Comparison of Noise Exposure Measurements Conducted With Sound Level Meters and Noise Dosimeters Under Field Conditions

by

Michael P. Valoski

John P. Seiler

Michael A. Crivaro

and

George Durkt

Informational Report Number 1230

Mine Safety and Health Administration

United States Department of Labor

June 1995

COMPARISON OF NOISE EXPOSURE MEASUREMENTS CONDUCTED WITH SOUND LEVEL METERS AND NOISE DOSIMETERS UNDER FIELD CONDITIONS

by

Michael P. Valoskj[1], John P. Seiler[2], Michael A. Crivaro[3], and George Durkt[4]

ABSTRACT

Occupational noise exposure measurements are usually conducted using a measurement methodology based on sound level meters or noise dosimeters. Various researchers have examined the relative accuracies of these instruments in both laboratory and field studies: however, a paucity of data exists as to their absolute accuracies in relationship to the reference position. The reference position, which is the center of the head with the worker absent, mainly stems from the early laboratory research on damage-risk assessments of noise exposure. Whenever any object enters the sound field, the sound level of the sound field at the measurement location changes. This study makes absolute and relative comparisons between the measuring positions where noise dosimeters and sound level meters are used in assessing noise exposures. This field study concludes that there is no practical difference between the sound levels measured with sound level meters or noise dosimeters as long as the instruments meet type 2 tolerances as defined in the American National Standards Institute standard S1.4. Type 2 instruments are generally specified as having an accuracy of + 2 dBA. In addition, this study corroborates previously reported laboratory studies that were used to formulate Mine Safety and Health Administration policy for the location of the noise dosimeter microphone.

INTRODUCTION

Noise exposures are usually assessed with either a sound level meter or a noise dosimeter depending upon instrument availability or the personal choice of the industrial hygienist or acoustical engineer. The Mine Safety and Health Administration (MSHA) in its noise regulations for coal mining (30 CFR Part 70) and

---

[1]Industrial Hygienist, Physical and Toxic Agents Division, Pittsburgh Safety and Health Technology.

[2]Supervisory Electronics Engineer, Physical and Toxic Agents Division, Pittsburgh Safety and Health Technology Center.

[3]Physicist, Physical and Toxic Agents Division, Pittsburgh Safety and Health Technology Center.

[4]1ndustrial Hygienist, Physical and Toxic Agents Division, Pittsburgh Safety and Health Technology Center.

metal/nonmetal mining (30 CFR Part 56 and 57) permits the use of either instrument for assessing the noise exposure of miners. The testing and evaluation of noise dosimeters and sound level meters has shown that both types of instruments accurately measure the sound level of a sound field (l-8). This study assesses which microphone position yields data most compatible to the reference position under realistic field mining conditions. This field study only assessed the microphone locations and not the inherent accuracy of the instruments or sampling methodology.

The reference position, which was adopted for this study, is defined in the scientific literature as the measurement of the undisturbed sound field at the center of the head without a person in the sound field (9,lO). This reference position stems from the early experimental work conducted to determine a damage-risk criteria for noise exposures using temporary threshold shifts. Almost all of this work was conducted under laboratory conditions. Unfortunately, it is not practical to measure noise exposures in the field at the reference position. In addition, anybody or anything that enters the sound field distorts the sound field thus making accurate noise measurements difficult to conduct. Depending upon the microphone location in relation to the object placed in the sound field, the measured sound level can equal, exceed, or be lower than the sound level at the reference position.

This study attempts to determine the relationship between the sound level at the various measurement locations employed when using a noise dosimeter or sound level meter and the reference location. It is clear that the reference noise measurements cannot be conducted simultaneously with the noise dosimeter and/or sound level meter noise measurements since the latter is tied to the worker while the former requires his absence. In the laboratory, the removal from and replacement in the sound field of a worker presents no special problem because the environmental sound field is easily controlled. However, at actual work sites the removing and replacing a worker from the sound field, while maintaining a constant sound field, presents many difficulties. This required a judicious selection of machine-type, operating mode, and instrumentation in order to surmount these difficulties.

Most researchers have concluded that both the sound level meter and noise dosimeter are accurate. The usual experimental design was to compare the results of one methodology with the other (4,7,8,11-14). Simply comparing the results of sound level meter and noise dosimeter measurements only yields information about their relative accuracies; however, little information is obtained about their absolute accuracies in relation to the reference position. If the results agreed, one could argue both measurements were equally accurate. However, if the results disagreed, one could not state definitively which measurement was more accurate. For the most part, noise exposures measured with noise dosimeters have agreed with those measured with sound level meters in steady state sound fields. However, when the sound field fluctuated rapidly, the noise exposures measured with noise dosimeters tended to be higher than those measured with sound level meters (7,8,14). It is difficult to accurately determine the sound level in a fluctuating sound field by simply watching the needle move. Most researchers believe that the noise dosimeter better integrates the contribution of short term fluctuations in the sound field (7,8,14) l

Furthermore, the problem is compounded by the differences in noise exposures resulting from the noise dosimeter microphone location on the body of the worker (14-22). Many locations in and around the ear have been used when assessing noise exposure with noise dosimeters. Researchers have simply used the position which was most convenient for them. In fact, not all researchers have even reported the noise dosimeter microphone position (23-25). In addition, many instrument manufacturers have not specified the optimum location for the microphone when assessing noise exposures. Depending upon the frequency and the position of the noise dosimeter microphone in relationship to the noise source, the difference for a 12.5 millimeter microphone can range up to 16 dB from the reference position under free field conditions and up to 3 dB under reverberant field conditions (16). The magnitude of these differences varies with microphone size (15-20). Microphone positioning is critical for directional high frequency noise sources in a free field. Therefore, it is necessary to specify the position of the noise dosimeter microphone on the worker in order to assure uniformity of measurement results. Likewise, the location of the sound level meter microphone must also be specified (26) l Microphone orientation is also a problem at the reference position.

