Evaluation of Potential Noise Hazards to Mechanics and 911 Dispatchers at a Fire Department

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Health Hazard Evaluation Report
HETA 2007-0235-3064
Anchorage Fire Department
Anchorage, Alaska
June 2008

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention

NIOSH *National Institute for Occupational Safety and Health*

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Abbreviations

"	inch
AFD	Anchorage Fire Department
AL	Action level
B&K	Brüel & Kjær
CFR	Code of Federal Regulations
dB	Decibels
dBA	Decibels, A-weighted scale
HCP	Hearing conservation program
HHE	Health hazard evaluation
HPD	Hearing protection devices
Hz	Hertz
KEMAR	Knowles Electronic Mannequin for Acoustic Research
kHz	Kilohertz
Leq	Equivalent continuous noise level
Lpeak	Peak noise level
MP3	Moving Picture Experts Group layer 3
mV	Millivolt
NAICS	North American Industry Classification System
NCB	Balanced noise criteria
NIHL	Noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
REL	Recommended exposure limit
SPL	Sound pressure level
TWA	Time-weighted average
V	Volt

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation at the Anchorage Fire Department (AFD) in Anchorage, Alaska. The department submitted the request because its 911 dispatchers were concerned about feedback noise from communication headsets, and because it wanted to know if its mechanics should be in a hearing conservation program. A NIOSH investigator conducted an investigation at the AFD facilities in May 2007.

What NIOSH Did

- We monitored mechanics' noise exposure.
- We measured noise levels in the dispatch area.
- We interviewed 911 dispatchers.
- We looked at worker injury and illness records for trauma to the ears.
- We looked at 911 dispatchers' hearing test results for signs of hearing loss.
- We tested 911 dispatchers' headsets for sound quality and response.
- We studied samples of feedback noise heard by 911 dispatchers.

What NIOSH Found

- Mechanics' exposure to noise was above the NIOSH recommended exposure limit.
- Most of the mechanics' noise exposures occurred over a short time period.
- The potential for harm to 911 dispatchers' hearing was low although the feedback noise was low.

What AFD Managers Can Do

- Enroll mechanics in a hearing conservation program.
- Train employees on the proper use of radios.
- Consider building a communications center just for the 911 dispatchers, or modify the existing center to meet recommended noise criteria for buildings.

What AFD Employees Can Do

- Mechanics should wear ear plugs or ear muffs when working with loud equipment.
- 911 dispatchers and mechanics should take part in AFD's health and safety committee.

Summary

AFD mechanics are exposed to hazardous levels of noise, and should be enrolled in a hearing conservation program. AFD should take steps to reduce the feedback noise 911 dispatchers hear through their headsets.

On April 24, 2007, NIOSH received an HHE request from AFD management to assess whether the fire department's mechanics should be enrolled in an HCP, and to determine if feedback noise (or "squeal") that the 911 dispatchers heard through their headsets was hazardous to their hearing.

A NIOSH investigator visited the site to collect full-shift noise exposures on the mechanics, to interview the 911 dispatchers about their work environment, to measure noise levels in the dispatch area, and to review employee records pertinent to noise and hearing loss. NIOSH investigators also purchased headsets similar in manufacturer and model to those worn by AFD dispatchers for laboratory analysis in-house, and tested actual feedback noise recordings provided by the AFD.

Five AFD mechanics provided eight full-shift measures over two days. Five measures exceeded the NIOSH REL. One measure exceeded the OSHA AL; none exceeded the OSHA PEL. The primary source of noise exposure for the mechanics was a ½" impactor gun used to change tires on fire trucks. Of the seventeen 911 dispatchers who were present at the time of the NIOSH evaluation, 15 were interviewed. Nearly all expressed dissatisfaction with their work environment. Their main concerns were the temperatures in the work area (either too cold or too hot), uncomfortable chairs, and the distracting background noise (from visitors, alarms, etc.).

When compared to noise criterion curves, noise levels in the dispatch area were higher than recommended for a communications center. The headsets were adequate for their intended purposes, although the H251N had the best linear response between 150 Hz and 2000 Hz and thus provided the best sound quality. Analysis of eight feedback noise recordings produced average noise levels from 68 to 78 dB; the peak sound levels were between 84 and 100 dB. Although average levels were below the NIOSH REL, prolonged exposure to peak sound levels found in the recordings may result in dispatchers developing transient symptoms, such as headache, fatigue, and ringing in the ears, that are associated with exposure to high sound levels.

The high noise levels experienced by AFD mechanics warrant enrollment in a hearing conservation program. Also, AFD management, with employee input, should increase awareness among firefighters and other personnel who use radios of the effect

of feedback noise on the 911 dispatchers. Management should consider either building a communications center designed for communications work or modifying the existing space.

Keywords: NAICS 922160 (Fire protection), feedback noise, 911 dispatchers, mechanics, dosimetry, acoustical mannequin, balanced noise curve, room acoustics, communications cente

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INTRODUCTION

On April 24, 2007, NIOSH received an HHE request from AFD management. The request asked NIOSH to help determine if the fire department's mechanics need to be in an HCP, and determine if feedback noise (or "squeals") that dispatchers heard was hazardous to their hearing.

