Survey of noise in coal preparation plants

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In response to the continuing problem of noise induced hearing loss (NIHL) among mine workers, the National Institute for Occupational Safety and Health (NIOSH) has conducted numerous noise surveys in coal preparation plants. The research, consisting of worker dose monitoring, task observations, and equipment noise profiling, was completed in eight separate preparation plants. Worker dose monitoring was conducted for three shifts in most cases. Workers experiencing higher than allowable doses were task-observed for one full shift to correlate dose to noise source(s). Finally, noise levels on all floors, and in lunch rooms and control rooms, were characterized. Results indicate that only workers who routinely spend a significant portion of their shift in the plants (away from the control rooms) are susceptible to overexposure from noise. Certain pieces of equipment (screens, centrifuges, sieve bends) are the loudest primary noise sources responsible for the worker noise exposures.

I. INTRODUCTION

Prolonged exposure to noise over a period of several years can cause noise induced hearing loss (NIHL). While NIHL is the most common occupational disease in the United States today, with 30 million workers exposed to excessive noise levels,[1] the problem is particularly severe in all areas of mining (surface, processing plants, and underground). An early NIOSH analysis of NIHL in miners revealed an alarming prevalence of severe hearing loss.[2] For example, by age 60, over 70% of miners had a hearing loss of more than 25 dB, and about 25% had a hearing loss of more than 40 dB. A more recent, 1996 analysis of NIHL in miners, also performed by NIOSH, showed an apparent worsening of NIHL.[3] This recent analysis of a private company's 20 022 audiograms indicated that the number of miners with hearing impairment increased exponentially with age until age 50, at which time 90% of the miners had a hearing impairment.[3] In addition to government researchers, academics have reported that the "…policies and practices for preventing occupational hearing loss among miners are inadequate …".[4]

The Federal Coal Mine Safety and Health 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.[5] Data from more than 60 000 full shift Mine Safety and Health Administration (MSHA) noise surveys show that the noise exposure of selected mining occupations has decreased since the 1970s, although the percentage of miners considered overexposed under current MSHA noise regulations remains high.[6] MSHA found that the percentage of coal miners with noise exposures exceeding federal regulations, and unadjusted for the wearing of hearing protection, was 26.5% and 21.6% for surface and underground mining, respectively.

Despite the extensive work that ensued in the 1970s and 1980s, NIHL is still a pervasive problem, as outlined in Ref. 7. MSHA has published new Noise Health Standards for Mining.[8] One of the changes is the adoption of a provision similar to OSHA's Hearing Conservation Amendment. MSHA concluded in a survey that if an OSHA-like hearing conservation program were adopted, hypothetically, 78% of the coal miners surveyed would be required to be in a hearing conservation program.[9] Other requirements of the new regulations are a Permissible Exposure Level (PEL) of 90 dBA $L_{TWA(8)}$, no credit for the use of personal hearing protection, and the primacy of engineering and administrative controls for noise exposure reduction.

Improvements in both mining and noise monitoring equipment necessitate that new data be taken in order to base noise control decision making. In many cases, the existing data are specific to machine type and were obtained for characterizing noise source sound power rather than exposure assessment. There is also a great range in noise levels for a given occupation. For example, noise levels for continuous mining machine operators have a modal value of 90 dBA and a range that varies from 80 to 105 dBA.[10] Yet, at present, there is insufficient information to explain this variation in exposure for this and other mining occupations. Specifically, noise level data are needed that provide a time exposure history for workers in addition to information on noise sources. Such information will provide the basis for targeting and selecting engineering controls, in combination with administrative controls and personal protection equipment, to reduce noise exposures among the mining workforce.

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This study presents a survey and assessment of noise exposures in eight coal preparation plants from five states. Results concentrate on the sources of noise exposure, both in terms of occupations and plant location. Generalizations about the extent of the noise problem in preparation plants as well as the noise generating potential of the cleaning equipment are drawn.

II. SURVEY METHODS

A four-phase approach was taken to analyze noise in coal preparation plants, which included worker dose monitoring, task observations, equipment noise profiling, and reverberation time measurements. Each task is described in greater detail in the following sections, along with information on plant selection.

A. Plant selection

The number of coal preparation plants in the U.S. totaled 212 for the last census in 2000.[11] The average plant capacity is 1000 tons per hour (TPH), with 57 plants exceeding 1000 TPH, and 10 exceeding 2000 TPH. A sample of eight preparation plants with capacities between 300–2000 TPH was chosen for this study. The plants were located across the states of Pennsylvania, Kentucky, Virginia, Illinois, and West Virginia. They are owned by five different major coal companies that are members of the Noise Partnership, a consortium that was formed to reduce NIHL in the mining industry. The partnership includes members from government (NIOSH), regulation (MSHA), industry [Bituminous Coal Operators Association (BCOA)], labor [United Mine Workers of America (UMWA)], and professional associations. Participation in the surveys was voluntary for the plants, but 100% of the plants contacted participated.

