Informational Report 1034

The Noise Environment of the Underground Coal Mine

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ILLUSTRATIONS

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by

Thomas G. Bobick[1] and Dennis A. Giardino[2]

ABSTRACT

The Noise Group, Pittsburgh Technical Support Center, Mining Enforcement and Safety Administration, conducted a series of environmental noise surveys in 12 underground coal mines. More than 2,600 employees were included in this survey. Analysis of the data indicates that 7 percent of this total, including 20 percent of all face workers, are exposed to noise levels which are in excess of the prescribed limits set by the Federal Coal Mine Health and Safety Act of 1969. A projection of the effect that revisions in the noise standards would have on the underground coal mining industry is also presented.

INTRODUCTION

The enactment of the Federal Coal Mine Health and Safety Act of 1969 prescribed maximum noise exposure levels for workers in the coal mining industry. Section 206 of the Health and Safety Act established that the standards for noise as prescribed by the Walsh-Healey Public Contracts Act will be applicable to all coal mines.

On April 3, 1970, the Mandatory Health Standards--Underground Coal Mines (Subpart F, Noise Standard, of Part 70, Subchapter O, Chapter I, Title 30) was published in the Federal Register and became effective on June 30, 1970. During December 1970, a notice of intended rulemaking setting forth proposed amendments to the Noise Standard was published in the Federal Register. Comments received from interested parties regarding these amendments were mainly concerned with the complexity of the proposed maximum noise exposure levels. It was decided, therefore, that the maximum noise exposure levels would be those prescribed by the Walsh-Healey Public Contracts Act as amended on October 1, 1969, and subsequently published in the July 7, 1971, Federal Register. The permissible noise levels and related times of exposure are shown in table 1.

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TABLE 1. - Permissible noise exposures

Duration/day (hr)	Noise level (dBA)
8	90
6	92
4	95
3	97
2	100
l-1/2	102
1	105
3/4	107
l/2	110
l/4 or less	115

These standards are still in force today. However, there is pressure from different agencies to make these standards more stringent. Before addressing the effect more stringent standards would have on the mining industry, a detailed look is needed at the present noise environment of the underground coal mine.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the management of the coal companies listed in the text for their cooperation and their assistance while the surveys were conducted *at* their facilities. Also, appreciation is extended to Jerry W. Antel, engineering technician, Noise Group, for his assistance and suggestions during the data collection of this study.

OVERVIEW OF THE UNDERGROUND BITUMINOUS COAL MINING INDUSTRY

Production

Peak production of bituminous coal from underground mines in the United States was approximately 520 million tons in 1944. Underground production has been cyclic since then, with a low of approximately 273 million tons reached in 1961. The production picture for the period 1969 (when the Federal Coal Mine Health and Safety Act was passed) through 1974 is shown in table 2. The sudden drop in coal production in 1971 was due to the nationwide coal strike during that year. There was some recovery during the next 2 years, but it *was* not sufficient *to* match the levels of 1969 and 1970. The production for 1974 dropped again because of a 6-week strike at yearend. If that strike had not occurred, underground coal production might have reached 310 million tons.

TABLE 2. - Production of bituminous coal by underground mining in the United States

Year	Thousands of short tons
1969	347,131
1970	338,788
1971	275,888
1972	304,103
1973	299,354
1974	283,000

Table 3 lists the States which had a yearly production of at least 1 million tons, from 1969 to 1973. West Virginia, Kentucky, and Pennsylvania were the most productive States consistently accounting for about 70 percent of all underground coal production.

TABLE 3. - U.S. production of bituminous coal by underground mining from States with a minimum production of 1 million tons per year

(Thousand net tons)

State	1969	1970	1971	1972	1973
West Virginia	121,623	116,414	92,437	101,662	95,516
Kentucky	64,336	62,610	53,216	56,493	62,895
Pennsylvania	56,039	55,382	44,289	49,133	46,207
Virginia	30,373	33,093	29,446	31,721	23,437
Illinois	30,082	28,018	21,631	23,993	32,570
Ohio	18,625	18,111	12,862	16,269	16,225
Alabama	9,287	9,078	6,751	7,588	7,618
Utah	4,657	4,733	4,620	5,866	5,500
Tennessee	4,473	4,350	3,543	4,770	3,636
Colorado	3,615	3,858	3,329	3,070	3,361
Indiana	2,110	2,094	1,765	1,446	1,000

At the present time, underground coal production is approximately equal to the production from surface coal mines. In the future, a larger percentage of coal may be produced from new surface mines in the Western States using modern surface mining techniques. Despite this, any increase in coal demand probably will also result in an increase in the coal production from underground mines. In fact, the Project Independence blueprint calls for a 4.5 percent yearly increase in underground production to meet an anticipated 1985 coal demand of 1.2 billion tons.

Mining Methods

There are -four general methods for mining coal underground: (1) conventional, (2) continuous, (3) longwall, and (4) shortwall. For the continuous and conventional methods, the coal is mined by a continuous miner or gathered up by a loading machine after blasting; the freshly exposed strata are then supported by timbering or roof bolting. For a longwall system of mining, very large panels of coal are isolatedby a continuous miner. The major production tool is a cutting head (a shear or plow) which is pulled back and forth across an extremely wide coal face (usually 250 to 700 feet). Self-advancing hydraulic jacks support the roof while mining is in progress. As they moved forward, the roof is permitted to cave behind the support units. Shortwall mining is very similar to longwall but instead of the shear or plow, a continuous miner is used with the self-advancing roof jacks.

The continuous mining method is by far the most commonly used underground coal extraction procedure. In fact, it accounts for approximately 60 percent of the total tonnage of coal mines underground in the United States. Because of the widespread proliferation of this equipment, and its probablefuture application, any-noise study of the underground coal mining industry should have its focal point in continuous 'mining sections. This is precisely where the bulk of effort was expended for this survey.

SCOPE OF THE NOISE SURVEY

The 12 mines that were included in this survey were randomly selected from the major underground coal producers in the Eastern United States. Eleven of the 12 were located in the three high production States (West Virginia, Kentucky, and Pennsylvania).

A breakdown of all production sections surveyed by State and mining methods is given in table 4. More than twice as many continuous mining sections were surveyed than conventional sections. Only two longwall sections were included in the survey.

TABLE 4. - State and production method of mines surveyed

State	Number visited	Mining method		
		Continuous	Conventional	Longwall
Pennsylvania...........	4	16	1	1
West Virginia..........		14	0	1
Kentucky..............	2	7	10	0
Alabama................	1	2	6	0
Totals...........	12	39	17	2

A detailed listing of these mines, including location, seam name and thickness, the method of mining, average daily production and the total number of employees are presented in table 5.