NIOSH investigators purchased four Plantronics® (Santa Cruz, California) headsets (H81N, H91N, H131N, and H251N) that were similar in manufacturer and model to those worn by the AFD 911 dispatchers and tested these headsets in the NIOSH Acoustics Laboratory in Cincinnati, Ohio. Arrangements were made with the AFD to have actual 911 recordings available for analysis.

From May 7–10, 2007, a NIOSH investigator visited the AFD facilities to collect personal dosimetry measurements on mechanics and interview the dispatchers in a private setting. The NIOSH investigator also reviewed the OSHA Form 300–Log of Injuries and Illnesses ("OSHA Logs"), collected area sound level measurements, and reviewed audiometric test results for dispatchers.

ASSESSMENT

Detailed information on OELs associated with noise and room acoustics, as well as on health effects, is provided in the Appendix.

Mechanics

Five AFD mechanics provided eight full-shift measures. The employees wore NoisePro™ noise dosimeters from Quest® Technologies (Oconomowoc, Wisconsin) while they performed their daily activities. The noise dosimeters were attached to the wearer's belt, and a small remote microphone was fastened to the wearer's shirt at a point midway between the ear and the outside of the shoulder. A windscreen provided by the manufacturer of the dosimeter was placed over the microphone during recordings. At the end of the sampling period, the dosimeter was removed and paused to stop data collection. The information stored in the dosimeters was downloaded to a personal computer for interpretation with QuestSuite® Professional II computer software. The dosimeters were calibrated before and after the measurement periods according to the manufacturer's instructions.

The Quest dosimeters collect data for comparison with the three different noise criteria used in this evaluation, the OSHA PEL and AL and the NIOSH REL. The OSHA guidelines use a 90-dBA criterion level and a 5-dB exchange rate. The difference between the two OSHA criteria is in the threshold level employed, a 90 dBA threshold for the PEL and an 80 dBA threshold for the AL. The threshold level is the lower limit of noise values included in the calculation of the criteria; values less than the threshold are ignored by the dosimeter. The NIOSH guidelines differ from OSHA in that the criterion level is 85 dBA, and the exchange rate is 3 dB. There is no threshold requirement, so the threshold level for the dosimeters used in this evaluation was set to OFF. This allowed for the integration of all sound levels including those below 80 dBA. Table 1 summarizes the dosimeter settings used in this evaluation.

Table 1. Dosimeter settings

Parameters	OSHA AL	OSHA PEL	NIOSH REL
Response	Slow	Slow	Slow
Exchange rate	5	5	3
Criterion level	90 dBA	90 dBA	85 dBA
Threshold	80 dBA	90 dBA	OFF
Upper limit	115 dBA	115 dBA	115 dBA

911 Dispatchers

Area Noise Measurements

The spectral area noise measurements were made with a Quest Technologies Sound Pro Real-Time™ Analyzer Model and a ½"-diameter random incidence response microphone. The analyzer allows for the analysis of noise into its spectral components in a real-time mode. The ½"-diameter microphone has a frequency response range (± 2 dB) from 4 Hz to 21 kHz that allows for the analysis of sounds in the region of concern. One-third octave bands consisting of center frequencies from 25 Hz to 20 kHz were integrated for 30 seconds and stored in the analyzer for later analysis. The analyzer also calculates the overall unweighted value as a sound pressure level.

The area sound levels in the room where the dispatchers worked were captured at each workstation. The analyzer was located near the position where the employee was seated; the microphone was placed where the dispatcher's ears would be.

Employee Interviews

All 911 dispatchers at work on the days of the NIOSH evaluation along with the department manager were interviewed privately by the NIOSH investigator. Employees were asked about the number of years they had worked as dispatchers at AFD and in the profession. They were also queried about the physical characteristics of their work space (temperature, background noise, office ergonomics), whether they had been given a hearing test through work or experienced any changes in their hearing ability, and any other concerns about health and safety issues at their workplace.

Records Review

OSHA Logs from 2002–2006 were reviewed for any recordable injuries and illnesses related to hearing loss. It should be noted that OSHA only started tracking occupational hearing loss in 2004. Audiograms for 19 dispatchers, including two individuals who retired within the past year, were also reviewed for trends in hearing decrement.

Lab Analysis of Headsets

NIOSH purchased four Plantronics headsets (H81N, H91N, H131N, and H251N) and appropriate connectors for testing at the NIOSH Acoustics Laboratory. NIOSH was provided with eight recordings of feedback noise identified by the AFD dispatchers as problematic. The recordings were obtained from AFD servers and supplied to NIOSH in MP3 format. A simulated problem recording was also obtained from AFD. The recordings were played back into an acoustics test fixture, KEMAR, with standard adult-size artificial external ears and ½" B&K microphones Type 4165 (Naerum, Denmark). The microphones were powered by a B&K 2807 power supply, and the output was evaluated with a Stanford Research Systems Model SR785 signal analyzer. The microphones were calibrated using a B&K 4230 acoustic calibrator that produces a 94-dB SPL tone at 1000 Hz. The calibration tone was used as a reference signal to evaluate the various sound levels of the recordings. The recordings were transferred to a personal computer for analysis. The test setup is shown in Photos 1 and 2.

