THESIS

# NOISE EXPOSURE ASSESSMENT IN THE POUDRE FIRE AUTHORITY

Submitted by

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ABSTRACT

NOISE EXPOSURE ASSESSMENT IN THE POUDRE FIRE AUTHORITY

According to the National Institute for Occupational Safety and Health (NIOSH), it is estimated that 22 million workers are exposed to hazardous levels of noise. Firefighters are part of this population of workers that are at potential risk of overexposure to such noise and subsequent noise-induced hearing loss. In fact, one NIOSH study found that 53 of 56 (96%) firefighters had detectable hearing loss.

To ascertain the sources of firefighter noise exposures, noise samples were taken at ten Poudre Fire Authority stations on the equipment and emergency vehicles using a sound level meter. Results indicated that five of the six pieces of equipment located at the stations exceeded 85 dBA; and 13 of the 15 pieces of equipment on the trucks exceeded 85 dBA. Equipment that exceeds 85 dBA is important to identify since hearing loss can begin to occur at these levels. Code-3 operations that involve fire truck siren were measured at 92 dBA, and the operation of truck pumps at "high" psi was measured at 91 dBA. A 24-hour noise dose to firefighters was estimated to be at 48% of the OSHA permissible exposure limit.

According to the OSHA Occupational Noise Control Standard, engineering controls are required to lower the noise levels below the eight-hour permissible exposure limit or hearing protection must worn when engineering controls are not feasible. Given the variability in the time of use of relatively loud firefighting equipment and the

difficultly of measuring full-shift firefighter noise exposures, it is recommended that hearing protection be worn to help reduce the risk of noise induced hearing loss.

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## LIST OF ACRONYMS

| | |
|---|---|
| ACGIH | American Conference of Governmental Industrial Hygienists’ |
| ANOVA | Analysis of Variance |
| ANSI | American National Standards Institute |
| CFR | Code of Federal Regulations |
| dB | Decibel |
| dBA | Decibel, A-weighted |
| dBC | Decibel, C-weighted |
| HCP | Hearing Conservation Program |
| Hz | Hertz |
| ISO | International Organization for Standardization |
| kHz | Kilohertz |
| Leq | Equivalent Continuous Sound Pressure Level |
| NIHL | Noise Induced Hearing Loss |
| NIOSH | National Institute for Occupational Safety and Health |
| NRR | Noise Reduction Rating |
| OSHA | Occupational Safety and Health Administration |
| PEL | Permissible Exposure Limit |
| PTS | Permanent Threshold Shift |
| SD | Standard Deviation |

| | |
|---|---|
| SLM | Sound Level Meter |
| SPL | Sound Pressure Level |
| TLV | Threshold Limit Value |
| TTS | Temporary Threshold Shift |
| TWA | Time Weighted Average |
| U.S. | United States |

# CHAPTER 1: INTRODUCTION

Noise is something that is a common part of everyday life, but when excessive, can be damaging to the human ear. The control of excessive noise may not always be easy, and loud noise may actually be warranted, such as sirens and warning alarms. Sirens and alarms are commonly emitted from fire trucks and emergency vehicles. While these warning sirens, alarms, and horns are important to warn the public of emergency equipment movements, emergency personnel operating these vehicles may be at risk for hearing loss.

It is common to see more than one fire truck at a house fire and other emergency vehicles arriving at the scene with sirens and horns blaring. Since emergency crews are focused on the fire, their priorities of saving those inside, the structure itself, and the surrounding structures; the noise levels to which firefighters are exposed are not always a primary concern. While fighting a fire, it is very important for the firefighters to be able to hear what is going on inside the structure (e.g., voices from colleagues or victims, or even animals); they also need to be able to hear commands from the captain outside the structure giving orders. If the firefighters are not able to hear well, they may not be as successful at their job as necessary. Hearing loss affects the firefighter’s ability to hear victims in a fire that need to be rescued and also the captain’s communications, which may include evacuating the structure for their own safety. It is for these reasons that this research is critical in identifying those noise sources that may impair firefighters' hearing, and secondarily, so that they may protect themselves from these hazardous noise exposures.

Some improvements have been made to reduce firefighter noise exposures over the years, including the installation of sirens on the front of the truck that face away from the truck occupants, as opposed to the siren on top of the trucks. Such improvements came from several studies that resulted in recommendations to the firefighting community. These studies were conducted in collaboration with the Hamilton Fire Department, Pittsburgh Burearu of Fire, and the Memphis Tennessee Fire Department.(1,2,3) These studies showed consistent results of noise exposure through out the stations and trucks.