B. Equipment and process

Nearly all coal preparation plants employ the same basic coal cleaning processes of crushing, screening, separation, flotation, and dewatering (drying). In general, the raw feed enters the plant on one of the upper floors, and flows downward by gravity through the cleaning process. Eventually, the clean coal and waste are deposited on separate belts on one of the lower floors for removal to the clean coal storage area and refuse area, respectively. Finally, the bottom floor usually contains the sumps and pumps used to recycle water and separation media back to the appropriate equipment on the upper floors. Specific equipment found in most of the plants included sieve bends, magnetic separators, froth flotation cells, banana screens, drain and rinse screens, deslime screens, heavy media cyclones, coal spirals, centrifuges, clean coal and refuse conveyors, crushers, heavy media vessels, vacuum filters, and pumps. In addition, since compressed air is used in the cleaning process, the plants have compressor rooms.

C. Dosimetry

Quest model Q-400 dosimeters were mounted on workers just prior to the start of the shift. Microphones were installed at mid-shoulder as recommended by MSHA,[12] and contained a wind screen. The Q-400 is a type II instrument and has two independent dosimeters that were programmed to log A-weighted $L_{AV}, L_{\mathrm{MAX}}, L_{\mathrm{MIN}}$, and L_{PK} (Ref. 13) at 10-s intervals. One dosimeter was set to record the MSHA permissible exposure limit (PEL) and the other measured the 8-h, A-weighted, equivalent sound level, L_{Aeq8}, which could be used for subsequent analyses. $L_{TWA(8)}$ represents the A-weighted constant sound level that over 8 h would result in the recorded shift dose.[13] The MSHA PEL uses a 5 dB exchange rate (ER), a 90 dBA criterion level (L_C), a 90 dBA threshold (L_{TH}) level, and an 8 h criterion time, T_C. Thus, a full day's exposure (100% dose) would occur if a worker is exposed to a steady noise at the 90 dBA criterion level for 8 h. Mean shift time, $\bar{T}$, and dose, $\bar{D}$, were computed for the measured data. The mean $L_{TWA(8)}$ was computed from the average dose as

$$\overline{L_{TWA(8)}} = L_C + Q \log\left(\frac{\bar{D}}{100}\right), \tag{1}$$

where $L_C = 90$ dBA is the criterion level, $Q = \log(ER)/\log(2)$ or 16.61 for the 5 dB ER. Since shift times varied from plant to plant, the average L_{AV} was also computed as

$$\overline{L_{AV}} = L_C + Q \log\left(\frac{8\bar{D}}{100\bar{T}}\right). \tag{2}$$

The above means were used to compute following standard deviations: $S_{L_{TWA(8)}}, S_T$, and $S_{L_{AV}}$.

Asymmetric standard deviations for dose were computed from $\overline{L_{TWA(8)}}$ values as

$$S_D^{\pm} = \left(\frac{100\bar{T}}{T_C}\right) 10^{(\overline{L_{TWA(8)}} \pm S_{L_{TWA(8)}} - L_C)/Q}. \tag{3}$$

This unconventional practice prevented the dose dispersions from being negative, as would occur if computed in the usual way. The M samples of L_{AV} data were also postprocessed to produce cumulative dose plots for each shift as

$$D(k) = 100 \frac{T_S}{T_C} \sum_{i=1}^{k} 10^{(L_{AV}(i) - L_C)/Q}, \tag{4}$$

where $T_S = 10$ s is the sampling time, and i, k are discrete time indices.

D. Task observations

Detailed time-at-task observations were conducted for each job classification. Note that for most jobs, the worker is required to move throughout the plant performing various tasks. A crew of technicians and mining engineers monitored three shifts for each job classification. As the worker moved or changed activities, the shift time and activity were logged, along with any comments from the observer. The observation resolution can be as fine as 10 s, as with the dosimeter logging. These observations were later used to determine the noise exposures for certain activities as well as exposures within the plant.

E. Equipment noise profiling

Sound level measurements (L_{eq}) were made throughout the plant in order to determine the distributed noise levels. A measurement grid was established, with measurements occurring approximately every 1.5–6 m, depending upon the density of the noise sources within the floor. Two different instruments were used to measure data: Quest model 2900 (type II) sound level meters (SLM) and/or a Brüel and Kjær (B&K) 2260 investigator (type I). Measurements typically included *A*-weighted, *C*-weighted, and linear overall sound levels and linear 1/3-octave band levels, which were *A*-weighted in postprocessing. The instruments were mounted on a tripod, with the microphones 1.5 m from the floor (approximate ear height), angled at 70° from horizontal, and facing the noise source as per the manufacturer's recommendations. A slow response time with an averaging time of 30 s was also employed. The instruments were field-calibrated at the start and end of each shift and undergo annual NIST-traceable calibrations. Postprocessing included spatially interpolating linear sound pressures to create noise contour plots, and determining the average L_{eq} in the vicinity of specific types of equipment. Sound levels were taken from grid points nearest to the equipment, typically within a few meters. Average values were computed from linear L_{eq} quantities as was done in Eq. (2). Standard deviations are computed from the dBA levels.