Photo 1. Test setup using KEMAR and SR785 analyzer

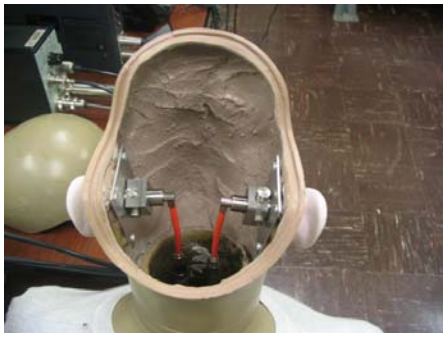


Photo 2. The KEMAR artificial acoustic fixture with B&K 4165 microphones

The recordings were analyzed using the NIOSH noise measurement software that reports average and peak sound levels of each recording as well as analyzing the frequency spectrum and octave and one-third octave band spectra. In addition to evaluating the quality and sound levels produced by the recordings, the overall performance of the four headsets was also tested using the sound source feature on the SR785 signal analyzer to produce a swept sine signal from 100 Hz to 20 KHz with increasing levels of outputs from 10 mV to 5 V.

RESULTS AND DISCUSSION

Mechanics

Five mechanics provided eight personal noise measures over the 2-day evaluation at the maintenance shop. The personal noise exposures are shown in Table 2. Five of the eight measures exceeded the NIOSH REL of 85 dBA. One measure exceeded the OSHA AL of 85 dBA.

Table 2. Full-shift personal noise exposures for AFD mechanics

Sample ID	Duration (hh:mm)	OSHA AL		OSHA PEL		NIOSH REL	
		Dose (%)	TWA (dBA)	Dose (%)	TWA (dBA)	Dose (%)	TWA (dBA)
A	10:04	13.5	75.6	8.4	72.1	97.1	84.9
B	09:54	3.6	66.1	1.3	58.9	16.9	77.3
C	09:58	28.7	81.0	21.8	79.0	263	89.2
D	11:03	10.6	73.9	5.0	68.5	59.6	82.8
E	10:04	65.8	87.0	55.7	85.8	1351.5	96.3
F	10:00	37.2	82.9	31.3	81.6	4631.3	101.7
G	10:06	19.5	78.2	10.3	73.6	110.2	85.4
H	09:53	22.3	79.2	12.7	75.1	112.7	85.5

The various dose percentages are the amounts of noise accumulated during a work day, with 100% representing the maximum allowable daily dose.
OSHA AL = 85 dBA; OSHA PEL = 90 dBA; NIOSH REL = 85 dBA

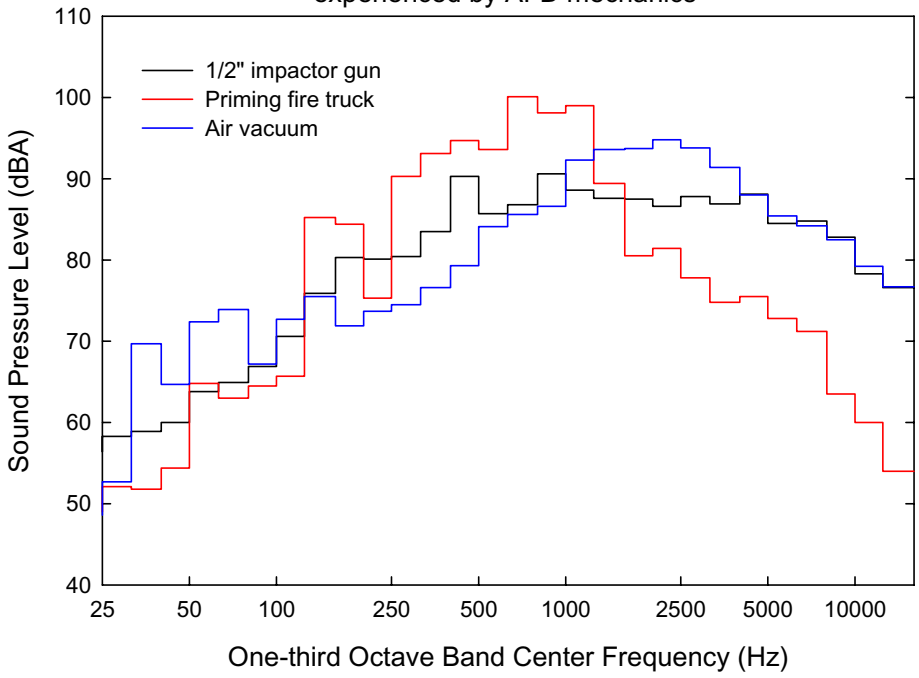
The loudest noise exposures occurred when mechanics used a ½" impactor gun to screw or unscrew lugnuts from fire engine tires. Spot measurements showed that noise exposures when screwing or unscrewing lugnuts could approach or exceed an employee's daily allowable dose in less than one minute. A 48-second exposure when unscrewing lugnuts from a tire had an average noise level of 111 dBA. Average noise levels when screwing lugnuts were 113 dBA for a 45-second exposure, and 120 dBA for a 54-second exposure. Tires on two trucks were changed during the NIOSH evaluation.