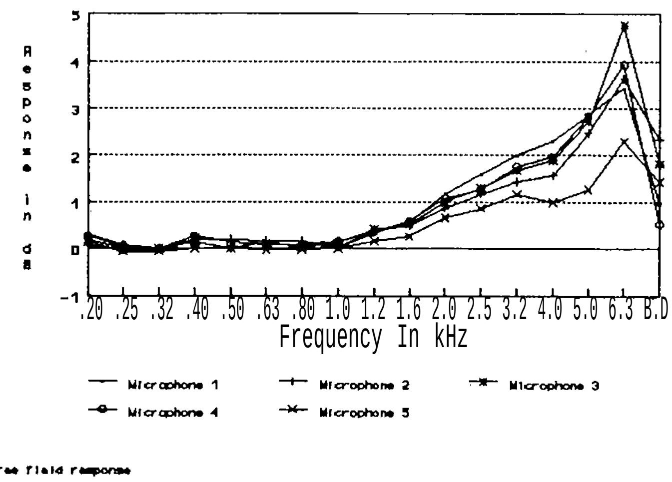
EXPERIMENTAL PROCEDURE

Prior to making any field measurements, the responses of all field microphones were compared to a microphone calibrated by the National Bureau of Standards (NBS)[5] . The linearity and frequency responses of the field microphones were determined. Ceramic microphones (12.5 millimeters in diameter) were used to collect the field data. The frequency responses were conducted in an anechoic chamber which has a lower cutoff frequency of 200 Hertz (Hz). The linearity measurements were conducted in a coupler. In order to minimize the correction factors, the microphones were matched as closely as possible for frequency and linearity responses. Figure 1 shows the free field frequency response of the microphones. At the time of the data collection, most of the noise measuring instrumentation, used by MSHA inspectors for conducting noise

[5]The name of NBS has been changed to the National Institute of Science and Technology.

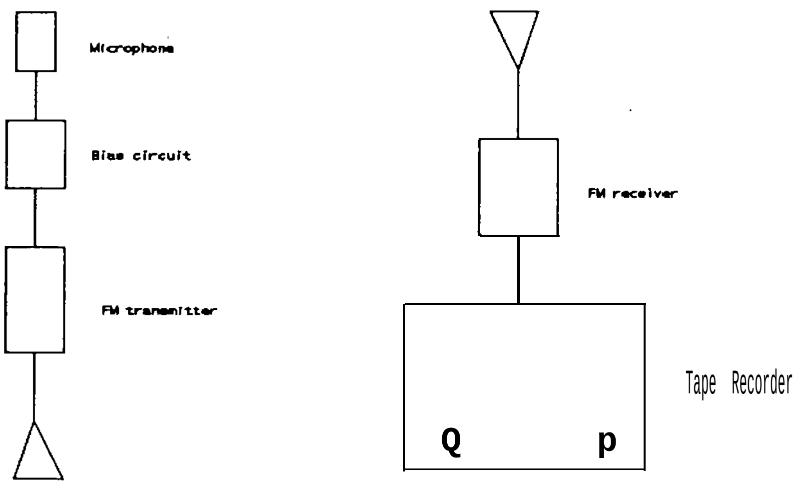
exposure surveys, were equipped with 12.5 millimeter diameter microphones.

Fig. 1 Frequency response of microphones



The measuring system consists of a 12.5 millimeter diameter microphone connected to a frequency modulated (FM) transmitter for transmitting the noise signal. A FM receiver receives the signal and the demodulated audio signal is fed into a tape recorder. At the laboratory, the taped data is analyzed with a real time analyzer. Figure 2 presents the schematic of the measurement system.

Fig. 2 Schematic of instrumentation



In addition to calibrating the field microphones, comprehensive calibration work was conducted on all field instrumentation so that any relationships between the sound level meter position, noise dosimeter position, and the reference position would be strictly due to the positions and not due to differences between the equipment. The laboratory tests, which were conducted in an anechoic chamber, determined both the frequency response and the linearity response for the total component package, including the tape recorder and the FM transmitting and receiving units, of each measuring system.

A sound field was established using the NBS calibrated microphone and then each measuring system was subjected to the field. The fields were varied by frequency and level. The microphone response to the sound field was evaluated based upon the taped data. Thus each measuring system was tested in its entirety.

Any deviations of the measurement system from the ideal response, as determined by comparison with the NBS calibrated microphone, were used to correct the raw data.

All tests were conducted where the worker would normally operate the piece of mining equipment. The mining machines were located where they could be safely operated in a locked-up mode with the worker absent. The locations simulated the environment in which the mining machines operated. For example, mining machines which are operated at the face were withdrawn to a dead end heading or to just behind the face, not to a crosscut or haulage way. The safety of the personnel conducting the environmental noise measurements and the mining machine operator was considered. Also, the sound field generated by the mining machine had to remain constant over time.

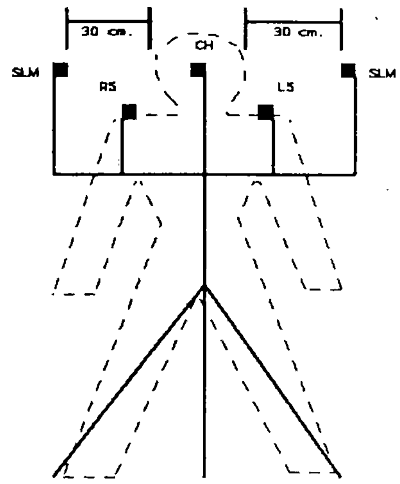
With the mining machine in a locked-up mode and with the operator absent the following series of tests were conducted:

4 Center of head reference measurements, sound level meter position measurements, and right and left shoulder noise dosimeter positions weretaken using a microphone mounted on a tripod equipped with a test fixture so that the microphone diaphragms pointed in a vertically upward direction. Figure 3 presents a schematic of the measurement locations.

b) Field gradient measurements were taken in and around the space which would be occupied by the worker to ascertain the existence of possible spatial differences in the sound field.

c) Sound level meter position measurements were taken by a measurement technician in the vicinity of the space which would be occupied by the worker's head, approximately at ear level, 30 centimeters from the ear. The 12.5 millimeter diameter microphone was attached to

Fig. 3 Microphone positions In undisturbed sound field



the body of a sound level meter (GenRad 1983[6]) thus simulating the geometric effects of an actual sound level meter. Measurements a) and b) above were repeated with the sound level meter and technician present.

With the mining machine in the locked-up mode and with the operator Present the following series of tests were conducted:

d) Dosimeter microphones were attached to the left and right shoulders of the operator with the microphones located at the top of the shoulder, midway between the neck and the end of the shoulder with the microphone pointing in a vertical upward direction. This is the position 'specified by MSHA for inspectors to assess the noise exposure of miners.