F. Reverberation time measurements

Reverberation time measurements were conducted in two typical plants while they were shut down for extended maintenance. The measurements could be used to determine whether treating walls of the plant with absorptive materials could be expected to significantly reduce the noise levels in the plant. Tests were completely automated in accordance with the ISO-140 standard[14] by the BZ7404 building acoustics software package installed on the B&K 2260 Investigator. A B&K 2716 bridging amplifier drove the B&K 4296 omnidirectional sound source in order to generate high levels of pseudorandom noise at one location of the plant floor. At another floor location, the B&K 2260 Investigator measured the decay in all 1/3-octave bands after abruptly switching off the noise source. The instrument measures either T_{20} or T_{30} reverberation times (time for the noise to decay 20 or 30 dB, respectively, in each 1/3-octave band) and extrapolates to the more characteristic T_{60} reverberation time (time to decay by 60 dB). Three combinations of source/receiver locations were measured on each floor where either the source or the receiver was moved between measurements.[14] At each source/receiver location a total of 5 decay times were measured and averaged together by the instrument to find the average T_{60} time.

The Sabine formula[15] was used to compute the overall change in reverberation times when absorptive treatments covered varying percentages of the walls. These were converted to the Sabine absorption coefficient, α, by also taking into consideration the room volumes and surface areas. Next the room constants, both with (R_1) and without (R_0) acoustical treatments, were computed from the absorption coefficients. Assuming distances far from the source, the theoretical maximum reduction in sound pressure was computed as

$$\Delta L_P \approx -10 \log\left(\frac{R_1}{R_0}\right). \tag{5}$$

TABLE I. Characteristics of coal preparation plants surveyed.

Plant No.	State	Raw feed (TPH[a])	Reject (%)	No. of floors	Total floor area, (ft^2)
1	PA	1000	31	8	58 200
2	WV	2000	52	6	81 850
3	PA	2000	33	12	142 650
4	VA	1000	27	7	63 350
5	PA	1000	21	10	51 400
6	KY	300	38	5	15 505
7	KY	2000	51	5	75 084
8	IL	1500	38	5.5	31 582

[a]Tons per hour.

III. SURVEY RESULTS

A. Coal preparation plant characteristics

All the plants were of similar construction; steel I-beams covered by either single ply corrugated steel sheeting or two-ply sheeting with insulation in between the plies, and concrete or steel grating floors. Table I summarizes the specific characteristics of each plant, including raw feed capacity, reject (rock), number of floors, and total square footage. Reject is potentially important since rock is harder than coal and thus typically produces more noise.

B. Worker classifications

In general there are four specific job classifications. The first class of worker is the "control room operator," who is positioned in the enclosed control room and is surrounded by video monitors and alarms. Typically, this person remains in the control room the entire shift. A second classification is a "mechanic/electrician." This worker is responsible for equipment maintenance throughout the plant and surrounding facilities. His time in the plant varies depending on plant maintenance needs during a particular shift. The worker that typically spends the entire shift, except for lunch and breaks, in the plant is the "plant attendant." This worker's duties can be located throughout the entire plant or on specific floors. This person is generally responsible for checking equipment operation, making measurements of process variables, and cleaning. The fourth job class is the "utility worker" whose job is to help the plant attendants or mechanic/electricians. Effort was made to determine the total number of workers in each occupation class for the eight plants, and is presented in Table II. Note that the same workers may have been surveyed across different shifts. Also, if a sample was considered atypical (e.g., partial shift monitoring), it was not included in the analysis.

TABLE II. Plant jobs surveyed by plant.

Occupation	Number of employees (number surveyed)								
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8	Total
Control Rm. Oper.	3(0)	3(1)	4(1)	3(0)	4(1)	3(2)	3(1)	2(2)	25(8)
Elec./Mech.	6(0)	4(0)	17(3)	9(0)	21(0)	1(0)	3(0)	2(0)	63(3)
Utility Man	9(0)	3(0)	9(4)	9(0)	8(1)	0(0)	1(0)	2(3)	41(8)
Plant attendants	3(1)	9(3)	3(3)	3(2)	4(3)	3(2)	19(7)	2(4)	46(25)
Total Workers	21(1)	19(4)	33(11)	24(2)	37(5)	7(4)	26(8)	8(9)	175(44)

C. Worker noise exposure

Table III provides a statistical summary for three of the job categories, including the number of samples, N, mean dose, and asymmetric standard deviation of dose. The Mechanic/Electrician job class did not have enough samples ($N=3$) to be statistically relevant, and hence statistical data are not reported for this class.