The mechanics change the tires on the fire trucks at the beginning of the summer and winter seasons. In Alaska, the summer season is from April to September, and the winter season is from October to March. In the late summer season (or the early winter season), snow tires are installed on fire trucks, and in the early summer season (or late winter season), they are replaced with normal tires. At the time of this evaluation (early May) most snow tires on the fire trucks had been changed.

The NIOSH investigator also measured noise levels when employees were priming a fire truck. Priming ensures that the water lines in the truck are functioning properly. The priming was done by switching on a toggle on a side panel of the truck. The priming activity observed during this evaluation lasted less than one minute. Another source of loud noise was an air vacuum pump used to clean up debris (metal shavings, garbage, etc.) after a job. The noise spectral data from the ½" impactor gun, priming, and the air vacuum pump are shown in Figure 1. The frequency range exceeding 85 dBA associated with the ½" impactor gun

was 500–5000 Hz, the frequency range exceeding 85 dBA for the truck priming activity was 315–1600 Hz, and the frequency range exceeding 85 dBA was 800–6300 Hz for the vacuum pump. These frequencies covered the range associated with NIHL, which usually occurs between 2000–6000 Hz.

Figure 1: Spectral noise data for typical noise exposures experienced by AFD mechanics



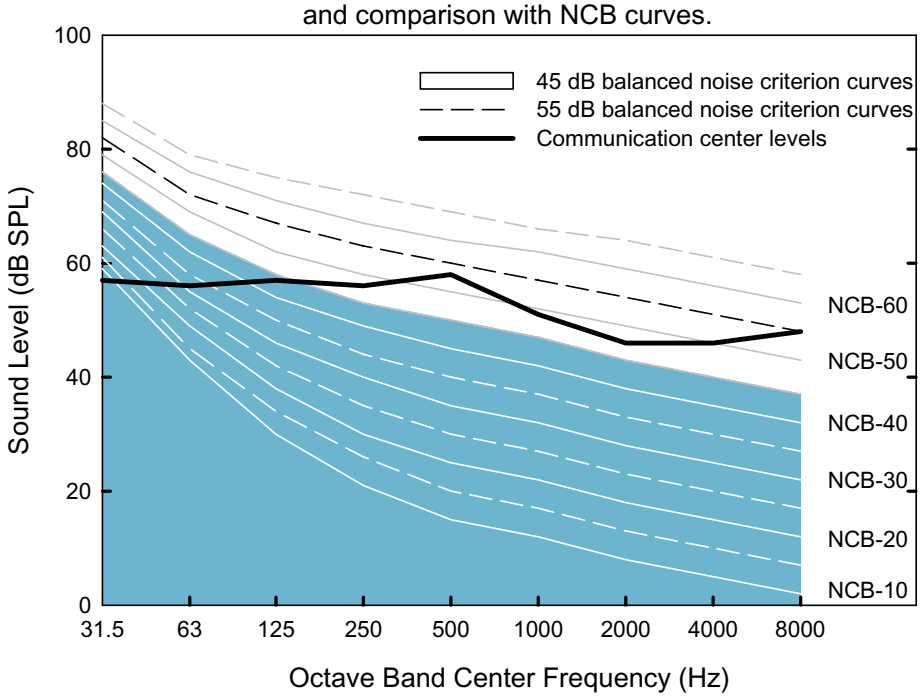
911 Dispatchers

Area Noise Measurements

Area noise sampling was conducted in the dispatch area during the day shift. Noise spectrum data were recorded at each workstation, regardless of whether the workstation was occupied by a 911 dispatcher. Noise levels during the day shift had a median value of 60 dB SPL. The third octave band data were combined into octave bands to simplify their analysis and to compare the area room noise values to the NCB criterion [ANSI 1995]. The octave band data for the dispatch area are shown in Figure 2. The NCB-55 curve is representative of the room noise at the dispatch center. The room noise conditions at this location are characterized as light maintenance shops, industrial plant control rooms, office and computer equipment rooms (NCB 45–55); shops and garages (NCB 50–60); and work spaces where speech or telephone

communication is not required (NCB 55–70). NCB 45 or less are appropriate for an office setting. Therefore, the room acoustics in the dispatcher area are not appropriate for a communications center. More information on NCB curves is provided in the Appendix.

Figure 2: Spectral data from communications center and comparison with NCB curves.



Employee Interviews

Of the seventeen 911 dispatchers present during the NIOSH site visit, 15 were interviewed. Of the 15, five were men and 10 were women. Their ages ranged from 26–56 years (mean age was 42 years). Fourteen 911 dispatchers (93%) said the temperature in the dispatch area was either too hot or too cold. Most 911 dispatchers said that their chairs were uncomfortable, and because they may spend approximately 10 hours sitting down, chair comfort was of great concern. They suggested that management survey their needs, and ensure that enough chairs suitable for the 911 dispatchers be made available during each shift.

Many of the 911 dispatchers said that they were distracted during their annual hearing tests, done in a mobile test facility, because of the noisy ambient environment. For example, employees mentioned that they could hear airplanes when taking the audiometric test. They also said that annual audiometric testing

was done at the end of the work day, and questioned whether, after a full shift of noise exposures, the annual tests would accurately reflect their hearing ability.

