (shown by a steep slope in the plot in Figure 8). However, when he moved away from the fan to service equipment in another location, his exposure dropped considerably, shown by a relatively flat segment on the cumulative dose line. For situations like this, miners should be made aware that noise exposure is cumulative throughout the day, and making an effort to move equipment to a quieter working area will reduce the potential for NIHL.

Additional guidance on technologically and administratively achievable engineering and administrative noise controls is available from MSHA's Program Information Bulletin P08-12 (PIB) (6). This PIB presents technologically or administratively achievable controls that individually or in combination have been shown to achieve at least a 3 dB(A) reduction in a miner's noise exposure. Some of the engineering noise controls MSHA considers to be technologically achievable in reducing the noise exposure of miners operating mobile equipment include the following:

- Acoustically treated environmental cabs.
- Barriers, such as windshields and partial acoustic panels.
- Exhaust mufflers.
- Redirection of the exhaust away from the operator.

The PIB considers the following to be applicable examples of administrative controls:

- Sharing of work tasks and/or rotation of miners from noisy activities to quieter ones.
- Limited duration of work shifts.
- Providing quiet areas while taking breaks.
- Eliminating tasks that are unnecessarily noisy.
- Restricted or limited miner access to high noise areas.
- Following of manufacturer-recommended drilling parameters for thrust, torque, and rotational speed.

Hearing loss and overexposure to noise continues to be a problem throughout the mining industry. This study shows some of the work tasks and machinery that cause overexposure to hard-rock miners. Using information about exposures and with a variety of suitable noise controls to choose from, it becomes much more feasible to reduce noise exposure and the risk of NIHL.

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