TABLE 5. - Listing of mines surveyed

Mine name	Location	Seam, thickness	Mining method	Average Production (tons/day)	Total men	Underground employees	Surface employees
Eureka No. 40 mine.	Scalp Level, Pa.	Upper Kittanning 70 inches.	Continuous	970	90	60	30
Lancashire No. 25 mine.	Barnesboro, Pa.	Lower Freeport 40-42 inches.	Continuous Longwall	3,000	318	224	94
Fawn mine.........	Saxonburg, Pa.	Upper Freeport 54-60 inches.	Continuous Conventional	2,000	100	90	10
Russellton mine....	Russellton, Pa.	Upper and Lower Freeport 52-84 inches.	Continuous	2,300	266	197	69
Lundale No. 1 mine.	Lundale, W. Va.	Cedar Grove 48-72 inches.	Continuous	1,600	133	115	18
No. 116 mine.......	Eunice, W. Va.	Eagle 48-60 inches.	Continuous	750	86	81	5
Olga mine......... .	Coalwood, W. Va.	Pocahontas No. 4 48-66 inches.	Continuous Longwall	4,500	455	373	82
No. 10 Wisconsin mine.	Benham, KY...	"A" 78-84 inches	Conventional	2,000	75	51	24
No. 1 mine.........	River, KY....	Miller's Creek 28-30 inches.	Conventional	800	80	67	13
Star underground mine.	Central City, KY.	Kentucky No. 9 60-66 inches.	Conventional	7,200	294	277	17
Maxine mine........	Quinton, Ala.	American 32-54 inches.	Conventional Continuous	6,000	422	357	65
No. 32 mine........	Lynch, Ky....	High Splint 42-60 inches.	Continuous	6,300	313	290	23

NOISE SURVEY PROCEDURE

.Occupation Selection

Arrangements were made with the mine management and MESA District inspection personnel to conduct each noise survey at a particular mine. The inspection personnel assisted the Noise Group while at the mine.

From table 5, the total number of employees for all 12 mines included in this survey was 2,632. A detailed noise survey was not conducted on all of these workers. Rather, a screening technique was used to select those individuals who were exposed to noise levels in excess of 90 dBA for extended periods of time. These individuals, it was felt, were the ones most likely to suffer hearing impairment. Consequently , these workers were studied in detail. As it turned out, most of these high-risk employees were the ones who normally operate production or supportive face equipment. For the sake of completeness, a listing of all the job occupations and number of men in each category for the 12 mines is given in appendix A.

Noise Level--Time Study

The noise survey consisted of measuring and noting two variables: (1) the sound levels to which the worker was exposed and (2) his exposure time to those levels per work shift. To measure the sound level, two General Radio 1565-A sound level meters were used in all the surveys. These sound level meters meet the specifications of Section 70.505(a) of Subpart F--Noise Standard of the Mandatory Health Standards--Underground Coal Mines. The sound level meters were operated on the A-weighted network, slow response and were acoustically calibrated before, during, and after each shift. Calibration was done using the General Radio 1562-A sound level calibrator which emits a 114 dB, 1,000 Hz tone re 20 $\mu N/M^2$. When possible, noise measurements were taken with the microphone oriented in a vertically upward direction, approximately 1-l/2-feet away from the employee's ear closest to the noise source .

The total time of exposure at each sound level was determined by a partial shift time study of that occupation. These partial shift studies consisted of recording the time of exposure at each sound level during the various operations for one complete cut of coal and noting the tonnage produced for that cut. The resulting full shift exposure was then calculated based on the total tonnage produced on that section for a normal production shift.

Octave Band Analysis

In addition to the sound level meter, an octave band analyzer (OBA) was used occasionally during these surveys. When used, the OBA (General Radio Type Model 1558-BP) permitted the determination of the frequency content of the noise. This device electronically separates the noise signals into nine octave bands which cover the audible frequency range. As the various frequencies are dialed through the OBA, a sound level is measured for each

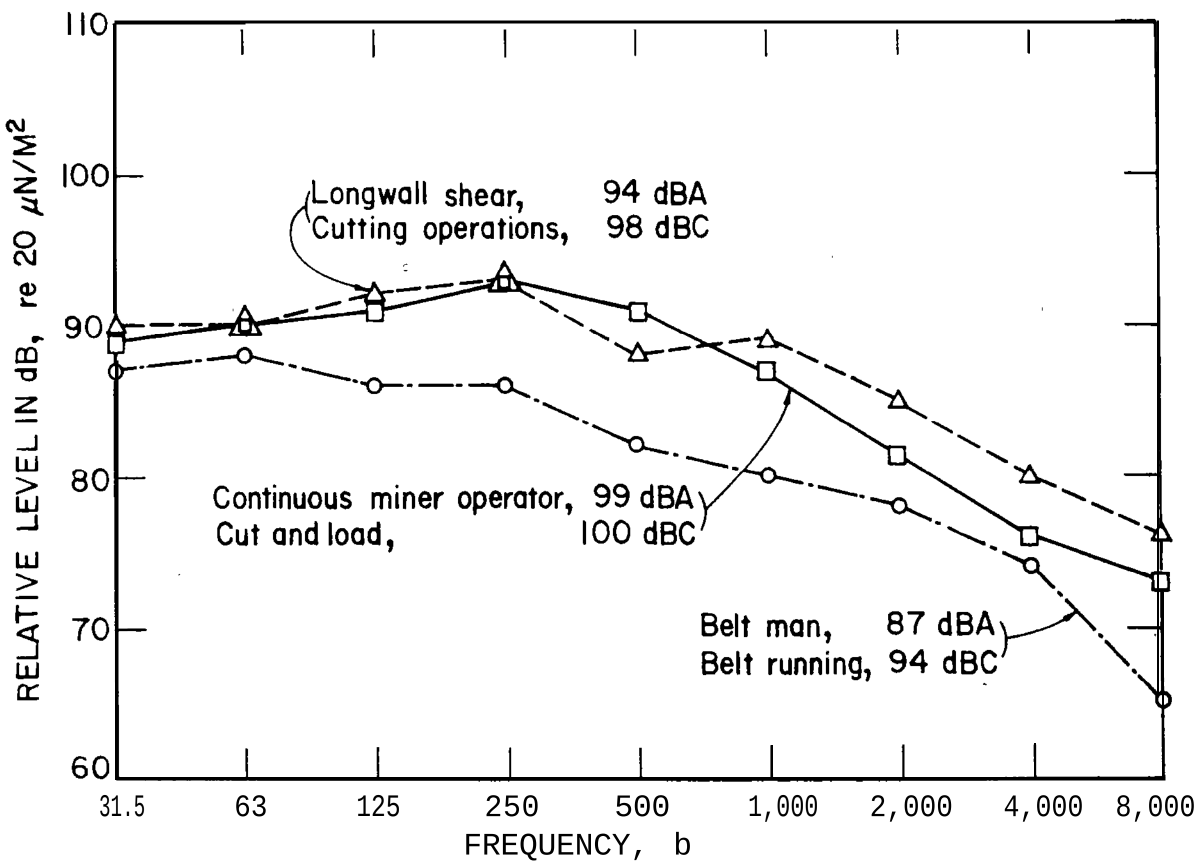

FIGURE 1. - Typical octave band spectra for three different underground mining occupations.

band. If all of these sound levels are acoustically added together (1)[3] (after applying the A-weighting correction values for each band), the overall dBA level is obtained. Thus, the OEA permits a more thorough examination of the noise involved. Figure 1 illustrates typical noise spectra for three underground occupations: a continuous miner during the cut and load operating mode, a longwall shear making a pass across the face, and a belt conveyor operating while loaded with coal.