D. Noise profiles

The noise was categorized as continuous with high overall levels generally experienced throughout the plant. Figure 1 presents a noise contour plot of the overall A-weighted L_{eq} measurements from a representative floor. Levels are consistently high and range from 95 to 100 dBA, as indicated by the scale to the right of the figure. Figure 2 is an example of a much larger floor, with varying-noise levels (87–104 dBA) and a specific area of higher noise caused by a group of clean-coal screen-bowl centrifuges. Each plant typically had one or two floors with more modest levels (90 dBA) of noise. A fairly typical 1/3-octave band spectrum of the noise in the vicinity (within 1–2 m) of a raw coal screen is shown in Fig. 3, where the linearly weighted data are represented by the black bars and the A-weighted data are represented in grey. Screens are found to have very relatively high sound levels.

Figure 4 provides information on the average equivalent sound levels recorded in the vicinity of various pieces of equipment surveyed in the plants. They are sorted from quietest to loudest. The equipment type and total number of unique locations within the eight plants where each type of equipment was found (N) are given in the x axis labels. Standard deviations are also included on the plot where appropriate.

E. Dose/source relationships

The logged L_{AV} values recorded by the dosimeter were converted to a cumulative dose plot using Eq. (4). The resulting plots were then annotated using the information ob-tained from the task observations. A representative cumulative dose plot for a utility man serving as a plant attendant is shown in Fig. 5 and a cumulative dose plot for a mechanic is provided in Fig. 6. No equivalent plot is given for the control room operator, since their exposures are generally small.

F. Reverberation time and noise control

The measured areas and volumes for the six measured floors are given in Table IV. Each floor varies in the number and type of equipment, as well as room surface area and overall volume. It is typical for floor plans to get smaller with respect to the building height. Also given in the last column of Table IV, is the range for the average absorption coefficient for each floor in the bandwidth of 250–4000 Hz. Figure 7 graphically depicts the T_{60} and absorption coefficient calculations across the 1/3 octave bands for one of the floors.

Sample calculations based on Eq. (5) were made to determine the potential effectiveness of adding absorptive materials to the walls of the six measured plant floors. The results were predicted from applying an EAR E-100SM aluminum-faced, urethane-foam, absorbing-material to various percentages (15%, 40%, and 60%) of floor surface areas. The absorption coefficients for the material are {0.81, 0.61, 0.73, 0.71, 0.69} in the {250, 500, 1000, 2000, 4000} Hz 1/1-octave bands, respectively. In many cases much of the ceiling and wall area was amenable to being covered with material, making the 60% area coverage practical. Predicted reductions range from 0.9 to 10.6 dB across the bands. The reductions were then arithmetically averaged across the 250–4000 Hz 1/1-octave bands and are presented in Fig. 8.

IV. DISCUSSION

Dose and noise survey data from the eight coal preparation plants suggest that overexposures to noise can easily occur, particularly in plant attendants. Plant attendants are found to experience significantly higher exposures than other job categories when examining the data given in Table III. The mean value nearly equals the citable range and one stan-

TABLE III. Data summary for job classes.

Job class	N	$\bar{D}(\%)$	$S_D^+(\%)$	$S_D^-(\%)$	$\bar{T}_i$ (h)	$\overline{L_{TWA(8)}}$ (dBA)	$\overline{L_{AV}}$ (dBA)
Plant attendant	22	129	165	101	8:49	91.1	92.0
Control room operator	7	25.4	60.6	17.9	10:23	80.1	78.2
Utility man	7	66.6	102	39.6	9:31	85.5	85.8