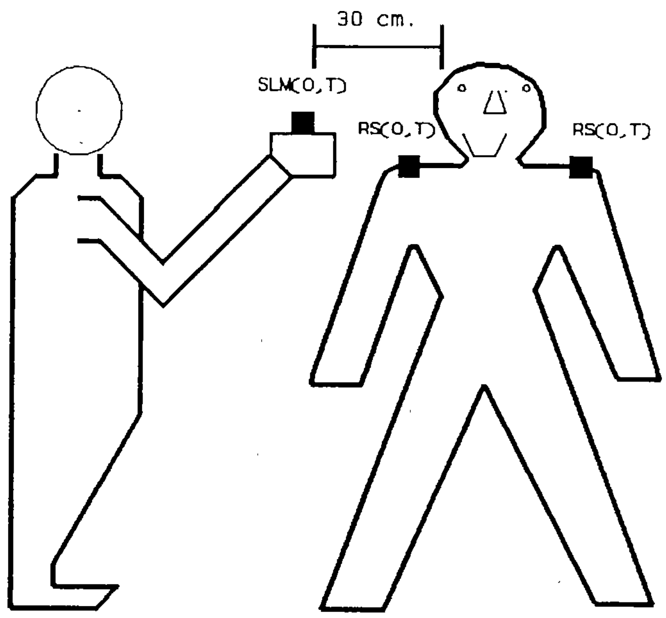
e) The simulated sound level meter was used by a measurement technician in much the same way as an inspector would, sequentially placing the instrument 30 centimeters from the operator's right and left ear. Simultaneous with the evaluation of the sound level meter position, the dosimeter microphone positions on the operator's left and right shoulders were also evaluated. Figure 4 is a schematic of the measurement positions.

Table 1 summarizes the measurement locations for tests a, d, and e. In addition two other tests were conducted. They are:

---

[6]Reference to manufacturers is made to facilitate understanding and does not constitute an endorsement by the Mine Safety and Health Administration.

Fig. 4 Microphone positions on operator



f) A field monitor was used at a remote location (1.8-3.0 meters away from the mining machine) to sample the sound field during the course of the above tests a) through e). If the sound field changed significantly according to the monitor, the entire series of tests, starting with the center of the head position, were repeated.

9) Acoustic calibration test tones were used on all microphones immediately before and after each sequence of tests and recorded on magnetic tape. The acoustic calibration tones were chosen to be at approximately the same sound pressure level as the noise being measured in order that the noise would not overdrive the tape recording system.

All noise measurements, except the calibration test tones which were taped when the equipment was not operating, for each series of tests were completed before the piece of mining equipment was turned off and the mining equipment was restarted prior to the next sequence of tests. A two minute sample was tape recorded for each test in the test series. The test sequence was conducted in triplicate on each machine.

DATA ANALYSIS

The field monitor data were analyzed on a Bruel and Kjaer Type 2307 chart recorder which presents the level versus time data.

Also, for each test a frequency spectrum was obtained using a GenRad model 1995 integrating real time analyzer. Substantial changes to either the A-weighted sound level or frequency spectrum would invalidate the entire series of tests. Fortunately, this did not occur.

All taped data were analyzed using the integrating real time analyzer. An integration time of approximately 120 seconds was used. The fairly long integration time was chosen to minimize the effects of any minor fluctuations in the sound field. All frequency spectra were in third octave bands from 200 to 8000 Hz. In order to simplify drawing conclusions, the third octave band frequency spectra were converted to A-weighted sound levels. All conclusions are based upon the A-weighted sound levels.

RESULTS

Table 2 presents the mining machines selected and location where the mining machine was used at a mine. The mining machines were chosen so that they comprised equipment normally found at strip mines, underground mines, and preparation plants. The equipment surveyed is not intended to be a representative or a random sample of mining equipment.

Table 3 presents the corrected A-weighted sound levels at the selected positions for each piece of mining equipment. Because of environmental constraints, it was not always possible for the technician to measure the sound level on both sides of the worker in the sound field. Normally, a mine inspector would measure the sound level on the side of the miners which is exposed to the highest sound levels. The results for the sound level meter position are either the highest sound level measured at the two possible sound level meter positions or the sound level at the one sound level meter position which could be measured safely by the measurement technician [SLM(O,T)]. The A-weighted sound level at the reference position was subtracted from the A-weighted sound level at each position and this information is presented in table 4. Negative differences result from the reference position having a higher sound level than the measured position.

The sound levels with the worker absent are presented in table 5 with table 6 presenting the differences from the reference position. Table 7 summarizes the data in table 6.

Table 8 presents data similar to table 3 except the sound levels are for the most and least exposed ear. As with the previous data, data were collected for only the worker and both the worker and measurement technician in the sound field. HMS is the highest sound level with only the worker in the sound field and LMS is the lowest. HBS is the highest sound level when both the worker and measurement technician were in the sound field and LBS is the lowest.

Table 9 presents data for the shoulder from which the sound level meter position was located and compares the A-weighted sound levels at the sound level meter position with the dosimeter position on the same shoulder. Table 10 summarizes the data in table 9 by the location of the mining machinery.

DISCUSSION

Table 11 summarizes the results of the measurements at the various positions in relationship to the reference position for the surveyed mining equipment. The measurements on the operator of the track mounted drill showed the largest deviation from the reference position with the locomotive showing the second largest deviation. For both of these pieces of mining equipment the measured sound level at the selected positions was less than the sound level measured at the reference position. Comparing the positions in the undisturbed sound field with the measurements on the worker showed that the deviation from the reference position was less for the undisturbed sound field than for when the worker was in the sound field.

In order to explain the relatively large differences, the third octave band frequency spectra were examined because free field errors for microphone placement are highest for high frequency sound. Only the track mounted drill had substantial energy in the high frequencies.

There are two possible reasons that the track mounted drill deviated so measurably from the reference position. First, the clothes of the miner and/or measurement technician would absorb the high frequency noise, thereby reducing the sound level as measured by a noise dosimeter or sound level meter. Secondly, any barrier (e.g.,the miner's head) would reduce the sound level as measured with a noise dosimeter or sound level meter in the shadow zone. It is believed that the effect of absorption probably exceeds the barrier effect because the sound fields were fairly uniform and the sound level was lower than the undisturbed sound field when measured on both shoulders of the worker. No explanation can be offered as to why the locomotive deviated so much from the reference position.

Experimental variability resulted in large standard deviations. The large standard deviations complicate the drawing of conclusions based upon the data.