Records Review

The OSHA Logs showed no hearing loss or ear injuries. Three of the nineteen audiograms only had baseline data; of the 16 audiograms with multiple tests, none indicated that the employees' hearing levels decreased because of their employment with AFD. Two employees showed moderate hearing loss in their baseline audiograms. The baseline audiograms for all employees were administered shortly after they were hired.

Lab Analysis of Headsets

The average and peak sound levels from the test signal and each of the feedback noise recordings are shown in Table 3. The average length of each squeal was 500–700 milliseconds.

Table 3. Average and peak sound pressure levels

Event	Leq (dB)	Lpeak (dB)	Comment
Test Signal	67–68	84–85	Peak at 1.4 kHz
Squeal 1	69–71	85–87	Peak at 2.6 kHz
Squeal 2	74–77	97–99	Peak at 2.4 kHz
Squeal 3	68–69	84–85	Peak at 2.7 kHz
Squeal 4	72–75	93–95	Peak at 2.4 kHz
Squeal 5	74–76	94–97	Peak at 2.3 kHz
Squeal 6a	69–70	87–90	Peak at 1.4 kHz
Squeal 6b	69–72	90–91	Peak at 2.6 kHz
Squeal 7	77–78	97–100	Peak at 1.7 kHz

The results show that while the average noise levels from the recorded radio squeals and the test signals were below the NIOSH REL, peak sound levels reached as high as 100 dB on the medium volume setting. These spikes in sound levels appeared at frequencies ranging from 1.4 kHz to 2.7 kHz, which have been shown to cause more damage to hearing than low frequency sound levels [NIOSH 1996]. The NIOSH REL provides that exposure at the 100 dB levels not exceed 15 minutes during an 8-hour work shift. Dispatchers would have to be exposed to a high number of these spikes in their working day before they reach their maximum allowable limit. However, repeated and prolonged exposures at the peak levels found in this evaluation can result in symptoms such as headache, fatigue, or ringing in the ears.

Previous studies on telephone and call center operators found that the risk of hearing damage is minimal [Alexander et al. 1979; Patel and Broughton 2002]. In the call center study, the noise exposures of 150 operators from 15 call centers across a wide range of industry sectors were evaluated [Patel and Broughton 2002]. The study found that while exposure to high-level noise was possible, the daily personal noise exposure level was unlikely to exceed 85 dBA.

Performance of Headsets

The four Plantronics headsets were tested for linearity, quality of sound, and frequency response. Figures 3–6 show that all four headsets were capable of producing output levels in excess of 110 dB SPL. The y-axis shows the sound level in dB SPL and the x-axis shows the frequency in Hz. A swept-sinusoidal signal was applied to each headset at 10 mV, 100 mV, 1 V, and 5 V. The corresponding output response is plotted in each figure. All four headsets cut off sound signals above 4 kHz, thus limiting harmful high frequency signals from reaching the ear. The H251N headset showed lower output as the input exceeded the 1V signal level. This indicates the presence of a noise-limiting circuit in the headset itself. The presence of the noise limiting circuitry in the headset makes the H251N superior for protection against spurious noise signals.