The investigator of this study conducted noise sampling on all pieces of fire-fighting equipment (e.g., trucks and tools) at ten stations of the Poudre Fire Authority and estimated times of firefighter exposure to noise sources based on a PFA Captain's estimate of exposure time. One challenge in estimating noise exposure is that firefighters in the PFA work a 24-hour shift rather than a typical eight-hour shift. The noise data were compared to published noise exposure limits to determine which noise sources could cause hazardous noise exposure. While other studies evaluated just the trucks and primary firefighting tools, this research addressed the comprehensive noise sources not addressed by previous studies by evaluating all pieces of equipment and tools that could be used by a firefighter during their shift.

# CHAPTER 2: LITERATURE REVIEW

As defined in the Webster's Dictionary, noise is sound that lacks agreeable musical quality or is noticeably unpleasant. It is also any sound that is undesired or interferes with one's hearing of something.[(4)] Sound is a form of energy and is made when air molecules vibrate and move in a pattern called waves, or sound waves.[(5)] These waves propagate a pressure wave through an elastic medium, such as air or wood.[(6)] The pressure of sound is measured in decibels (dB), (a logarithmic scale by factors of ten), and if excessive, can cause damage to the ear.

Hearing loss is an ongoing battle in the workplace. Noise standards have been mandated by the Occupational Safety and Health Administration (OSHA) and recommended by the National Institute for Occupational Safety and Health (NIOSH), the American Conference of Governmental Industrial Hygienists (ACGIH), and the National Fire Protection Association (NFPA) to reduce noise exposure. Organizations are required to measure noise levels and provide protective measures if warranted. Unfortunately, the control of noise may be difficult for some industries, such as emergency response. Specifically, noise control in the fire-fighting industry is difficult because loud noise is used as a control to warn people of impending danger. The relatively loud sirens and horns of fire trucks serve an alert system to the public to avoid the perimeter of emergency vehicles; however, those same alert systems have the potential to harm the hearing of firefighters inside of the truck or the surrounding emergency area. In addition, research has shown that firefighters are exposed to relatively loud noise from rescue equipment such as chainsaws (113 dBA), jaws of life (94 dBA), and chisels (106 dBA).[7]

Noise-exposure research of firefighters' duties and tasks that have been evaluated has shown that the highest noise exposure on a regular basis occurs during code-3 vehicle operations.[8] A code-3 vehicle operation occurs when the truck siren and horns are in operation which occurs most commonly when the trucks are going through traffic and may reach noise levels of 115 dBA. Additionally, firefighters execute code-2 operations which involve driving the truck without sirens or horns. Executing code-3 operations on a regular basis may expose firefighters to hazardous levels of noise.

However, not included in these noise exposure assessments is the measurement of firefighter noise exposure during the actual fighting of a fire within a structure. Current personal noise monitoring equipment limitations (e.g., resistance to heat from a fire) and the need for rapid response to an alarm have not allowed investigators to conduct personal noise dosimetry to evaluate firefighter noise exposures during actual firefighting activities.

Unfortunately, hearing loss among firefighters has been found to be 32.8 percent greater than the United States general population.[8] Further, controlling firefighter noise exposure to prevent this hearing loss not only protects the firefighter's life by being able to hear clearly during an emergency, but it also protects the lives of the victims that they rescue by being able to hearing voices in a burning structure. Therefore, firefighters are faced with the decision of protecting their hearing by using of hearing protective devices, or risk damage to their hearing by not using hearing protective devices so that they can clearly hear communications and victims' voices.

Further, according to a study conducted by Oxford University, researchers stated that more than 90% of approximately 230 firefighters agreed that good hearing was essential for the majority of fire ground tasks.[9]

An additional challenge facing the estimation of firefighter noise exposure is that noise-control standards and recommendations, which dictate noise exposure limits, were developed to control typical, eight-hour work-day noise exposures, yet most firefighters do not work a typical eight-hour shift. Rather, most firefighters work 24-hour shifts and some work 48-hour shifts. Firefighters in this study worked 24- hour shifts.