Table 12 summarizes the results based upon the equipment location at the mines. Mostly, the average measured sound level was within 2 dBA of the sound level at the reference position, except for the sound level meter position when measuring noise underground. This deviation is attributed mainly to the results obtained measuring the sound levels of the track mounted drill. Deleting the track mounted drill from the underground equipment greatly reduces the deviation from the reference. The reported accuracy of measuring sound levels with sound level meters across brands and observers is within 2 dBA.(6) The findings of this experiment are consistent with the reported results.

Table 12 shows that on the average, across all measured mining machinery, the sound levels measured on the worker are lower than the sound levels measured at the reference position, except for the strip mining occupations. This implies that the noise exposures measured with noise dosimeters tend to underestimate the noise exposure of a worker in reference to damage-risk assessment based upon temporary threshold shifts.

When the noise exposure is measured at the sound level meter position by a measuring technician, the measured noise exposure tends to be lower than the noise exposure as measured with a noise dosimeter. The situation with the sound level meter is more deleterious than with the noise dosimeter. The track mounted drill is the exception.

A one way analysis of variance (ANOVA) was conducted to determine if the differences were statistically significant.(27) Statistically significant differences were found between the measurement positions and the reference position at the 95 percent confidence level. Because the track mounted drill had substantially different frequency spectra and it is difficult to accurately measure high frequency noise, it was deleted from the analysis. The differences remained statistically significant when the track mounted drill data were deleted from the ANOVA.

Because the ANOVA found at least one statistically significant difference, a Fisher's Least Significant difference test was conducted to find which differences were significant.(27) Again the track mounted drill was deleted from this analysis. Table 13 summarizes the findings. Basically, the differences between the reference position and the sound level meter position and between the sound level meter position and the left shoulder noise dosimeter position were statistically significant.

In order to explain the statistically significant differences between the reference position and the sound level meter position, the differences between the measurement positions in the undisturbed sound field (nobody in the sound field) and the reference position were tested for statistical significance at the 95 percent confidence level. As with the data when the worker, and when the worker and measurement technician were in the sound field, the Fisher's Least Significant Difference test was conducted. Statistically significant differences were found between the reference position and every measurement position. Therefore, the inclusion of a worker in the sound field reduced the gradient across the microphone positions as compared to the undisturbed sound field.

In addition, the sound levels at the noise dosimeter position and sound level meter position in the undisturbed sound field were compared to the same positions when the miner or the miner and measurement technician were in the sound field. ANOVA showed that there was no statistically significant difference between the sound levels with and without the people in the sound field. Therefore, the inclusion of people in the sound field did not appreciably change the sound field at individual measurement locations, even though the gradient across the microphone positions was reduced.

Many regulations, which require the use of instrumentation which meets American National Standards Institute Type 2 tolerances as defined in S1.4, state that the results are accurate to within 2 dBA. Table 14 presents the percent of measurements for each classification of mining machinery which lie within the selected tolerances of the reference position. The most favorable position to measure the noise exposure of a worker appears to be the noise dosimeter position. Approximately 65% of the noise dosimeter location measurements fell within 2 dBA of the reference position. Both shoulder locations appeared to be equally accurate.

Also, an analysis was conducted using the highest sound level at each instrument microphone location. The track mounted drill was deleted because its frequency spectrum differed greatly from the other pieces of equipment. ANOVA demonstrated that statistically significant differences at the 95 percent confidence level existed between the microphone locations. Fisher's Least Significant Difference Test identified the significant differences which are presented in table 15. The highest sound level measured at the noise dosimeter position agrees very well with the sound level measured at the reference position.

CONCLUSIONS

This study has determined that there is no practical difference between the occupational sound levels measured with sound level meters and noise dosimeters as long as type 2 instrumentation is used. Type 2 instrumentation is generally specified as having an accuracy of +2 dBA.

The noise dosimeter position and the sound level meter position tend to have lower sound levels than the reference position. Admittedly, the difference is small compared to the standard deviation. The differences between the reference position and the sound level meter position and between the left shoulder noise dosimeter position and the sound level meter position were statistically significant. The sound level meter position tended to be lower than the dosimeter position.

No statistically significant difference was found between the noise dosimeter position on either the left or right shoulder. Both shoulder locations appear to be equally accurate.

Statistically significant differences were found between the reference position and the various measurement positions in the undisturbed sound field. This indicates that a noise gradient exists between the microphone positions. Unfortunately, the statistically significant differences between the noise dosimeter microphone locations and the sound level meter microphone locations cannot be explained as simply noise gradient effects.

The addition of a miner, or a miner and the measurement technician, into the sound field did not cause a statistically significant change in the sound levels at the various measurement locations. Therefore, the sound field did not change appreciably with the inclusion of people although a miner or a miner and measurement technician in the sound field lessened the gradient across the microphone positions.

By choosing to locate the noise dosimeter microphone on the shoulder exposed to the highest sound level, close agreement with the reference position was obtained. This indicates that prior knowledge of the most exposed shoulder can improve the accuracy of the noise exposure measurements when using noise dosimeters.

In addition, this field study corroborates the laboratory studies that formed the basis for MSHA's selection of a noise dosimeter microphone measurement location. MSHA's noise dosimeter microphone measurement location is at the top of the shoulder, midway between the neck and end of the shoulder with the microphone pointing in a vertical upward direction.

Table 1. Summary of test measurement locations and conditions

Location	Undisturbed	Condition Operator only	Operator and technican
Center of head	CH	NA	NA
Right dosimeter	RS	RS (0)	RS(O,T)
Left dosimeter	LS	LS(0)	LS(O,T)
Sound level meter	SLIM	SLM(O)	SLM(O,T)

Table 2. Mining machine tested and location of the mining machine

Mining Machine	Manufacturer	Model	Location
Track mounted drill	Ingersoll Rand	ECM 350	Underground
Load-haul-dump	Eimco	912D	Underground
scoop	Acme	SlDl	Underground
Locomotive	Plymouth	TMDR-22	Underground
Loading machine	JoY	14B4	Underground
Undercutter	JoY	10RU	Underground
Roof bolter	J.S. Fletcher	SDBA13	Underground
Crane	Grove	RT 522	Surface
Load-haul-dump	Wagner	ST5A	Surface
Picking table			Plant
Pumps			Plant

Table 3. A-weighted sound levels at the measurement position for each piece of mining equipment