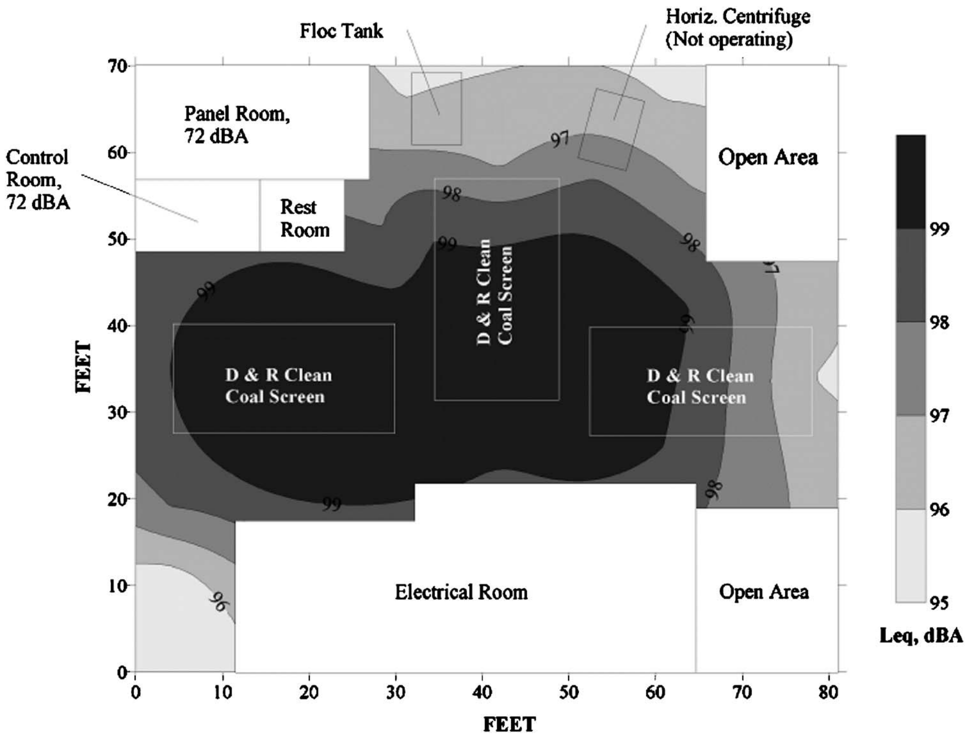

FIG. 1. Example of a high noise floor containing drain and rinse (D&R) screens (Plant 5).

dard deviation is more than double the citable dose. Citations are not issued until the dose exceeds 132%, allowing for the type II accuracy (2 dB) of most noise dosimeters. In contrast, it is found that the control rooms can be considered a “quiet area,” having only a 22.4% average dose with a positive standard deviation of 60.6% such that $(\bar{D}+S_D^+)<132\%$. The highest recorded dose for all eight control room operators is 99.6%, which also occurred for the longest shift of 12:26 (hours:minutes). In addition, this particular subject was atypical in that he had responsibilities that required him to periodically leave the control room and work in noisier environments. The doses for all utility men surveyed were all

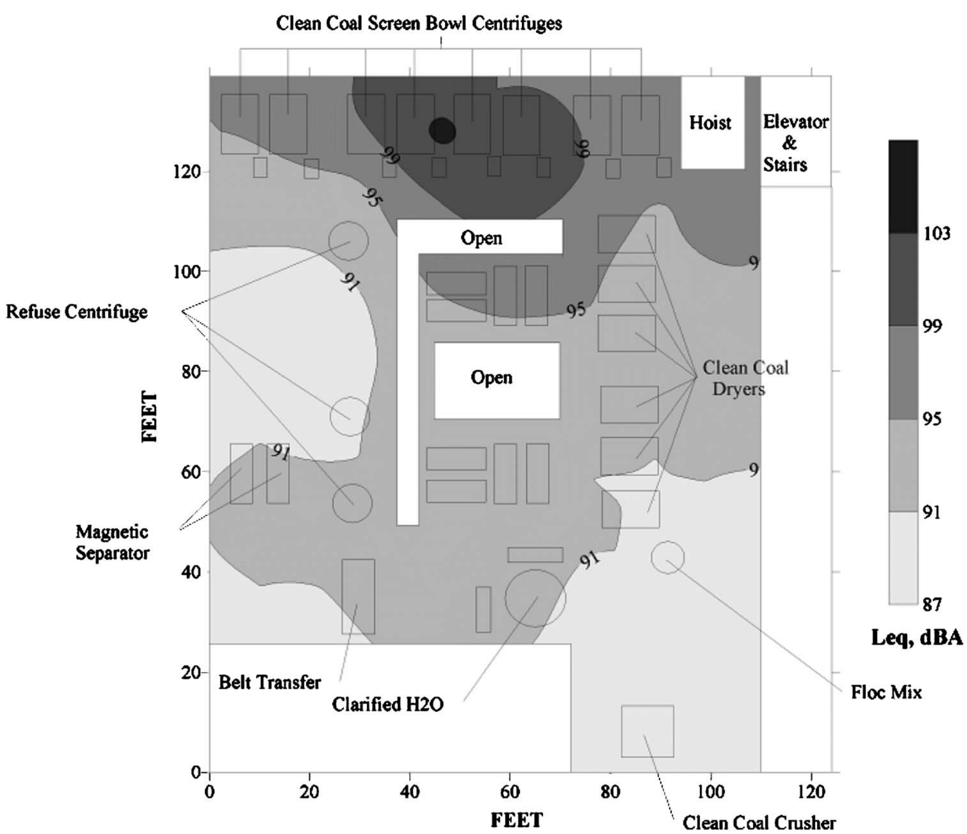

FIG. 2. Example of a varying noise floor.

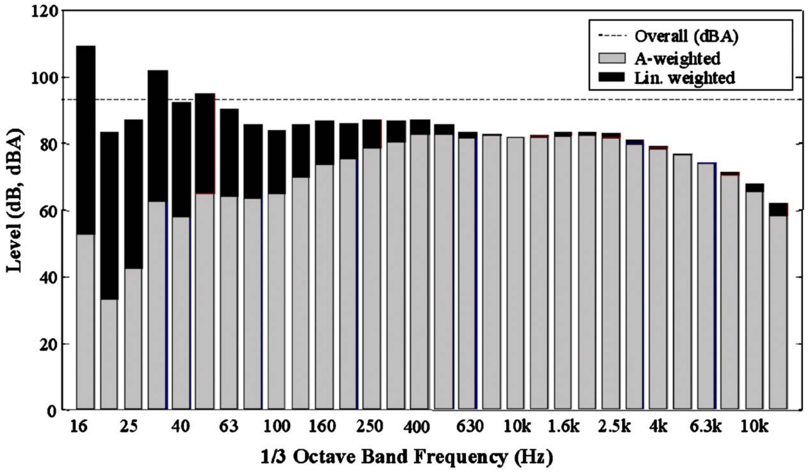

FIG. 3. Linear and A-weighted 1/3-octave bands measured near raw coal screens.

below 105% and averaged 63.5%. Doses within a single positive standard deviation are just below the 132% citable level.