NOISE EXPOSURE OF FACE WORKERS

Overall Data

Undoubtedly the noisiest location in an underground coal mine is at the working face. The primary activity at the face, which is the brute force extraction of coal, requires a tremendous amount of mechanical energy. Unfortunately, a byproduct of this force expenditure is the generation of

'Underlined numbers in parentheses refer to the list of references preceding the appendixes.

noise. Measurements made in an underground environment indicate that, in many cases, the noise levels are excessive.

Face mining machinery, like most machines,has several different operating modes. The rotary roof bolter, for example, has three separate modes of operation: tramming, drilling, and tightening. The noise emitted in each mode is distinctive, having different characteristics of frequency and level. Thus, when ascribing a noise level to a machine, it is essential that the operating mode be specified.

The noise levels at the operator's position for eight different types of face machinery, in several different operating modes, were measured in these surveys. In all, 182 individual mining machines were surveyed. Table 6 lists the eight machines investigated, the number of each type surveyed, along with the average noise level and average operating time per shift for all the operating modes. The standard deviations in the time and noise level data are included to indicate the range of the values observed. Although the mantrip is usually not considered a face operation, it is included because it does add to the noise exposure of the worker in transporting him to the face.

Noise Exposure Index

The noise exposure index (NEI) is defined as the ratio of actual exposure time at a certain noise level, to the permitted exposure time, that is:

$$NEI = \frac{C}{T}, \qquad (1)$$

where C = actual time (measured in mine)

and T = permitted exposure time (as given in table 1).

If the noise level should change during the course of an employee's work shift, an NEI must be calculated for each different noise level. The total or accumulated NEI for that shift is then the sum of all the individual NEI's, that is:

$$NEI = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots, \qquad (2)$$

where C_1 = actual exposure time for noise level No. 1,

C_2 = actual exposure time for noise level No. 2 . . . ,

T_1 = permitted exposure time for noise level No. 1,

and T_2 = permitted exposure time for noise level No. 2 . . .

A worker is considered out of compliance if his daily total NEI exceeds unity. In practical terms, this means that his actual exposure time has exceeded the permitted exposure times as definedby table 1.

TABLE 6. - Average noise levels and operatin? times of the face equipment surveyed

Machine type	Number surveyed	Operating mode	Average noise level (dBA)	Average operating time per shift (min)
Continuous miner.	33	Tram........	87.3±4.1*	57±34*
		Cut only....	95.1±3.1	29±19
		Load only...	94.2±2.3	29±26
		Cut and load.**	97.2±2.6	108±47
Loading machine	18	Tram........	91.7±3.6	73±25
		Load**......	96.7±2.4	97±32
		Clean-up	99.3±3.1	47±27
Shuttle car....	47	Tram........	86.6±1.8	106±58
		Load**......	89.7±2.5	6l±30
		Unload......	89.0±2.7	38±17
Cutting machine	17	Tram........	85.7±3.3	51±21
		cut**.	91.4±2.3	118±43
		SumP........	94.9±2.0	18±6
Coal drill.....	17	Tram........	83.6±2.9	51±23
		Drill**.....	87.7±3.2	47±16
		Maneuver	84.2±2.0	22±12
Rotary roof bolter.	37	Tram........	85.5±2.2	46±27
		Drill**.....	93.2±3.2	91±31
		Bolt........	91.2±3.6	7±3
		Idle........	85.1±2.0	34±10
Stoper.........	11	Drill**.....	119.4±1.8	139±58
		Bolt........	106.1±7.8	33±27
		Idle........	100.1±4.0	32±3
Longwall shear.	2	Cutting	89.5±4.9	177± 3
Mantrip........	58		92.6±3.2	31±14

*± values represent one standard deviations in measurements.
** Major operating mode.

An alternate determination for NEI can be obtained using the following expression:

$$NEI = \frac{C}{15} \times 2^{\frac{L-115}{5}}, \qquad (3)$$

where C = actual exposure time as measured during a noise survey (minutes)

and L = noise level in dRA as measured during a noise survey.

Using this expression in conjunction with the data given in table 6, the total NEI for each machine type was calculated. Table 7 gives a percentage breakdown of the machine populations for different NEI ranges. As can be seen, one-third of the continuous miners and loading machines are out of compliance with current noise standards. As expected, 100 percent of the stopers (pneumatic roof drills), but surprisingly only 5 percent of the rotary roof drills are out of compliance. Table 8 is another way to look at the NEI data. Here a breakdown of worker population for various ranges of NEI is given. It can be seen that the noncompliance segment for the entire population of underground workers is only 7 percent; while more than 20 percent of the face workers are out of compliance. If one were to include the "susceptible" NEI range of 0.75 to 1.0, then fully 30 percent of all face workers would not comply with present noise standards. This NEI range is considered susceptible since a slight increase in the noise levels and/or operating times will result in over exposure for these employees.

TABLE 7. - Noise exposure index distribution of face equipment surveyed

Equipment category	Population	Percentage of equipment with NEI of			
		0 to 0.49	0.50 to 0.74	0.75 to 1.0	Greater than 1.0
Stoper............	11	0	0	0	100.0
Continuous miner..	33	27.3	15.2	24.2	33.3
Loading machine...	18	0.6	16.7	44.4	33.3
Rotary drill......	37	64.9	27.0	2.7	5.4
Shuttle car.......	47	93.6	6.4	0	0
Cutting machine...	17	58.8	35.3	5.9	0
Coal drill........	17	100.0	0	0	0
Longwall shear....	2	50.0	50.0	0	0

TABLE 8. - Noise exposure index distribution for underground coal mine workers

Worker category	Total population	Percentage of workers with NEI of			
		0 to 0.49	0.50 to 0.74	0.75 to 1.0	Greater than 1.0
All...............	2,632	78.1	10.6	4.1	7.2
Face..............	778	56.9	12.9	9.9	20.3
Nonface,..........	1,854	86.8	9.8	1.7	1.7

Comparison of Face Equipment

From the previous table, it can be seen that better than 20 percent of all face workers are out of compliance. Because of this, a detailed analysis of the face equipment is given. Figure 2 shows a bar graph evaluation of the operating time and noise level in the major mode of operation for the equipment surveyed. The major operating modes are indicated in table 6. As can be seen, the pneumatic stoping drill is by far the worst noise offender. The next loudest equipment is the loader and continuous miner, followed by the cutting machine and rotary roof bolter. Table 9 lists the computed NEI for the major operating mode of the equipment surveyed. However, the listed NEI value is only a partial noise exposure index for the equipment specified. The other operating modes (listed in table 6) will add to the worker's overall NEI for the full working shift.