Mining Equipment	Test	CH	RS(0)	LS(0)	RS(0, T)	LS (0, T)	Su(0.T)
Track mounted drill	1	98.1	91.8:	93.1	91.6	93.4	94.4
	2	96.6	93.2	93.4	92.5	93.3	91.1
	3	96.7	91.6	90.9	90.6	91.0	93.1
LHD (underground)	1	84.3	84.4	83.0	84.4	82.3	83.6
	2	82.1	84.2	83.0	83.6	82.6	83.0
	3	85.0	84.3	84.9	84.3	83.9	83.7
Scoop	1	94.5	93.9	92.9	93.8	93.7	92.3
	2	93.9	94.1	92.3	94.2	92.1	92.3
	3	93.3	94.1	92.9	94.2	93.0	92.5
Locomotive	1	97.3	94.9	94.0	93.5	93.7	93.1
	2	98.9	96.8	92.2	97.0	9i.3	96.3
	3	97.2	94.1	93.3	93.8	y93.9	94.1
Loading machine	1	112.1	109.2	110.5	108.3	110.9	107.8
	2	112.9	109.4	112.0	109.3	112.1	107.6
	3	111.9	110.0	111.0	109.9	110.9	108.9
Undercutter	1	99.7	102.2	101.2	102.7	101.1	99.8
	2	104.1	102.9	104.9	103.1	106.1	101.1
	3	103.8	104.4	103.9	104.5	103.6	101.6
Roof bolter	1	91.8	95.7	94.6	94.9	93.4	90.0
	2	90.5	91.0	94.9	91.0	91.8	89.2
	3	91.9	91.8	93.0	91.8	91.5	90.9
Crane	1	84.8	84.6	89.8	85.0	88.7	85.7
	2	84.4	84.8	86.6	85.1	86.3	87.5
	3	84.2	84.3	87.9	84.0	88.5	87.6
MD (surface)	1	97.4	98.6	97.4	97.9	97.3	97.8
	2	97.8	99.0	98.2	98.5	97.6	97.8
	3	97.6	99.8	98.0	99.4	97.6	97.4
Picking table	1	99.1	98.7	99.3	97.7	98.6	97.6
	2	99.9	97.9	98.9	96.8	97.7	97.2
	3	99.0	98.7	100.1	97.6	99.2	97.2
Pumps	1	95.5	94.9	95.4	94.5	95.1	93.6
	2	95.4	94.0	94.3	93.5	94.3	93.1
	3	95.7	94.2	94.8	94.0	94.6	93.6

Table 4. The difference from the reference position to the measurement position for each piece of mining equipment

Mining Equipment	Test	Measurement position - reference position RS(02	LS(O)	RS(O,T)	LS(O,T)	SLM(O,T)
Track mounted drill	1	-6.3	-5.0	-6.5	-4.7	-3.7
	2	-3.4	-3.2	-4.1	-3.3	-5.5
	3	-5.1	-5.8	-6.1	-5.7	-3.6
LHD (underground)	1	0.1	-1.3	0.1	-2.0	-0.7
	2	2.1	0.9	1.5	0.5	0.9
	3	-0.7	-0.1	-0.7	-1.1	-1.3
scoop	1	-0.6	-1.6	-0.7	-0.8	-2.2
	2	0.2	-1.6	0.3	-1.8	-1.6
	3	0.8	-0.4	0.9	-0.3	-0.8
Locomotive	1	-2.4	-3.3	-3.8	-3.6	-4.2
	2	-2.1	-6.7	-1.9	-6.6	-2.6
	3	-3.1	-3.9	-3.4	-3.3	-3.1
Loading machine	1	-2.9	-1.6	-3.8	-1.2	-4.3
	2	-3.5	-0.9	-3.6	-0.8	-5.3
	3	-1.9	-0.9	-2.0	-1.0	-3.0
Undercutter	1	2.5	1.5	3.0	1.4	0.1
	2	-1.2	0.8	-1.0	2.0	-3.0
	3	0.6	0.1	0.7	-0.2	-2.2
Roof bolter	1	3.9	2.8	3.1	1.6	-1.8
	2	0.5	4.4	0.5	1.3	-1.3
	3	-0.1	1.1	-0.1	-0.4	-1.0
Crane	1	-0.2	5.0	0.2	3.9	0.9
	2	0.4	2.2	0.7	1.9	3.1
	3	0.1	3.7	-0.2	4.3	3.4
LHD (surface)	1	1.2	0.0	0.5	-0.1	0.4
	2	1.2	0.4	0.7	-0.2	0.0
	3	2.2	0.4	1.8	0.0	-0.2
Picking table	1	-0.4	0.2	-1.4	-0.5	-1.5
	2	-2.0	-1.0	-3.1	-2.2	-2.7
	3	-0.3	1.1	-1.4	0.2	-1.8
Pumps	1	-0.6	-0.1	-1.0	-0.4	-1.9
	2	-1.4	-1.1	-1.9	-1.1	-2.3
	3	-1.5	-0.9	-1.7	-1.1	-2.1

Table 5. A-weighted sound levels at the measurement position for each piece of mining equipment without anyone in the sound field

Mining Equipment	Test	CH	RS	LS	SLM
Track mounted drill	1	98.1	97.0	96.6	97.3
	2	96.6	96.1	97.9	94.8
	3	96.7	98.1	98.6	96.1
LHD (underground)	1	84.3	83.2	82.4	84.0
	2	82.1	83.1	82.0	83.0
	3	85.0	83.4'	83.8	83.2
scoop	1	94.5	94.7	93.8	93.9
	2	93.9	93.7	92.4	93.5
	3	93.3	93.8	92.9	93.3
Locomotive	1	97.3	93.4	95.1	94.4
	2	98.9	95.4	93.6	95.4
	3	97.2	93.4	93.7	94.0
Loading machine	1	112.1	106.8	108.2	108.0
	2	112.9	108.4	108.1	108.8
	3	111.9	109.2	109.7	109.8
Undercutter	1	99.7	99.8	98.3	98.6
	2	104.1	102.0	103.7	101.4
	3	103.8	102.7	101.9	101.9
Roof bolter	1	91.8	93.5	94.4	90.7
	2	90.5	92.1	93.0	92.4
	3	91.9	90.7	92.6	92.3
Crane	1	84.8	84.7	86.8	87.1
	2	84.4	54.9	84.6	87.0
	3	84.2	32.4	85.6	87.2
LHD (surface)	1	97.4	98.0	97.3	97.8
	2	97.8	98.1	97.3	98.3
	3	97.6	97.5	95.6	98.5
Picking table	1	99.1	97.4	98.2	98.5
	2	99.9	97.3	97.7	98.5
	3	99.0	97.4	99.3	97.9
Pumps	1	95.5	95.5	94.7	94.4
	2	95.4	94.2	93.8	93.8
	3	95.7	94.9	95.0	94.9