In the United States (U.S.) alone, there are more than 1.1 million firefighters; of those 1.1 million, 323,350 are full-time and 825,450 are volunteers.[10] Examination of firefighter demographics by age group and the percentage of firefighters in each age group reveals the following; 16-19 years old (3.5%), 20-29 (21.4%), 30-39 (28.2%), 40-49 (25.9%), 50-59 (15.4%), 60 and over (5.5%).[10] When examining the size of communities that firefighters protect, 74% of career firefighters are in communities that protect a population of 25,000 or more;95% of the volunteers are in departments that protect a population of less than 25,000; and of that more than 50% are located in small, rural departments that protect a population of less than 2,500.[10]

Given this large population of firefighters and the importance that good hearing plays in rescue efforts, it is imperative that firefighters be protected from the insidious effects of elevated noise exposures.

Physiology of The Ear

In order for a person to hear the sounds around them, the sound pressure waves must go through a series of events before one actually "hears." As quoted from the National Institute of Deafness and Other Communication Disorders, the following series of events occur for a person to hear sound.[(11)]

"1- Sound waves enter the outer ear and travel through a narrow passageway called the ear canal, which leads to the eardrum.

2- The eardrum vibrates from the incoming sound waves and sends these vibrations to three tiny bones in the middle ear. These bones are called the malleus, incus, and stapes.

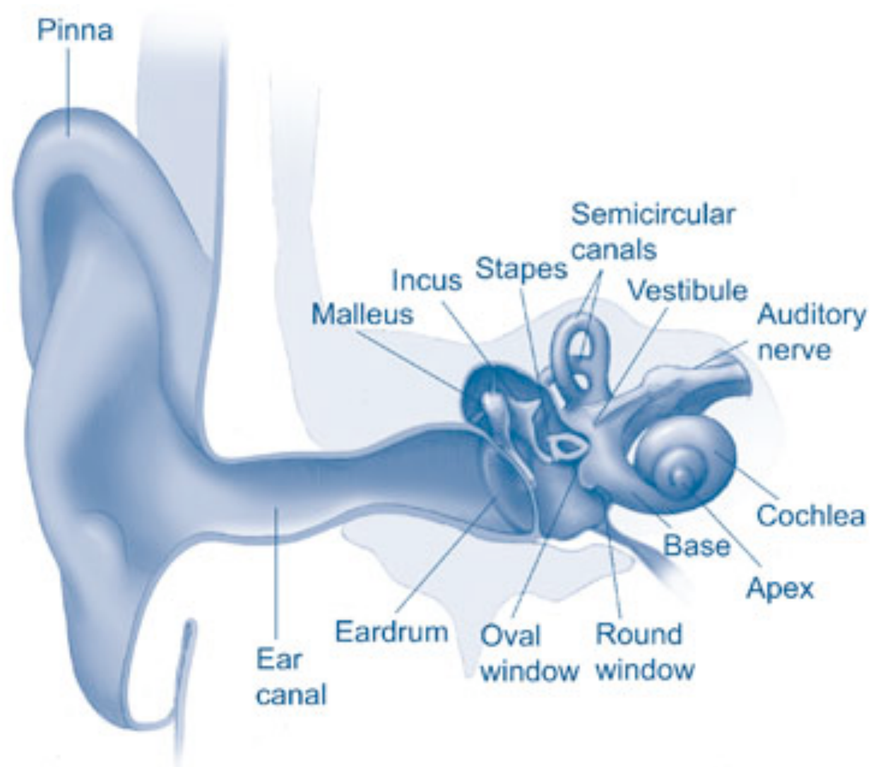
3- The bones in the middle ear amplify, or increase, the sound vibrations and send them to the inner ear—also called the cochlea—which is shaped like a snail and is filled with fluid. An elastic membrane runs from the beginning to the end of the cochlea, splitting it into upper and lower portions. This membrane is called the "basilar" membrane because it serves as the base, or ground floor, on which key hearing structures sit.

4- The sound vibrations cause the fluid inside the cochlea to ripple, and a traveling wave forms along the basilar membrane. Hair cells—sensory cells sitting on top of the membrane—'ride the wave.'

5- As the hair cells move up and down, their bristly structures bump up against an overlying membrane and tilt to one side. This tilting action causes pore-like channels, which are on the surface of the bristles, to open up. The auditory nerve carries this electrical signal to the brain, which translates it into a "sound" that people recognize and understand.

6- Hair cells near the base of the cochlea detect higher-pitched sounds, such as a cell phone ringing. Those nearer the apex, or centermost point, detect lower-pitched sounds, such as a large dog barking."

Figure 2.1: Human Ear [11]




<u>Noise-Induced Hearing Loss</u>

Noise is everywhere in the world, whether it is people talking, music playing, traffic in the distance, or the wind blowing and rattling leaves on trees. Even though local governments may have noise ordinances to protect quality of life, over-exposure to noise still occurs from non-occupational sources, such as lawnmowers or string trimmers, and may result in hearing loss.[11] However, noise from occupational sources is strictly regulated in most work places to help prevent hearing loss.