TABLE 9. - Noise exposure indices of the major operating modes of the equipment surveyed

Equipment	Major operating mode	Average NEI
Mantrip.......:.....	Mantrip..............	0.09
Coal drill..........	Drill................	0.00
Shuttle car.........	Load.................	0.00
Cutting machine.....	.Cut..................	0.30
Rotary roof bolter..	Drill................	0.30
Loader.............	Load.................	0.51
Continuous miner....	Cut and load.........	0.61
Stoper.............	Drill.	17.10

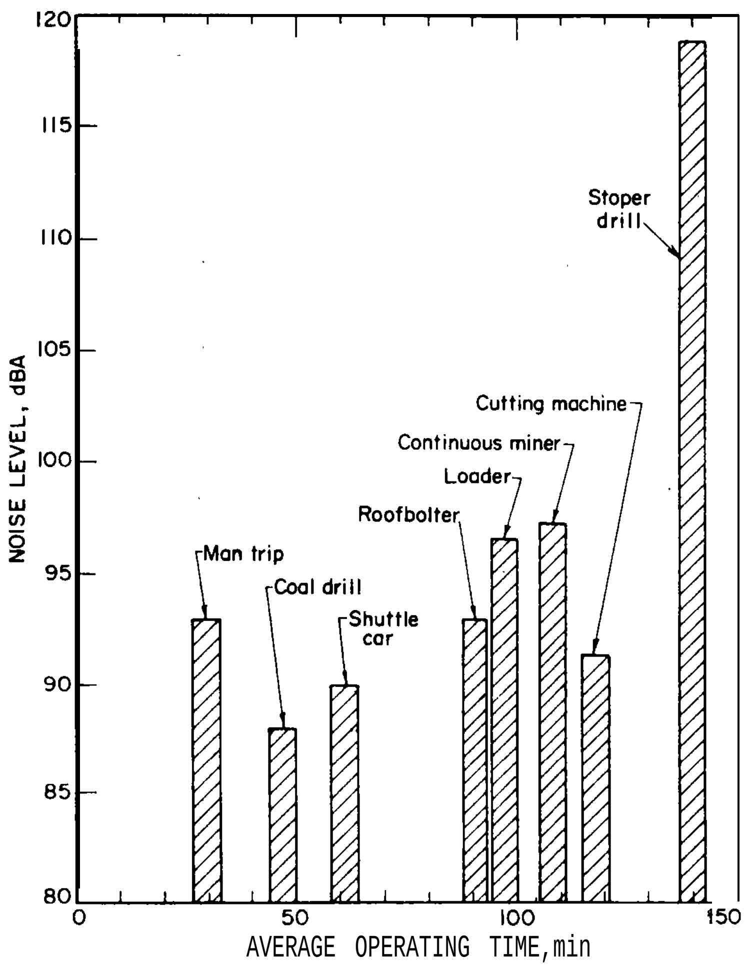

FIGURE 2. - Noise level-time data for the underground face equipment surveyed (major operating mode).

Some indication of the statistical variations in the measured parameters can be obtained from figure 3. Here rectangular areas in the dBA-time space define the range of the observed parameters for a 68-percent confidence limit (one standard deviation). For example, 68 percent of the shuttle cars surveyed had noise levels in the range of 87.2 to 92.2 dBA and operating times in the range of 31 to 91 minutes per shift. This is displayed on the graph by the rectangular area marked "shuttle car." In general, rectangular areas that are "squashed" along the dBA axis represent machine types which have large variations in noise level and small variations in operating time, while rectangular areas "squashed" along the time axis represent machine types having a small variation in noise level and a large variation in operating time.

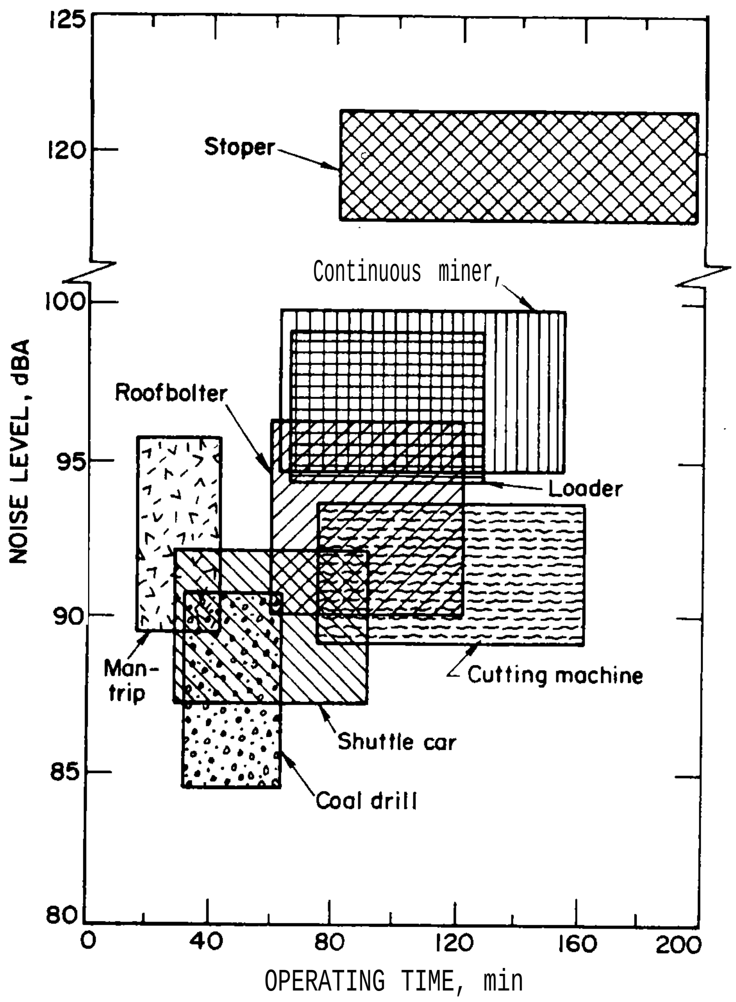

FIGURE 3. - Typical variations in noise level and operating times for underground face equipment surveyed (major operating mode).

Again, it can be seen that stopers exist in a class by themselves, showing a noise level range of 117.6 to 121.2 dBA and an operating time range of 81 to 197 minutes per shift.

It is interesting to note that although the average noise levels between different machine types are quite large (88 dBA for the coal drill to 119 dBA for the stoper), the variations in the emitted noise levels for a particular machine type are relatively small (averaging about +3 dBA). This implies that the noise emission for a given machine type is, to a first approximation, independent of the manufacturer's brand and operating conditions encountered during the survey.