Some of the variability in doses was a result of the varying shift durations. Some plants work a standard 8 h shift, while others work a 12 h shift. This fact was reflected in the relatively large standard deviations in shift durations for the control room operator (2:04), plant operator (1:59), and utility man (2:11). The three mechanics surveyed all worked 8 h shifts, producing a relatively low standard deviation of 0:09. The time-weighted averages given in Table III provide a normalized representation of the measured doses, since they were defined as the equivalent continuous 8 h exposure levels that would result in the recorded shift dose. A 100% dose is equivalent to $L_{TWA(8)}=L_C=90$ dBA. L_{AV} measurements are independent of measurement duration and may be compared across work shifts of different lengths. Note that $L_{AV}=L_{TWA(8)}$ for a 100% dose over an 8 h shift and $L_{AV}>L_{TWA(8)}$ for shifts under 8 h and vice versa.

The high variability in the noise dose data ($60.6\% \leqslant S_D^+ \leqslant 411\%$) for each job suggests that the practice of single-shift monitoring is not adequate for characterizing doses for coal preparation plant workers. The variance can be attributed to several factors including plant processes, shift time, plant location, equipment serviced, individual worker traits, production, age of the plant, and plant construction. Another important variable that must be taken into consideration was the quality of plant maintenance (e.g., effects of "squeaky belts"), which was found to vary considerably between plants. Equipment noise levels were found to be approximately 8 dBA higher in two such cases. With the exception of shift time, no attempt was made to quantify the effects of these variables.

The characterization of noise sources in the plants was a complicated task for several reasons. First, the large number of pieces of equipment and their close proximity to each other made separating specific noise sources difficult at times. Next, the openness of the building allowed noise to propagate between floors. Finally, the measured noise came from multiple air-borne and structure-borne paths. Air-borne noise was present as direct noise, generated by the equipment, the process, and motors, and as reflected noise from the reverberant field (building walls, floors, etc.). Structure-borne noise paths resulted from equipment vibration and transfer of that vibration to the buildings structural components, which in turn radiate into the surrounding area. Noise profiles consisting of area noise sampling on noise contour plots for all plant floors revealed areas of high and low noise levels and permitted identification of the equipment generally responsible for the noise. Although levels varied considerably throughout the plant, the patterns of noise in any one location were judged to be stable.

Figure 4 provides information about the range of sound levels within the working area surrounding a particular type

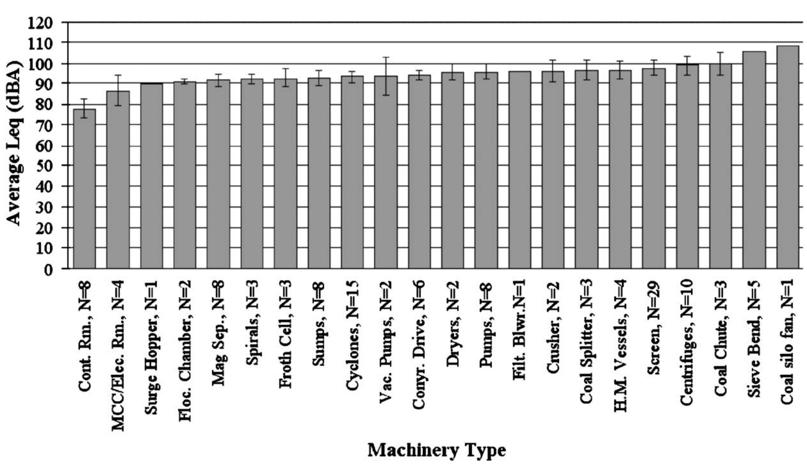

FIG. 4. Average overall equivalent sound levels in the vicinity of various types of mining equipment with 90 percentile confidence bounds shown.