Healthy young adults can hear sound ranging in frequencies from 20 Hertz (Hz) to 20,000 Hz.[12] Although the human ear can detect sound within this frequency range, when the hearing mechanism is exposed to excessively loud noises over a long period of time or a one-time impact or impulse noise; hearing loss may occur, thus decreasing the hearing sensitivity within the frequency range of hearing. This decrease in hearing sensitivity may develop into symptoms of noise induced hearing loss (NIHL) and this loss may increase gradually. Over time, the sounds a person hears may become distorted or muffled, and it may be difficult for the person to understand speech. The frequency range of human speech is between 200 and 8000 Hz.[6] Someone with NIHL may not even be aware of the loss, but it can be detected with a hearing test.[11] NIHL is manifested first in the mid-frequency range 3000 to 6000 Hz.[12] The middle frequencies are affected first because the outer ear canal is resonate at about 3k Hz, and these frequencies are affected most by narrow band noise.[6] Damage to the ear occurs in the inner part of the ear to the hair cells when the ear has been exposed to sounds that are too loud or sounds that are loud over a long period of time. When the ear is exposed to very loud noises, acoustic trauma can occur.[13] Acoustic trauma is an injury to the hearing mechanisms in the inner ear, this can be caused in two different ways. One way in which acoustic trauma can be caused is by long-term exposure to loud noises such as loud music or machinery.[13] Acoustic trauma can also occur when a person has been exposed to dangerous noise at decibels of 110 or more.[6] When acoustic trauma has occurred it can cause temporary or permanent hearing loss.[12] Hearing damage may start to occur at 85 dB.[11] When temporary hearing loss occurs, it can be a result from short-term exposure or neural fatigue, and hearing sensitivity returns to the pre-exposed level within hours or days.[12] If permanent sensory hearing loss has occurred, there may have been destruction to the sensory cells in the inner ear, and hearing sensitivity will not return to the pre-exposed level.[12] The hair cells are small sensory cells that convert sound energy into electrical signals that travel to the brain. Once the hair cells are damaged, there is permanent loss, and hair cells cannot grow back. The American Speech- Language-Hearing Association has categorized the degrees of hearing loss, as described in Table 2.1 below.

Table 2.1 Degree of Hearing Loss[14]

| Degree of Hearing loss | Hearing loss range (db HL) |
|---|---|
| Normal | -10 to 15 |
| Slight | 16 to 25 |
| Mild | 26 to 40 |
| Moderate | 41 to 55 |
| Moderately Severe | 56 to 70 |

<u>Noise Regulations</u>

In 1793, Ramazzinii, also known as the father of occupational medicine, observed that "coppersmiths became hard of hearing due to the continual din of hammering the metal, and that if they grew old at this work, they become completely deaf."[15]

Documented excessive workplace noise exposures continued into the 1800's, for example, when blacksmiths suffered from ringing in their ears from their work, known as tinnitus.(6) After all these years, there continues to be great concern about hearing loss in U.S. industries. Compensation for NIHL is now common, although there were few claims prior to World War II.(15) In fact, NIOSH wrote in 2010 that, "It is estimated that over 30 million workers are exposed to hazardous noise on the job."(16)

However, it was not until 1971 that OSHA promulgated the noise standard and later that the hearing conservation amendments were published (1981 and 1983, respectively).(6) The American Conference of Governmental Industrial Hygienists (ACGIH), the National Institute of Occupational Safety and Health (NIOSH), and the National Fire Protection Association (NFPA) also published recommendations and standards for noise exposure which will be addressed later.

To help assure that worker hearing is protected, the OSHA noise standard requires the implementation of a hearing conservation program, feasible noise controls, and the use of personal protective equipment if warranted. According to 29CFR1910.95(c)(1):

> "The employer shall administer a continuing, effective hearing conservation program…whenever employee noise exposures equal or exceed an 8-hour time-weighted average sound level (TWA) of 85 decibels measured on the A scale (slow response) or, equivalently, a dose of fifty percent."