Operating Mode Versus Noise Level

An estimation of the noise level and operating time for all modes of operation for each machine type was also made during this survey. The averages of these results are shown in figures 4 through 10. In the figures, the right hand vertical axis defines the average accumulated NEI, while the horizontal axis gives the average operating time in minutes. Each operating mode is specified in terms of average noise level and operating time by the corresponding rectangular blocks. The number immediately below the operating mode title gives the percentage of the total work cycle that is spent in that particular mode of operation.

The NEI for any part of the work cycle can be obtained from the figures by using the plotted NEI curve and the corresponding NEI axis. This NEI curve represents the reading that would be accumulated by a dosimeter installed on the machine operator. The slope of the NEI curve gives the rate of NEI accumulation as a function of operating mode; that is, the steeper the slope the higher the rate of NEI accumulation.

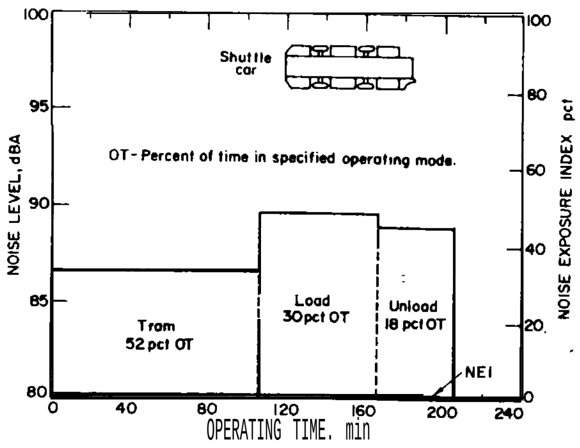

FIGURE 4. - The distribution of average operating times, average noise levels and resultant NEI's for the different operating modes of the shuttle car.

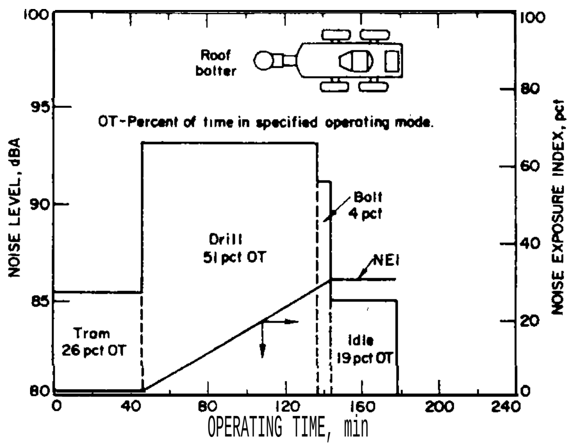

FIGURE 5. - The distribution of average operating times, average noise levels and resultant NEl's for the different operating modes of the rotary roof bolter.

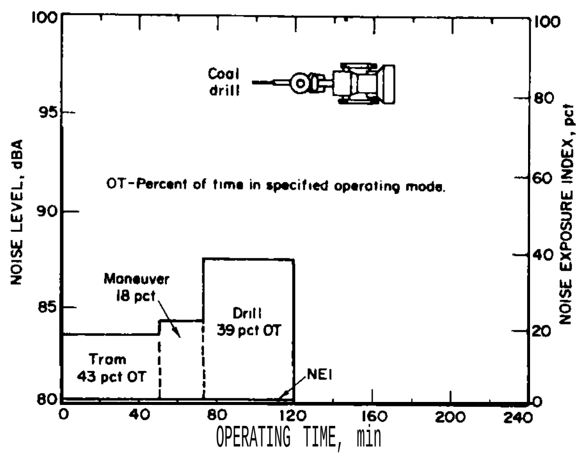

FIGURE 6. - The distribution of average operating times, average noise levels and resultant NEl's for the different operating modes of the coal drill.

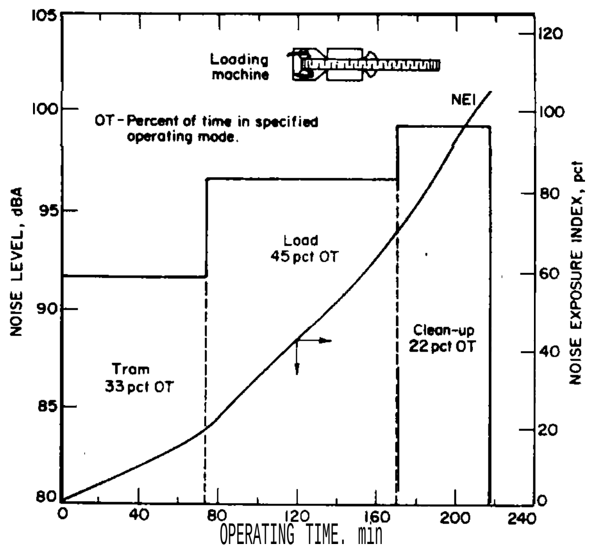

FIGURE 7. - The distribution of average operating times, average noise levels and resultant NEl's for the different operating modes of the loading machine.

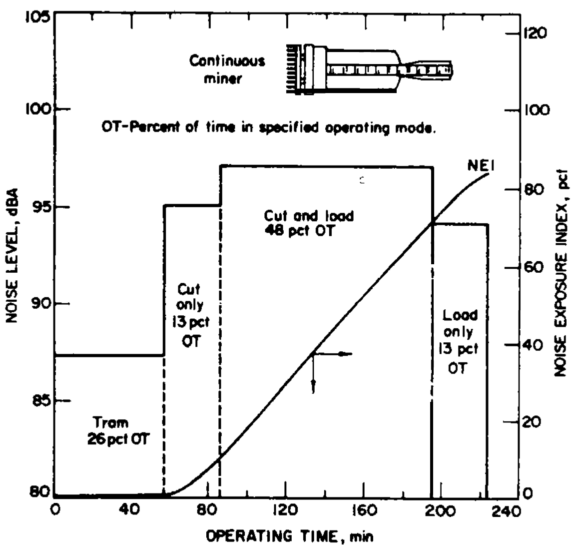

FIGURE 8. - The distribution of average operating times, average noise levels and resultant NEl's for the different operating modes of the continuous miner.

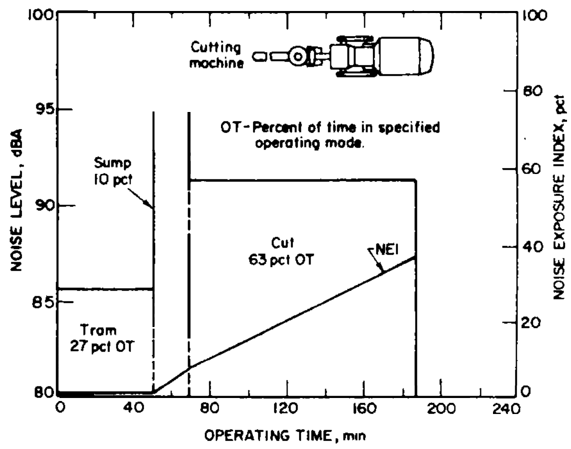

FIGURE 9. - The distribution of average operating times, average noise levels and resultant NEl's for the different operating modes of the cutting machine.