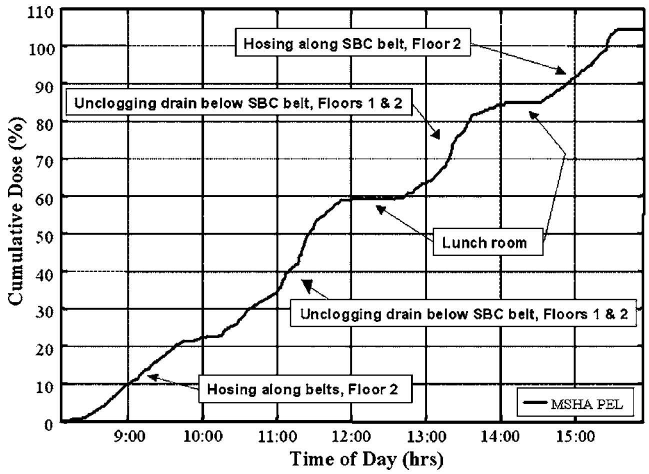

FIG. 5. Cumulative dose plot for utility man.

of equipment. Average equivalent sound levels measured in the vicinity of all pieces of equipment are ≥90 dBA, except the control room and the motor control center/electrical rooms (unmanned). Thus, spending an 8 h shift in close proximity to most all coal processing machines would result in 100% or more dose accumulation. Eleven of the machines produce overall sound levels above 95 dBA and two are above 100 dBA (sieve bends, 106.5 dBA and a coal silo fan, 108.2 dBA), which would accumulate dose at a much greater rate.

Noise contour plots were provided to the management of each plant. This information can be used to develop a plan for engineering or administrative controls that will mitigate or avoid worker exposures to these areas. Figures 1 and 2 illustrated that levels tend to be generally high enough throughout the plant, and that there are a few "quiet" areas within the plants where workers could spend a whole shift without overexposure. The wide range of levels (87–104 dBA) in Fig. 2 and the specific area of higher noise near the centrifuges at the top of the figure illustrate that the noise from one type of equipment can influence the sound field in the adjacent area containing quieter equipment. Where such influence was obvious, data were omitted from the averages in Fig. 4, but otherwise the effects would be difficult to quantify, since the continuous circuit operation of the plants does not permit equipment to be operated individually while loaded with coal. Overall A-weighted levels can easily exceed 100–110 dBA in the vicinity of equipment requiring attention, illustrating the importance of properly maintaining equipment.

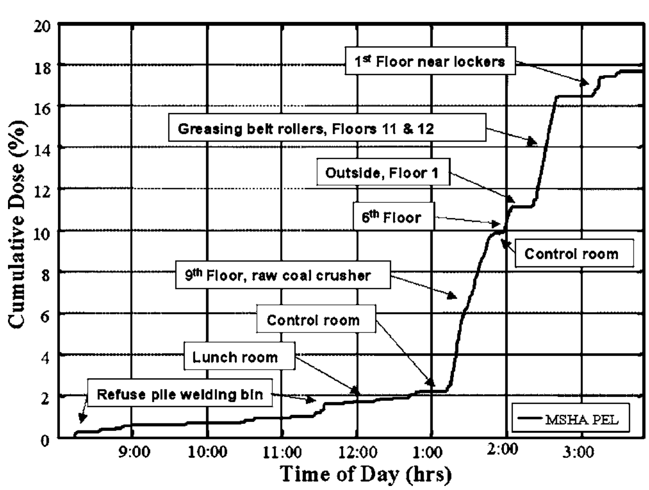

FIG. 6. Cumulative dose plot for mechanic.

TABLE IV. Surface areas, volumes, and average absorption coefficients for each measured floor.

Plant	Floor	Surface area (m^2)	Volume (m^3)	Avg. absorp. coeff. (0.25–4 kHz)
3	5	4400	9400	0.185–0.372
3	8	2300	3900	0.148–0.280
3	11/12	1500	2700	0.150–0.187
5	3	970	1040	0.103–0.197
5	7	1100	1400	0.119–0.182
5	10	1100	1400	0.087–0.141

The typical 1/3-octave band noise spectrum given in Fig. 3 illustrates that the noise was dominant in the low-frequency bands, particularly the 16 and 31.5 Hz 1/3-octave bands, which are the subharmonic and driving frequency of most electric motors throughout the plant. Linearly weighted sound levels on most floors were routinely over 100–110 dB in the 16 and 31.5 Hz bands. While this high amplitude, low-frequency sound can be uncomfortable, it is the A-weighted sound that is currently used to predict NIHL.[13,16] The A-weighted machinery noise has the highest contributions from 500 to 4000 Hz, which are also the bands that are most contributive to hearing loss.

The cumulative dose plots in Figs. 5 and 6 corroborate that dose is accumulated at the highest rates when working in the vicinity of equipment. No accumulation of dose indicates that the noise levels were below the threshold for the MSHA PEL. The utility man in Fig. 5 spent much of his shift on floors 1 and 2, and received a similar rate of dose while on each floor, albeit at a higher dose while unclogging drains between 11:00 and 11:50 and 1:00 and 1:35. Although the mechanic in Fig. 6 received only an 18% dose, the plot reveals that he received nearly 45% of his dose while repairing the raw coal crusher on floor 9 and approximately 25% while greasing belt rollers on floors 11 and 12. Had he spent more time in these or other loud areas, his shift dose would have been considerably greater.