Figure 3: Frequency response of the H81N headset

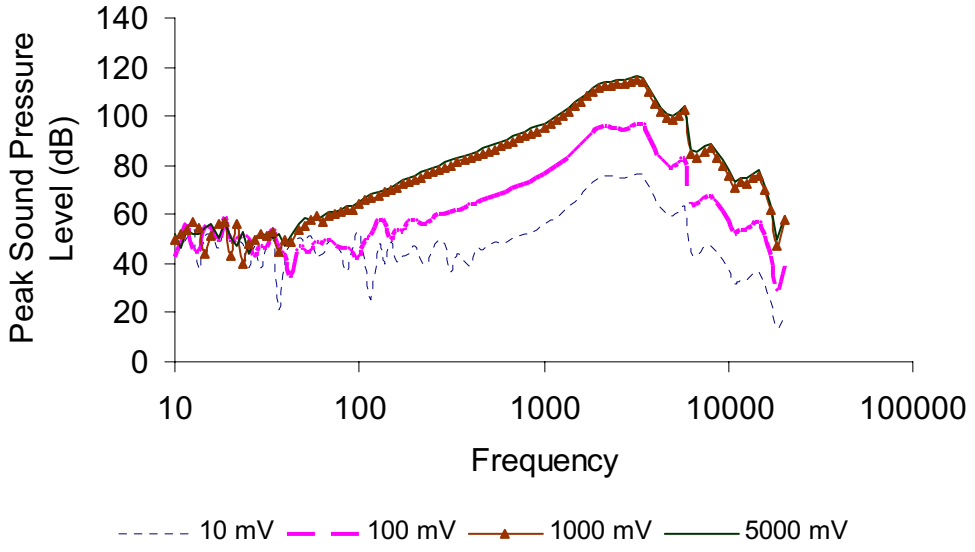


Figure 4: Frequency response of the H91N headset

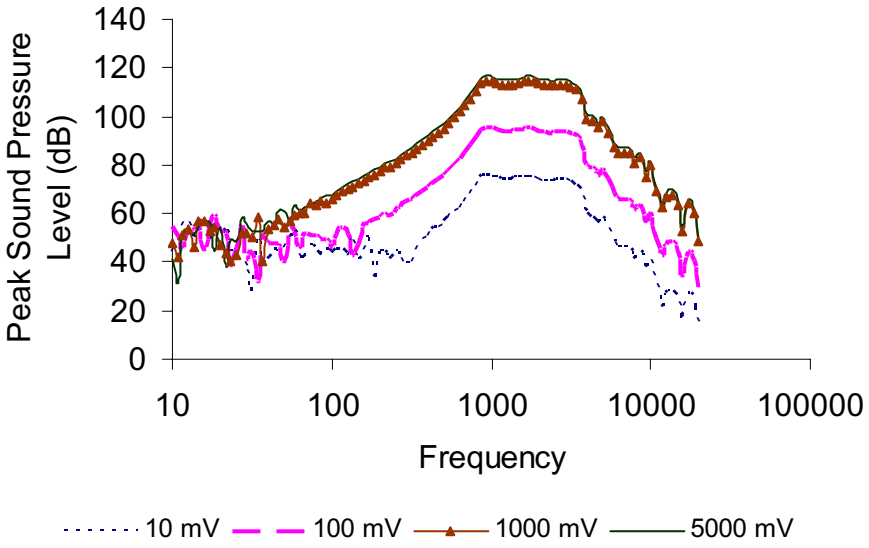


Figure 5: Frequency response of the H131N headset

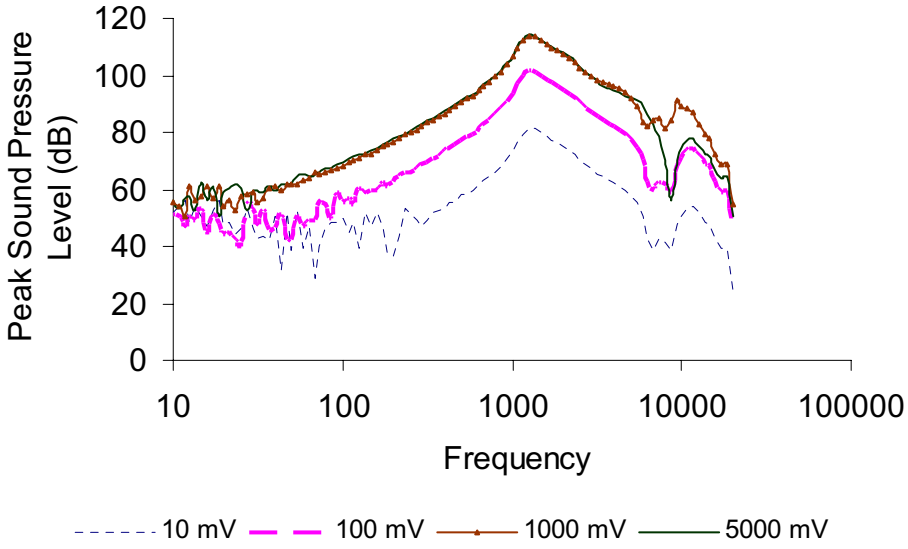
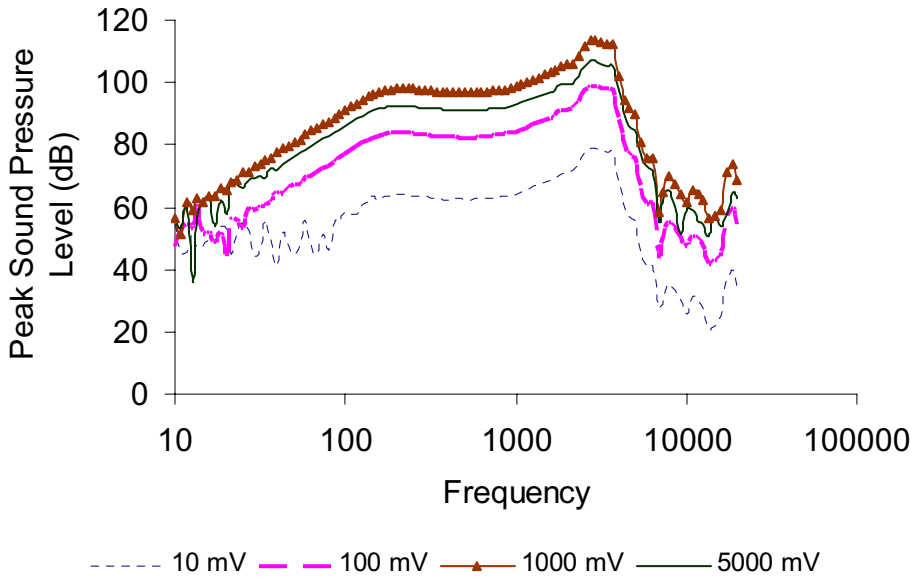
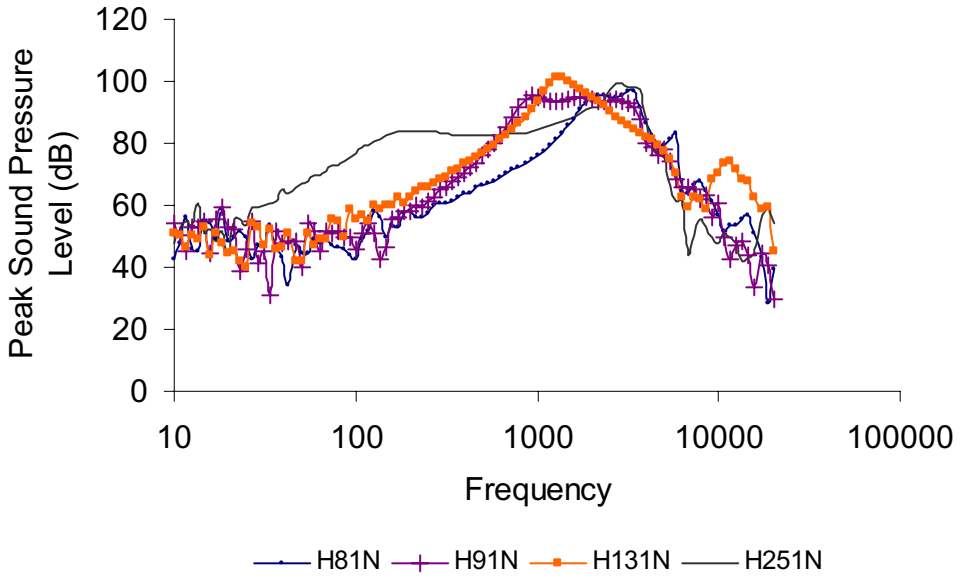