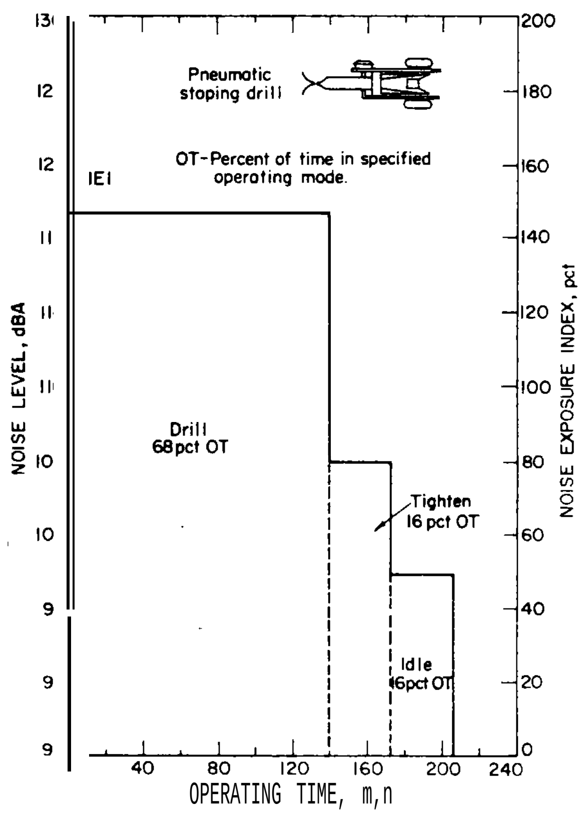

FIGURE 10. - The distribution of average operating times, average noise levelsand resultant NEl's for the different operating modes of the pneumatic stoping drill.

It should be noted that the data given in figures 4 through 10 are average values of noise levels and operating times. Therefore, it follows that the indicated NEI values, which are calculated from the noise levels and operating times, are themselves average values. Thus, for the given NEI value, 50 percent of the machine population surveyed have NEI values in excess of this average, while 50 percent have NEI values less than the given average value.

As an example of the usefulness of these graphs, consider figure 7 which defines the operating modes for the loading machine work cycle. Here the following information can be obtained:

1. The average loader trams for 73 minutes, or 33 percent of the work cycle, producing a noise level of 92 dBA.

2. The average loader loads coal for 97 minutes, or 45 percent of the work cycle, emitting a noise level of 97 dBA.

3. The average loader operates in the clean-up mode for 47 minutes,or 22 percent of the work cycle, producing a noise level of 99 dB4.

4. The accumulated NEI for the entire work cycle is 1.05. The tram mode contributes 0.20 while the load and clean-up modes contribute 0.50 and 0.35, respectively, to the total NEI.

5. The NEI rate of accmulation for the average loader is maximum in the clean-up mode, about 0.7 percent NEI per minute of operation. The NEI rate for the tram mode is 0.3 percent NEI per minute of operation while for the load mode it is 0.5 percent NEI per minute of operation.

Changes in the Noise Environment Since 1970

The first comprehensive noise survey conducted in underground coal mines was done shortly after the passage of the Federal Coal Mine Health and Safety Act of 1969. The results of this survey were reported in a Bureau of Mines publication (3).

A comparison of the results obtained in the 1970 survey and the results of the present survey is shown in table 10.

TABLE 10. - Comparison of data for the 1970 and the present surveys

Machine type	Sample size		Operating mode	Average noise level (dBA)	
	1970 survey	present survey		1970 survey	Present survey
Continuous miner........	17	33	Tram..............	88	87.3
			Cut only..........	-	95.1
			Load only.........	-	94.2
			Cut and load......	97	97.2
Loading machine.........	8	18	Tram..............	90	91.7
			Load..............	99	96.7
			Clean-up..........	-	99.3
Shuttle car.............	8	47	Tram..............	87	86.6
			Load..............	93	89.7
			Unload............	88	89.0
Cutting machine.........	5	17	Tram..............	86	85.7
			cut.	92	91.4
			Sump..............	96	94.9
Coal drill..............	3	17	Tram..............	-	83.6
			Drill.............	94	87.7
			Maneuver..........	-	84.2
Rotary roof drill.......	12	37	Tram..............	87	85.5
			Drill.............	95	93.2
			Bolt..............	-	91.2
			Idle..............	87	85.1
Stoper..................	9	11	Drill.............	112	119.4
			Bolt..............	103	106.1
			Idle..............	84	100.1
Mantrip.................		58	Mantrip...........	93	92.6

Since operating times were not reported for the 1970 survey, no comparison on an NEI basis is possible. As can be seen,the only significant changes in noise level occur for the coal drills and the pneumatic roof drills. The apparent decrease in noise level for the coal drills is probably attributed to the difference in sample size for the two studies (only three coal drills for the 1970 and 17 for the present survey). The apparent increase in the pneumatic roof drill noise level is not quite so easy to explain. It may be due to the fact that the noise emission for this particular type of equipment is strongly dependent upon operating conditions. Differences in roof hardness, operating air pressure and operator skill could drastically affect noise output. Except for these two drill types, there is little change in the sound levels measured for the different job occupations of face workers in underground coal mines. The overall data reported for this survey are a good verification that the noise levels of unmodified equipment used in underground coal mines have remained virtually the same since 1970.

FORECAST OF FUTURE SITUATIONS IN UNDERGROUND COAL MINES

Hearing Loss and Noise Standards

Since the end of World War II, intensive studies have been conducted concerning the effects of industrial noise on hearing loss. In general, the studies have shown that permanent hearing loss increases as;

1. The intensity of the noise increases.

2. The time of exposure increases.

3. The rest or quiet period between noise exposures decreases.

The occupational hearing loss syndrome follows a familiar pattern. The individual when first exposed to excessively loud noise usually incurs a temporary threshold shift (TTS) in hearing acuity. This hearing loss, as its name implies, is a temporary loss. Recovery can occur within a short time after exposure provided that the recovery environment is suitably quiet (less than 80 dBA). Over many years of accumulated exposure, where the subject has repeatedly experienced the noise exposure-recovery phenomena, the degree of recovery becomes less and less. At this stage, from a pathological point of view, deterioration of the sensory receptors in the inner ear has occurred. This nerve (hair cell) damage is irreversible, producing a permanent threshold shift (PTS) or hearing loss which is nonrecoverable. The subject will thus experience this hearing impairment for the rest of his natural life.