Table 6. The difference in A-weighted sound levels between the measurement position and the reference position for each piece of mining equipment without anyone in the sound field

Mining Equipment	Test	Measurement position - Reference position RS	Ls	SLM
Track mounted drill	1	-1.1	-1.5	-0.8
	2	-0.5	1.3	-1.8
	3	1.4	1.9	-0.6
LHD (underground)	1	-1.1	-1.9	-0.3
	2	1.0	-0.1	0.9
	3	-1.6	-1.2	-1.8
scoop	1	0.2	-0.7	-0.6
	2	-0.2	-1.5	-0.4
	3	0.5	-0.4	0.0
Locomotive	1	-3.9	-2.2	-2.9
	2	-3.5	-5.3	-3.5
	3	-3.8	-3.5	-3.2
Loading machine	1	-5.3	-3.9	-4.1
	2	-4.5	-4.8	-4.1
	3	-2.7	-2.2	-2.1
Undercutter	1	0.1	-1.4	-1.1
	2	-2.1	-0.4	-2.7
	3	-1.1	-1.9	-1.9
Roof bolter	1	1.7	2.6	-1.1
	2	1.6	2.5	1.9
	3	-1.2	0.7	0.4
Crane	1	-0.1	2.0	2.3
	2	0.5	0.2	3.2
	3	-1.8	1.4	3.0
LHD (surface)	1	0.6	-0.1	0.4
	2	0.3	-0.5	0.5
	3	-0.1	-2.0	0.9
Picking table	1	-1.7	-0.9	-0.6
	2	-2.6	-2.2	-1.4
	3	-1.6	0.3	-1.1
Pumps	1	0.0	-0.8	-1.1
	2	-1.2	-1.6	-1.6
	3	-0.8	-0.7	-0.8

Table 7. The mean difference and standard deviation (s.d.) from the reference position to the measurement position for each piece of mining equipment without anyone in the sound field

Mining Equipment	Test	Measurement position minus reference position RS	LS	SLM
Track mounted drill	mean	-0.1	0.6	-1.1
	s.d.	1.3	1.8	0.6
LHD (underground)	mean	-0.6	-1.1	-0.4
	s.d.	1.4	0.9	1.4
scoop	mean	0.2	-0.9	-0.3
	S.d.	0.4	0.6	0.1
Locomotive	mean	-3.7	-3.7	-3.2
	S.d.	0.2	1.6	0.3
Loading machine	mean	-4.2	-3.6	-3.4
	s.d.	1.3	1.3	1.2
Undercutter	mean	-1.0	-1.2	-1.9
	s.d.	1.1	0.8	0.8
Roof bolter	mean	0.7	1.9	0.4
	s.d.	1.6	1.1	1.5
Crane	mean	-0.5	1.2	2.8
	s.d.	1.2	0.9	0.5
LHD (surface)	mean	0.3	-0.9	0.6
	s.d.	0.4	1.0	0.3
Picking table	mean	-2.0	-0.9	-1.0
	s.d.	0.6	1.3	0.4
Pumps	mean	-0.7	-1.0	-1.2
	s.d.	0.6	0.5	0.4

Table 8. A-weighted sound levels at the measurement position for each piece of mining equipment

Mining Equipment	Test	CH	HMS	L&E	HBS	LBS	SLM[O.TL
Track mounted drill	1	98.1	93.1	91.8	93.4	91.6	94.4
	2	96.6	93.4	93.2	93.3	92.5	91.1
	3	96.7	91.6	90.9	91.0	90.6	93.1
LHD (underground)	1	84.3	84.4	83.0	84.4	82.3	83.6
	2	82.1	84.2	83.0	83.6	82.6	83.0
	3	85.0	84.9	84.3	84.3	83.9	83.7
scoop	1	94.5	93.9	92.9	93.8	93.7	92.3
	2	93.9	94.1	92.3	94.2	92.1	92.3
	3	93.3	94.1	92.9	94.2	93.0	92.5
Locomotive	1	97.3	94.9	94.0	93.7	93.5	93.1
	2	98.9	96.8	92.2	97.0	92.3	96.3
	3	97.2	94.1	93.3	93.9	93.8	94.1
Loading machine	:x	112.1	110.5	109.2	110.9	108.3	107.8
	2	112.9	112.0	109.4	112.1	109.3	107.6
	3	111.9	111.0	110.0	110.9	109.9	108.9
Undercutter	1	99.7	102.2	101.2	102.7	101.1	99.8
	2	104.1	104.9	102.9	106.1	103.1	101.1
	3	103.8	104.4	103.9	104.5	103.6	101.6
Roof bolter	1	91.8	95.7	94.6	94.9	93.4	90.0
	2	90.5	94.9	91.0	91.8	91.0	89.2
	3	91.9	93.0	91.8	91.8	91.5	90.9
Crane	1	84.8	89.8	84.6	88.7	85.0	85.7
	2	84.4	86.6	84.8	86.3	85.1	87.5
	3	84.2	87.9	84.3	88.5	84.0	87.6
LHD (surface)	1	97.4	98.6	97.4	97.9	97.3	97.8
	2	97.8	99.0	98.2	98.5	97.6	97.8
	3	97.6	99.8	98.0	99.4	97.6	97.4
Picking table	1	99.1	99.3	98.7	98.6	97.7	97.6
	2	99.9	98.9	97.9	97.7	96.8	97.2
	3	99.0	100.1	98.7	99.2	97.6	97.2
Pumps	1	95.5	95.4	94.9	95.1	94.5	93.6
	2	95.4	94.3	94.0	94.3	93.5	93.1
	3	95.7	94.8	94.2	94.6	94.0	93.6

Table 9. The difference in A-weighted sound levels for the dosimeter position from the sound level meter position when both measurements were on the same side of the operator of the mining equipment