Reverberation time measurements (Table 4) may also be helpful in determining if treating the entire plant would be helpful for reducing noise levels and exposures. Of the six floors, floor 5 from the first plant (data not presented) had the highest absorption coefficients (0.185–0.372), which was partially attributable to a layer of sand that had accumulated from sandblasting activities. The second plant had smaller absorption coefficients in general ($\bar{\alpha} \in [0.087-0.197]$) than the first plant ($\bar{\alpha} \in [0.148-0.372]$). Floor 10 of the second plant was the acoustically hardest floor, with absorption coefficients ranging from 0.087 to 0.141. The 1/3-octave measured T_{60} and $\bar{\alpha}$ spectrums for this floor are given in Fig. 7. Note from Fig. 7 that the reverberation time decreases and

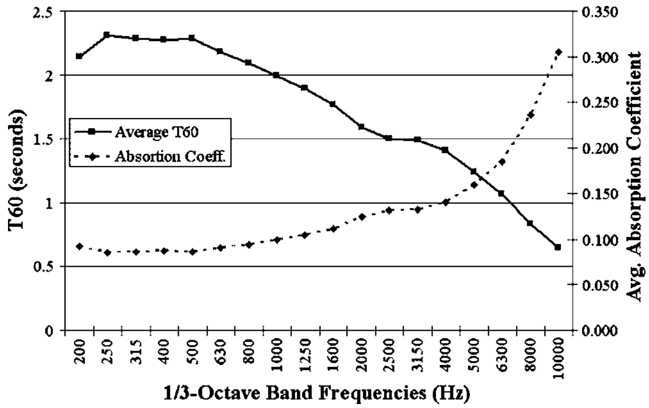

FIG. 7. Example measured T_{60} and computed average absorption coefficient for floor 10 of the second plant where T_{60} measurements were performed.

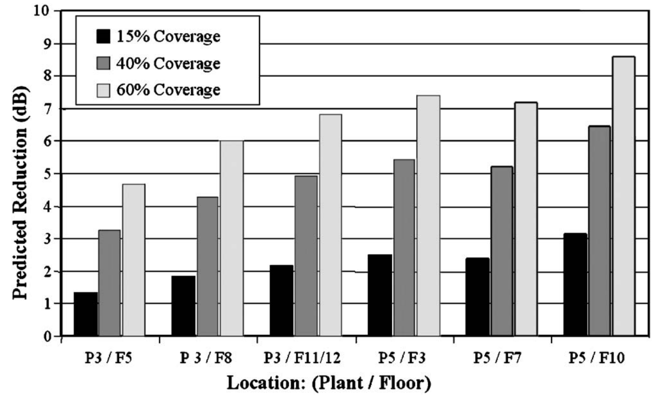

FIG. 8. Average predicted decrease in the reverberant field.

the absorption coefficient increases with frequency, since absorptive materials, whether inherent or introduced, work best at high frequencies.

The plant floors were found to be acoustically "hard" to "medium," and thus some improvements in noise levels were expected with treatments. Figure 8 shows that *predicted* reductions can be as high as 8.5 dB. The large predicted reductions are encouraging, however reductions from adding absorptive materials rarely exceed 3–5 dBA in practice.[17] Better control than expected was predicted at lower octave bands, a result of the good low-frequency performance of the treatment material and relatively small initial absorption coefficients in those bands. Any absorptive materials selected must hold up to harsh, industrial conditions and meet flammability requirements governed by MSHA.

V. CONCLUSIONS

Noise levels and worker noise exposures in eight coal preparation plants were assessed as part of a cross-sectional survey of noise in the mining industry being conducted by NIOSH. Assessment techniques included noise dosimetry, task observations, contour mapping of noise fields, and reverberation time measurements. The maps were provided to plant management to be incorporated into their noise management programs. Overall noise levels were found to range from 75.9 to 115 dBA throughout the plant. The open construction of the plant provided many direct paths for noise to propagate between floors. Most areas of the plant (except control rooms, electrical rooms, and motor control centers) were found to have noise levels in excess of 90 dBA, suggesting the noise overexposure will occur if a full 8 h shift is spent within the plant. Plant maintenance was found to be an important concern, with A-weighted levels increasing by 8 dB in two cases as a result of squeaky belts or bearings. These results are corroborated by the dosimetry and task observations of individual workers, although much higher dose accumulation rates occur when proximal to equipment. For most occupations, the shift-to-shift variability in noise dose is large. Most of the variation is due to differences in exposure levels as the worker moves about the plant or shift lengths (8 h versus 12 h shifts). Depending upon a worker's location, the average dose accumulation rates varied between 0.25–31%/h with instantaneous values being much higher. Two of the four plant worker categories (plant attendant and mechanic/electrician) had reported shift doses above 132% (the MSHA citable level). The high variability in dose indicates that the current practice of partial or single shift monitoring for compliance may not adequately characterize worker noise exposures. Reverberation time (T_{60}) measurements were performed on six floors from two representative plants. Floors were found to be fairly acoustically "hard," suggesting that absorptive-treatments may provide significant control.

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