Figure 6: Frequency response of the H251N headset



A comparison of the responses of the four headsets to the same signal in Figure 7 shows that the H251N headset exhibited the best linear response of the four headsets over a frequency range of 150 Hz to 2000 Hz; thus this headset was capable of providing the best sound quality. Because most of the radio "squeals" happened between 1.4 and 2.7 kHz, the H131N frequency response exhibited the worst performance in comparison to the other headsets in limiting high level transmission at these frequencies. The results are also comparable to previous studies that have shown insert-type headsets provide 7–9 dB of increased sound output relative to over-the-ear headsets [Fligor and Cox 2004].

Figure 7: Comparison of Plantronics headsets at 100 mV



CONCLUSIONS

This evaluation found high noise exposures among mechanics. Of the full-shift personal noise measures, 63% exceeded the NIOSH REL despite the short exposure durations. Most of the 911 dispatchers expressed dissatisfaction with their work environment, stating that their work space was either too cold or too hot, their chairs were uncomfortable, and that there was distraction from visitors and loud alarms. Based on the sound levels measured in the dispatch area, the room acoustics are not considered optimal for a communications center. The high background noise caused the dispatchers to increase the headset volume level to overcome the masking provided by the noisy environment. If the background noise is reduced (for example through administrative measures such as limiting visitors to the dispatch area) then 911 dispatchers should be able to reduce the headset volumes, thereby reducing the potential for high level squeals. Based on the review of the audiograms there was no evidence of NIHL among the 911 dispatchers.

The recordings produced peak sound levels up to 100 dB. However, average levels that provide a better representation of

CONCLUSIONS (CONTINUED)

daily exposure were not considered hazardous, because they did not exceed the NIOSH REL. Repeated and prolonged exposure to peak sound levels found in the recordings can result in dispatchers developing symptoms, such as headache, fatigue, or ringing in the ears, that are associated with exposure to high sound levels.

RECOMMENDATIONS

The following recommendations are provided to reduce hazards to the hearing of mechanics and dispatchers at AFD that are associated with exposure to high noise levels.

1. Establish an HCP for AFD mechanics. The basic elements of the program should, at a minimum, meet the requirements of the OSHA hearing conservation amendment [29 CFR 1910.95]. Other sources for defining effective hearing conservation programs are also available [Royster and Royster 1990; NIOSH 1996; Suter 2002].
2. Mechanics should be required to wear HPDs while maintaining fire trucks.
3. Most of the dispatchers' headsets are adequate for their intended use. However, the quality of the sound production and the overall performance of the H251N headset were superior to the other headsets. The dispatchers should consider quality when selecting their headset.
4. AFD should train firefighters and others who use the radio equipment on proper use of these radios and the effect of feedback signals that can be transmitted into the 911 dispatchers' headsets.
5. Administer audiometric tests at the beginning of the shift to prevent bias from any temporary threshold shift that may have occurred during the day. Also, hearing tests should be conducted in a quiet environment such as an audiologist's office.
6. Consider, in consultation with a room acoustics engineer, building a dedicated communications center for the dispatchers or modifying the existing area to meet NCB criteria.
7. Implement specific administrative control measures such as providing a wider selection of noise limiting headsets, providing chairs that are ergonomically suitable, and

Recommendations (continued)

ensuring a quiet working environment, to minimize health and comfort concerns among 911 dispatchers.

8. Encourage 911 dispatchers and mechanics to actively participate in AFD's health and safety committee.

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Appendix: Occupational Exposure Limits and Health Effects

In evaluating the hazards posed by workplace exposures, NIOSH investigators use both mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents as a guide for making recommendations. OELs have been developed by Federal agencies and safety and health organizations to prevent the occurrence of adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. However, not all workers will be protected from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of factors such as individual susceptibility, or pre-existing medical condition. In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit.