In an effort to protect the hearing of industrial workers, several noise standards have been proposed. All of them define two parameters: the maximum permissible noise level for an 8-hour exposure and a time-intensity trade-off factor. The time intensity trade-off factor specifies the relationship between noise level, exposure time and number of quiet periods between noise exposures. It is usually defined in terms of the allowable increase in noise level (dBA) for each halving of exposure time. For example, the present noise standard used by MESA permits exposure to a noise level of 90 dBA for an 8-hour work day. For each 5 dBA increase in the noise level, the permitted time of exposure is halved (table 1). This standard can thus be referred to as having a 90 dBA maximum permissible level for 8-hour exposure with a 5 dB time-intensity trade-off. For brevity, it is called a "90/5" standard.

Recently, in the December 18, 1974, Federal Register, the Environmental Protection Agency (EPA) recommended that the present noise standards should be reduced to a maximum sound level of 85 dBA for an 8-hour exposure period. Additionally, the EPA stated that the time-intensity trade-off value should be reduced from 5 to 3 dB. The EPA feels that these changes are necessary because the present 90/5 standard is not sufficient to protect industrial workers from a noise induced PTS of no more than 5 dB at 4,000 Hz after 40 years of exposure. Other experts, at variance with EPA, state that the risk of hearing impairment under the current 90/5 1s minimal. Their studies indicate that this hearing impairment risk is limited to the most sensitive 2 percent of the working population when exposed to a 90 dBA level for 30 years (2).

Because of this present controversy, changes in the current noise standards may occur in the very near future. A projection of the effect that revisions in the noise standard would have on the underground coal mining industry is presented in the following section.

Effect of Adopting New Noise Standards

Using the noise data collected during this study, the effect, in terms of compliance, will be considered for three possible revisions of the present noise standard. For the sake of brevity, a shorthand notation is used when referring to the three possible revisions. This notation and the standard revision it refers to is as follows:

90/3--90 dBA maximum permissible level for 8-hour exposure with a 3 dB time-intensity trade-off.

85/5--85 dBA maximum permissible level for 8-hour exposure with a 5 dB time-intensity trade-off.

85/3--85 dBA maximum permissible level for 8-hour exposure with a 3 dB time-intensity trade-off.

The data in table 6, specifically the average dBA levels and operating times, were used to calculate the total noise exposure index, according to equations 2 and 3,[4] for the present standard and the three possible variations for all face equipment surveyed. These results are shown in table 11. As can be seen, under the present standard (9015) only the stoper and loading machine operators are overexposed. The continuous miner operator with an NEI of 0.84 is in the susceptible range. It is interesting to note that under the present standard, the stoper operator is 18 times overexposed. As stated before, the pneumatic stoper is indeed the worst noise offender in underground coal mines. For the 90/3 standard, the equipment which initially has high NEI values will increase substantially; whereas the equipment with low NEI's will hardly increase at all. Table 12 gives the permitted time of exposure for specific noise levels under the 90 dBA for 8-hour exposure with a 3 dB time-intensity trade-off value.

[4] Equation 3 will be modified for each revision; these will be discussed in appendix B.

TABLE 11. - Comparison of the total NEI values for the different criteria

Machine type	90/5 standard	90/3 standard	85/5 standard	85/3 standard
Stoper	17.96	261.70	35.93	832.65
Continuous miner	0.84	1.55	1.85	5.11
Loading machine	1.06	2.02	2.12	6.40
Rotary roof drill	0.32	0.42	0.80	1.50
Cutting machine	0.37	0.46	0.87	1.57
Shuttle car	0.00	0.00	0.66	0.90
Coal drill	0.00	0.00	0.14	0.18
Longwall shear	0.00	0.00	0.69	1.05
Mantrip	0.09	0.12	0.19	0.37

TABLE 12. - 90 dBA for 8 hours with a 3 dB time-intensity trade-off

Noise level (dBA)	Time permitted per day (min)	Noise level (dBA)	Time permitted per day (min)
90	480.0	103	23.8
91	381.0	104	18.9
92	302.4	105	15.0
93	240.0	106	11.9
94	190.5	107	9.4
95	151.2	108	7.5
96	120.0	109	6.0
97	95.2	110	4.7
98	75.6	111	3.8
99	60.0	112	3.0
100	47.6	113	2.4
101	37.8	114	1.9
102	30.0	115	1.5

When the maximum permissible level for the 8-hour exposure is reduced from 90 to 85 dBA (keeping the trade-off value constant at 5 dB), the NH1 values are predicted to double. By comparing the values under the 90/5 and 85/5 columns in table 11, it can be seen that the NEI values for the stoper, loading machine, and the mantrip do increase by a factor of two. The NEI's for the remaining equipment increase an additional amount over doubling. The reason for this is that under the 90/5 standard any noise levels less than 90 dBA are not included when the total NEI is computed. However, under the 85/5 standard the previously ignored levels are now included and account for the additional increase in NEI values. This change would result in the continuous miner and the loading machine being definitely out of compliance. The rotary roof drill and the cutting machine would now have NEI values in the susceptible range. Table 13 gives the permitted exposure times under the 85 dBA maximum permissible level for 8-hour exposure with a 5 dB time-intensity trade-off value.

TABLE 13. - 85 dBA for 8 hours with a 5 dB time-intensity trade-off

Noise level (dBA)	Time permitted per day (min)	Noise level (dBA)	Time permitted per day (min)
85	480.0	101	52.3
86	417.9	102	45.5
87	363.8	103	39.6
88	316.7	104	34.5
89	275.7	105	30.0
90	240.0	106	26.1
91	208.9	107	22.7
92	181.9	108	19.8
93	158.3	109	17.2
94	137.8	110	15.0
95	120.0	111	13.1
96	104.5	112	11.4
97	90.9	113	9.9
98	79.2	114	8.6
99	68.9	115	7.5
100	60.0		

Finally, when both changes are applied to the present standard, the resultant NEI values increase quite dramatically and the situation becomes very critical. Table 14 gives the permitted exposure times under the 85 dBA maximum permissible level for 8-hour exposure with a 3 dB time-intensity trade-off value. Only the mantrip and the coal drill will have no trouble staying in compliance with the 85/3 standard. The index for the shuttle car is now in the susceptible range. A mere 15 percent (31 minutes) increase in the overall operating time will result in an NEI value of 1.05 (noncompli-ante) for the shuttle car operator. The remaining equipment types have resultant NEI's which are also out of compliance and will present formidable problems for the required noise control.