Mining Equipment	Test	SLM Shoulder	SLM Position	Dosimeter Position	Difference
Track mounted drill	1	left	94.4	93.1	1.3
	2	left	91.1	93.4	-2.3
	3	left	93.1	90.9	2.2
LHD (underground)	1	left	83.6	83.0	0.6
	2	left	83.0	83.0	0.0
	3	left	83.7	84.9	-1.2
Scoop	1	left	92.3	92.9	-0.6
	2	left	92.3	92.3	0.0
	3	left	92.5	92.9	-0.4
Locomotive	1	right	93.1	94.9	-1.8
	2	right	96.3	96.8	-0.5
	3	right	94.1	94.1	0.0
Loading machine	1	right	107.8	109.2	-1.4
	2	right	107.6	109.4	-1.8
	3	right	108.9	110.0	-1.1
Undercutter	1	left	99.8	101.2	-2.4
	2	left	101.1	104.9	-3.8
	3	left	101.6	103.9	-2.3
Roof bolter	1	left	90.0	94.6	-4.6
	2	left	89.2	94.9	-5.7
	3	left	90.9	93.0	-2.1
Crane	1	left	85.7	89.8	-4.1
	2	left	87.5	86.6	0.9
	3	left	87.6	87.9	-0.3
LHD (surface)	1	right	97.8	98.6	-0.8
	2	right	97.8	99.0	-1.2
	3	right	97.4	99.8	-2.4
Picking table	1	left	97.6	99.3	-1.7
	2	left	97.2	98.9	-1.7
	3	left	97.2	100.1	-2.9
Pumps	1	right	93.6	94.9	-1.3
	2	right	93.1	94.0	-0.9
	3	right	93.6	94.2	-0.6

Table 10. The mean and standard deviation of the dosimeter position from the sound level meter position

Location	Test	Difference
Underground	Mean	-1.3
	s.d.	1.9
Drills (underground)	Mean	0.4
	s.d.	2.4
Underground (deleting drills)	Mean	-1.6
	s.d.	1.7
Surface	Mean	-1.3
	s.d.	1.7
Preparation plant	Mean	-1.5
	s.d.	0.8
All	Mean	-1.4
	s.d.	1.7

Table 11. The mean difference and standard deviation (s.d.) from the reference position to the measurement position for each piece of mining equipment

		Measurement position - reference position				
Minins Equipment	Test	RS(0)	LS (0)	RS(0,T)	LS(O,TL	SLM(O,T)
Track mounted drill	mean	-4.9	-4.7	-5.6	-4.6	-4.3
	s.d.	1.4	1.3	1.3	1.2	1.1
LHD (underground)	mean	0.5	-0.2	0.3	-0.9	-0.4
	s.d.	1.4	1.1	1.1	1.3	1.1
scoop	mean	0.1	-1.2	0.2	-1.0	-1.5
	s.d.	0.7	0.7	0.8	0.8	0.7
Locomotive	mean	-2.5	-4.6	-3.0	-4.5	-3.3
	s.d.	0.5	l L-.8	1.0	1.8	0.8
Loading machine	mean	-2.8	-1.1	-3.1	-1.0	-4.2
	s.d.	0.8	0.4	1.0	0.2	1.2
Undercutter	mean	0.6	0.8	0.9	1.1	-1.7
	s.d.	1.9	0.7	2.0	1.1	1.6
Roof bolter	mean	1.4	2.8	1.2	0.8	-1.4
	s.d.	2.2	1.7	1.7	1.1	0.4
Crane	mean	0.1	3.6	0.2	3.4	2.5
	s.d.	0.3	1.4	0.5	1.3	1.4
LHD (surface)	mean	1.5	0.3	1.0	-0.1	0.1
	s.d.	0.6	0.2	0.7	0.1	0.3
Picking table	mean	-0.9	0.1	-2.0	-0.8	-2.0
	s.d.	1.0	1.1	1.0	1.2	0.6
Pumps	mean	-1.2	-0.7	-1.5	-0.9	-2.1
	s.d.	0.5	0.5	0.5	0.4	0.2

Table 12. The mean difference and standard deviation (s.d.) from the reference position to the measurement position for mining equipment by location

Location	Test	Measurement position - reference position				
		RS(0)	LS(0)	RS(O,T)	LS(0,T)	SL,M(O,T)
Underground	mean	-1.1	-1.2	-1.3	-1.4	-2.4
	s.d.	2.5	2.8	2.7	2.4	1.7
Drills (underground)	mean	-4.9	-4.7	-5.6	-4.6	-4.3
	s.d.	1.4	1.3	1.3	1.2	1.1
Underground (deleting drills)	mean	-0.4	-0.6	-0.6	-0.9	-2.1
	s.d.	2.0	2.5	2.2	2.1	1.6
Surface	mean	0.8	2.0	0.6	1.6	1.3
	s.d.	0.9	2.1	0.7	2.1	1.6
Preparation plant	mean	-1.0	-0.3	-1.8	-0.8	-2.0
	s.d.	0.7	0.9	0.7	0.8	0.4
All	mean	-0.7	-0.4	-1.0	-0.8	-1.7
	s.d.	2.2	2.6	2.3	2.4	2.0

Table 13. Summary of the Fisher's Least Significant Difference Test for microphone location

Measurement Microphone Location	Comparison microphone location				
	RS(0)	LS(O)	RS(0,T)	LS(0, T)	SLM (0, T)
C H	n sig[A]	n sig	n sig	n sig	sig[b]
RS (0)		n sig	n sig	n sig	n sig
LS (0)			n sig	n sig	s i g
RS(O,T)				n sig	n sig
LS (O,T)					n sig

[A] Not statistically significant at the 95 percent confidence level.
[B] Statistically significant at the 95 percent confidence level.

Table 14. The percent of measurements which were within selected tolerances of the reference position

Location	Tolerance in dba	RS (0)	LS(0)	RS(0,T)	LS(0,T)	SLM(O,T)
			Measurement position			
Underground	1	38.1	33.3	42.9	33.3	23.8
	2	47.6	61.9	57.1	71.4	42.9
	3	71.4	66.7	61.9	71.4	66.7
Drills (underground)	1	00.0	00.0	00.0	00.0	00.0
	2	00.0	00.0	00.0	00.0	00.0
	3	00.0	00.0	00.0	00.0	00.0
Underground (deleting drills)	1	44.4	38.9	50.0	38.9	27.8
	2	55.6	72.2	66.7	83.3	50.0
	3	83.3	77.8	72.2	83.3	77.8
Surface	1	50.0	50.0	83.3	50.0	66.7
	2	83.3	50.0	100.0	66.7	66.7
	3	100.0	66.7	100.0	66.7	66.7
Preparation plant	1	50.0	66.7	16.7	50.0	00.0
	2	100.0	100.0	83.3	100.0	50.0
	3	100.0	100.0	83.3	100.0	100.0
All	1	42.4	42.4	45.5	39.4	27.3
	2	63.6	66.7	69.7	75.8	48.5
	3	81.8	.72.7	72.7	75.8	72.7

Table 2. Summary of the Fisher's Least Significant Difference Test for microphone location

Measurement Microphone Location	Comparison microphone location				
	HMS	LMS	HBS	LBS	SLM(O,T)
CH	n sig[A]	sig[B]	n sig	sig	sig
HMS		sig	n sig	sig	sig
LMS			sig	n sig	n sig
HBS				sig	sig
LBS					n sig

[A] Not statistically significant at the 95 percent confidence level.
[B] Statistically significant at the 95 percent confidence level.