The primary sources of evaluation criteria for noise in the workplace are the NIOSH REL [NIOSH 1992], and the U.S. Department of Labor, OSHA PEL [29 CFR 1910.95]. Employers are encouraged to follow the more protective NIOSH REL, although they are required to adhere to the OSHA PEL for compliance purposes.

NIHL is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically [Ward et al. 2000]. While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, NIHL is insidious. Typically, it begins to develop at 4000 or 6000 Hz (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components [Suter 1978].

The dBA is the preferred unit for measuring sound levels to assess worker noise exposures. The dBA scale is weighted to approximate the sensory response of the human ear to sound frequencies near the threshold of hearing. The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels which are audible to the human ear. Because the dBA scale is logarithmic, increases of 3 dBA, 10 dBA, and 20 dBA represent a doubling, tenfold increase, and hundred-fold increase of sound energy, respectively. It should be noted that noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise specifies a maximum PEL of 90 dBA for of 8 hours per day [29 CFR 1910.95]. The regulation, in calculating the PEL, uses a 5-dB time/intensity

trading relationship, or exchange rate. This means that a person may be exposed to noise levels of 95 dBA for no more than 4 hours, to 100 dBA for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dBA is allowed by this exchange rate. The duration and sound level intensities can be combined in order to calculate a worker's daily noise dose according to the formula:

$$\text{Dose} = 100 \times (C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n)$$

where C_n indicates the total time of exposure at a specific noise level and T_n indicates the reference duration for that level as given in Table G-16a of the OSHA noise regulation. During any 24-hour period, a worker is allowed up to 100% of his daily noise dose. Doses greater than 100% exceed the OSHA PEL.

The OSHA regulation has an additional AL of 85 dBA; an employer shall administer a continuing, effective hearing conservation program when the 8-hour TWA value exceeds the AL. The program must include monitoring, employee notification, observation, audiometric testing, HPD, training, and record keeping. All of these requirements are included in 29 CFR 1910.95, paragraphs (c) through (o). Finally, the OSHA noise standard states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dBA, feasible engineering or administrative controls shall be implemented to reduce the workers' exposure levels.

NIOSH, in its Criteria for a Recommended Standard, proposes an exposure criterion of 85 dBA as a TWA for 8 hours, 5 dB less than the OSHA standard [NIOSH 1998]. The criterion also uses a more conservative 3-dB exchange rate in calculating exposure limits. Thus, a worker can be exposed to 85 dBA for 8 hours, but to no more than 88 dBA for 4 hours or 91 dBA for 2 hours. The NIOSH REL for a 12-hour exposure is 83 dBA or less.

Because of the different 8-hour criteria and exchange rates, the dose equations used to calculate the equivalent TWA values are different for the NIOSH and OSHA criteria.
The OSHA dose equation is

$$\text{TWA} = 16.61 \times \log_{10} [\text{Dose}/100] + 90,$$

and the NIOSH equation is

$$\text{TWA} = 10.00 \times \log_{10} [\text{Dose}/100] + 85.$$

The occupational noise regulation promulgated by OSHA and the NIOSH criterion are designed to prevent hearing losses from exposures to intense noise levels. However, noise of intensities lower than that which may cause a loss of hearing can be disruptive in the workplace.

Interference with speech is a possible result of unwanted noise. The noise can interfere with the efficiency and productivity of the staff and can be detrimental to the occupants' comfort, health, and sense of well being. One set of noise criteria for occupied interior spaces, the NCB curves, has been devised to limit

noise to levels where satisfactory speech intelligibility is achieved [Beranek 1988, 1989; ANSI 1995]. The noise criteria were devised through the use of extensive interviews with personnel in offices, factories, and public places along with simultaneously measured octave band sound levels. The interviews consistently showed that people rate noise as troublesome when its speech interference level is high enough to make communications difficult. The recommended space classifications and suggested noise criteria range for steady background noise heard in various indoor occupied activity areas are shown in Table A-1.

*Table A-1. Suggested NCB range for various occupied indoor areas

Type of space and acoustical requirements	NCB curve
Concert halls, opera houses, and recital halls	10–15
Large auditoriums, large drama theatres, and large churches	Not to exceed 20
Small auditoriums, small theaters, small churches, music rehearsal rooms, large meeting and conference rooms, and executive offices	Not to exceed 30
Bedrooms, hospitals, residences, apartments, hotels	25–40
Private or semi-private offices, small conference rooms, classrooms, libraries	30–40
Large offices, reception areas, retail shops and stores, cafeterias, restaurants	35–45
Lobbies, lab work spaces, drafting and engineering rooms, general secretarial areas	40–50
Light maintenance shops, industrial plant control rooms, office and computer equipment rooms, kitchens, and laundries	45–55
Shops, garages	50–60
Work spaces where speech or telephone communication not required	55–70

* ANSI S12.2-1995 Criteria for Evaluating Room Noise

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Acknowledgements and Availability of Report

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employers or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

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Below is a recommended citation for this report:
NIOSH [2008]. Health Hazard Evaluation Report: Evaluation of potential noise hazards to mechanics and 911 dispatchers at a fire department, Anchorage, Alaska. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA No. 2007-0235-3064.

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