TABLE 14. - 85 dBA for 8 hours with a 3 dB time-intensity trade-off

Noise level (dBA)	Time permitted per day (min)	Noise level (dBA)	Time permitted per day (min)
85	480.0	101	11.9
86	381.0	102	9.4
87	302.4	103	7.5
88	240.0	104	6.0
89	190.5	105	4.7
90	151.2	106	3.8
91	120.0	107	3.0
92	95.2	108	2.4
93	75.6	109	1.9
94	60.0	110	1.5
95	47.6	111	1.2
96	37.8	112	0.9
97	30.0	113	0.7
98	23.8	114	0.6
99	18.9	115	0.5
100	15.0		

DISCUSSION OF RESULTS

Referring to table 8, there were 778 face workers involved in this study. Under the 85/3 standard, the coal drill operator would be in compliance and the shuttle car operator would be in the susceptible range. Excluding the coal drill and shuttle car operators, the remaining occupations, which total 64 percent of all face employees, would be out of compliance. Assuming the operating times of the shuttle car operators would increase 15 percent, which is a likely possibility, then overexposure would result. If 50 percent of the shuttle car operators would be involved in this increase in time, then a total of 79 percent of the face employees would be overexposed.

The implications of the resulting data are overwhelming. Four out of every five face employees would be in violation of the Noise Standard if the proposed 85/3 standard should be implemented.

Obviously, the equipment manufacturers are the key to keeping the equipment operators in compliance. Redesigned mining equipment, which will produce lower levels of noise, is needed. Since an average of 4 to 5 years is needed to complete (from conception to production) a major redesign of mining equipment, the manufacturers should be addressing the noise problems produced by their equipment now. Unfortunately, at the present time, there are no regulations for equipment manufacturers to follow in designing products for noise compliance. Communications with several manufacturing firms has revealed that until such regulations are passed the manufacturers, not being sure of what permissible noise levels will be required, are not initiating redesign programs.

This is indeed a difficult situation since numerous noise sources on mining equipment could be eliminated by redesign or incorporation of standard noise control techniques. After the equipment is in the field, retrofitting is both time-consuming and costly due to machine downtime. The most logical place to apply noise control measures is in the plant during fabrication. Since the Noise Standard is here to stay and the coal mine owner and operator are required to address the compliance problem, the equipment manufacturers must start producing quieter equipment.

In the interim, it must be realized by both management and union employees of the operating coal mines that noise control of underground mining equipment is a necessity. Noise reduction can be achieved eventually by retrofitting existing equipment, but a more permanent solution would be for labor and management to begin demanding that equipment manufacturers produce quieter products. Until these quieter products are produced, modifications to present-equipment will be the only means to attenuate the noise. Management and union personnel should cooperate in applying and maintaining these noise control techniques. Although the goal of a quiet underground environment will be difficult to achieve, these noise problems can be controlled if everyone works together.

REFERENCES

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2. Burns, W., and D. Wi Robinson. Hearing and Noise in Industry. London: Her Majesty's Stationery Office, 1970, p. 235, et seq.

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APPENDIX A.--JOB OCCUPATIONS SURVEYED

Occupation	Job code number	Sample size
SECTION WORKERS (FACE)		
Belt/conveyor man	001	31
Electrician	002	45
Electrician helper	003	2
Mechanic	004	109
Mechanic helper	005	9
Rock duster	006	15
Shot firer/shooter	007	28
Stopping builder	008	6
Supply man	009	2
Timber-man	010	41
Wireman	011	1
Laborer	016	11
Bratticeman	032	28
Coal drill operator	034	39
Continuous miner helper	035	74
Continuous miner operator	036	93
Cutting machine operator	038	32
Jacksetter/longwall	041	36
Loading machine helper	042	31
Loading machine operator	043	39
Longwall shear/plow operator	044	7
Roof bolter	046	194
Roof bolter mounted	048	28
Section foreman	049	116
Shuttle car operator	050	243
Stall driver	051	1
Tail gate operator	052	3
Utility man	053	63
Bridgeman	055	5
UNDERGROUND (NONFACE)		
Belt/conveyor man	101	71
Electrician	102	20
Electrician helper	103	5
Mechanic	104	39
Mechanic helper	105	24
Rock duster	106	1
Stopping builder	108	16
Supply man	109	29
Timberman	110	5
Wireman	111	10
Belt vulcanizer	112	1
Laborer	116	216
Rodman	117	3
Oiler/greaser	118	4
Welder	119	3
Coal dump operator	122	7

Occupation	Job code number	Sample size
UNDERGROUND (NONFACE)--Continued		
Transit man	123	1
Nonface miner operator	136	1
Nonface loading machine operator	143	1
Labor foreman	149	5
Nonface tractor operator	150	2
Belt cleaner	154	13
Chainman	155	1
Driller	156	2
Pumper	157	8
Rock machine operator	158	15
UNDERGROUND TRANSPORTATION (NONFACE)		
Belt/conveyor man	201	6
Trackman	216	29
Cager	220	1
Brakeman/rope rider	262	29
Dispatcher	265	13
Motorman	269	122
ABOVE GROUND		
Conveyor operator	301	1
Electrician	302	35
Electrician helper	303	2
Mechanic	304	79
Mechanic helper	305	4
Mason	308	1
Supply man	309	13
Clean-up man	313	2
Coal sampler	314	2
Laborer	316	23
Rodman	317	2
Oiler/greaser	318	3
Shop welder	319	19
Hoist operator	321	10
Coal dump operator	322	8
Transit man	323	1
Shuttle car operator	350	1
Rock drill operator	356	1
Shop man	360	50
Brakeman	362	1
Bulldozer operator	368	16
Barge attendant	372	8
Car dropper	373	40
Cleaning plant operator	374	18
Road grader -operator	375	2
Coal truck driver	376	10
Crane/dragline operator	378	4
Dryer operator	379	1
Fine coal plant operator	380	5
Highlift operator	382	7

Occupation	Job code number	Sample size
ABOVE GROUND--Continued		
Lampman	385	11
Refuse truck driver	386	11
Scalper screen operator	388	4
Stripping shovel operator	391	1
Tipple operator	392	12
Carpenter	394	11
SUPERVISORY AND STAFF		
Master electrician	402	11
Master mechanic	404	2
Dust sampler	414	4
Maintenance foreman	418	14
Surveyor	423	2
Assistant mine foreman	430	25
Mine foreman	449	16
Engineer	456	5
Fire boss	462	14
Inspector	464	4
Superintendent	481	7
Outside foreman	489	15
Preparation plant foreman	494	7
Safety director	495	2
Timekeeper/clerk	497	10
Nonclassified men		41

APPENDIX B

To determine an employee's Noise Exposure Index under the present standard, equation 3 (page 9) is used. For each modification to the standard, the NEI equation will change. The equation which will be used to compute the NEI for the 90/3 standard is:

$$NEI = \frac{C}{15} \times 2^{\frac{L-105}{3}}$$

The equation which will be used to compute the NEI for the 85/5 standard is:

$$NEI = \frac{C}{15} \times 2^{\frac{L-110}{5}}$$

And finally, the equation which will be used to compute the NEI for the 85/3 standard is:

$$NEI = \frac{C}{15} \times 2^{\frac{L-100}{3}}$$