REFERENCES

1. Fortner, Ronnie L. and Nick Blaskovich, Jr. A Report on the Performance of Personal Noise Dosimeters, U.S. Department of Health, Education, and Welfare. DHEW (NIOSH) Publication No. 78-186, September 1978.

2. Stewart, Kenneth C. and Timothy Y. Yen Noise Dosimeter Performance, U.S. Department of Interior, Bureau of Mines, Report of Investigations RI 7876, 1974.

3. Yen, Timothy Y. and Kenneth C. Stewart Noise Dosimeter Performance-A Second Evaluation, U.S. Department of Interior, Bureau of Mines, Information Circular 8754, 1977.

4. Redmond, Gerald W. Hearing Loss in Steelworkers and Daily Noise Dose as Measured by the Noise Dosimeter - A Longitudinal Study, Doctoral Dissertation, University of Pittsburgh, Graduate School of Public Health, 1979.

5. Leasure, Jr., William A., Ronald L. Fisher, and Marilyn A. Cadoff Evaluation of Commercial Integrating-Type Noise Exposure Meters, U.S. Department of Commerce, National Bureau of Standards, Final Report NBSIR 73-417, December 1973.

6. Behar, A., A. Domenech, R. Moncaglieri, M. A. Bustos, and E. Dominguez Accuracy in the Measurement of Sound Levels in situ with Sound Level Meters, Applied Acoustics, Vol. 8, pp. 67-69, 1975.

7. Shackleton, S. and M. D. ,Piney A Comparison of Two Methods of Measuring Personal Noise Exposure, Annuals of Occupational Hygiene, Vol. 28, No. 4, pp. 373-390, 1984.

8. Jones, C. 0. and R. M. Howie Investigations of Personal Noise Dosimeters for Use in Coalmines, Annuals of Occupational Hygiene, Vol. 25, No. 3, pp. 261-277, 1982.

9. International Organization for Standardization (ISO) ,Acoustics - Determination of Occupational Noise Exposure and Estimation of Noise-Induc&d Hearing Loss Impairment, ISO/DIS 1999, 1982.

10. European Economic Community (EEC) Council Directive on the protection of workers from the risks related to exposure to noise at work (86/188/EEC), May 12, 1986.

11. Dotti, Norm Coal Mine Noise Dosimeter Evaluation, National Loss Control Service Corporation, Long Grove Illinois 60049, 1978.

12. Pierce, F. D. and R. D. R. Parker A Field Evaluation of Noise Measuring Instruments, American Industrial Hygiene Association Journal, Vol. 44, No. 9, pp. 665-670, September 1983.

13. McCormick, G. Personal Noise Exposure Part 3. Calculation of Noise Exposure in the Coal Mining Industry, Colliery Guardian, Vol. 235, No. 12, pp. 488-491, December 1987.

14. Hansen, Doan J., W. Gary Adams, and Robert A. Hochberg Comparison of Sampling Used During a Machine Shop Noise Survey, Applied Industrial Hygiene, Vol. 4, No. 3, pp. 75-80, March 1989.

15. Burks, J. Alton An Investigation of the Effects of the Head/Torso System on the Response of a Body-Mounted Microphone in Diffuse and Free Field, Doctoral Dissertation, University of Pittsburgh, Graduate School of Public Health, 1980.

16. Seiler, John P. Microphone Placement Factors for One-Half Inch Diameter Microphones, Masters Thesis, University of Pittsburgh, Graduate School of Public Health, 1982.

17. Redwood, Richard Anthony Investigation of the Errors in Noise Dose Measurements Caused by Wearing the Microphone, Masters Dissertation, University of Southampton, Institute of Sound and Vibration, 1971.

18. Marraccini, Leonard C. Optimum Microphone Placement for the Personal Noise Dosimeter, NoisExpo, Chicago, Illinois, June 4-6, 1974.

19. Muldoon, Terry L. Response Variations of a Microphone Worn on the Human Body, U.S. Department of the Interior, Bureau of Mines, Report of Investigations 7810, 1973.

20. Donovan, Jerry New Personal Dosimeters, NoisExpo, Chicago, Illinois, June 4-6, 1974.:.

21. Young, Robert W. Average Build-Up of Sound Pressure Level on a Person in an Ordinary Room, Presented at the Meeting of the Acoustical Society of America, St. Louis, MO, November 5, 1974. (Journal of the Acoustical Society of America, Vol. 56, p. S5, 1974).

22. Erlandsson, B., H. Hakansson, A. Ivarsson, and P. Nilsson Comparison between Stationary and Personal Noise Dose Measuring Systems, Acta Otolaryngology, Supplement, Vol. 360, pp. 105-108, 1979.

23. Ambasankaran, M., D. Brahmachari, V. K. Chadda, M.G. Phadnis, A. Raju, A. Ramamurthy. and V. R. Shah Occupational Noise Exposure and Hearing Level, American Industrial Hygiene Association Journal, Vol. 42, No. 7, pp. 551-555, July 1981.

24. McMahon, Kevin J. and Patrick E. McManus Occupational Noise Exposure in the Printing Industry, American Industrial Hygiene Association Journal, Vol. 49, No. 1, pp. 34-37, January 1988.

25. Deschant, Darrell L. The Efficacy of Hearing Conservation Programs in the Mining Industry, Doctoral Dissertation, Colorado State University, Department of Microbiology and Environmental Health, 1986.

26. Willson, Robert D. Personal Noise Dosimeter, Presented at the American Industrial Hygiene Association Conference, San Francisco, CA, May 17, 1972.

27. Dowdy, Shirley and Stanley Wearden Statistics for Research John Wiley & Sons, Inc. New York, New York, 1983.