As stated above in the OSHA Standard, a hearing conservation program should be implemented when noise levels are at an eight-hour time-weighted average of 85 decibels or greater. There are many parts to the hearing conservation program that the employer must develop to help protect the employee from hearing loss. In addition to reinforcing the OSHA Standard, one part of the Hearing Conservation Amendment is that: "the employer should develop and implement a monitoring program."[6]

For those workers that are exposed to different sound levels throughout their work period, the following calculation is used to determine whether or not the worker is over-exposed:

$$\underline{\%Dose = 100\ [C(1)/T(1) + C(2)/T(2) + ... + C(n)/T(n)]}$$

where C =total time of exposure at a specified noise level; T = total time of exposure permitted at that level[6] The permissible noise exposures in Table 2.2 below indicate the maximum amount of time a worker should be exposed according to OSHA, NIOSH, and ACGIH.[26,27,28] The OSHA permissible exposure limit (PEL) is mandatory to abide by for compliance; ACGIH and the NIOSH provide recommended noise exposure limits that are not enforceable by law but provide more conservative noise limits.

Table 2.2 Noise Standards

| Duration per day | OSHA | NIOSH | ACGIH |
|---|---|---|---|
| 8 | 90 | 85 | 85 |
| 6 | 92 | 86 | |
| 4 | 95 | 88 | 88 |
| 3 | 97 | 89 | |
| 2 | 100 | 90-91 | 91 |
| 1 ½ | 102 | 92 | |
| 1 | 105 | 94 | 94 |
| ½ | 110 | 97 | 97 |
| ¼ or less | 115 | 100 | 100 |

The Poudre Fire Authority not only follows OSHA standards but it also follows regulations stated in the NFPA 1500. In the NFPA standards it states:

NFPA 1500-7.18.1-.3 [17]

.1: Hearing protection shall be provided for and used by all members operating or riding on fire apparatus when subject to noise in excess of 90 dBA.

.2: Hearing protection shall be provided for and used by all members when exposed to noise in excess of 90 dBA caused by power tools or equipment, other than in the situation where the use of such protective equipment would create an additional hazard to the user.

.3: The fire department shall engage in a hearing conservation program to identify and reduce or eliminate potentially harmful sources of noise in the work environment.

History of Fire Fighting

There are many events and inventions that have occurred in the history of the U.S. to create the great fire protection that we know today. Benjamin Franklin was famously quoted in stating his advice for fire fighting that, "An ounce of prevention is worth a pound of cure," which is still relevant today.(18) By reviewing a few of the major events in the evolution of fire protection that have occurred, one can realize how far both, (the country and fire protection) have grown. Growth in fire protection has allowed changes to the fire department. These changes have had an effect on the firefighters' hearing by making changes to the equipment to allow for noise level and exposure to change.

In 1608, the first recorded structure fire occurred in the U.S. in the colony of Jamestown.(19) It was not until 1630 that fire prevention began in Boston when a selectmen of Boston ordered that "no man shall build his chimney with wood, nor cover his house with thatch."(19) Later, in 1648, Governor Peter Stuyvesant appointed four men to act as fire wardens.[20] Benjamin Franklin founded the Union Fire Company in Philadelphia in 1736, and this became the standard for volunteer fire company organization. Some of the equipment used during this time were leather buckets to fight the fire and strong bags and baskets to pack and transport goods. Another tool that was important during fire fighting was the bed key; this tool was used to quickly disassemble the wooden frame beds since it was quite often the most valuable item owned by a family.[20] Many other historical "firefighting" events occurred, as seen in Table 2.3 below, that resulted in our modern fire-fighting efforts today.

Table 2.3 Historical Events of Firefighting History[21]

| Year | Event |
|---|---|
| 1654 | Joseph Jynks of Saugus, MA, builds first American fire "enjyne" |
| 1743 | First successful pumping engine built in America |
| 1829 | George Braithwaite built first fire engine using steam to pump water. |
| 1845 | Dr. William F. Channing of Boston invents the fire-alarm telegraph. |
| 1871 | Rubber-lined, cotton-jacketed, fire hose begins to replace the riveted leather hose. |
| 1874 | Automatic sprinklers introduced. |
| 1904 | Successful breathing apparatus invented but not adopted for a number of years. |
| 1907 | Gasoline-powered motors and pumps begin to appear in the fire service. |
| 1907 | Invention of first pumper with a single engine to do both driving and pumping. |
| 1911 | New York City created Committee on Safety which led directly to Safety to Life Committee of National Fire Protection Association. |
| 1913 | Binghamton Clothing Factory fire results in new standard for building exits. |
| 1913 | Life Safety Code ® is established. |
| 1918 | International Association of Firefighters Union organized. |
| 1923 | United States Chamber of Commerce sponsors National Fire Waste Council with contest for fire prevention in cities by local chamber of commerce. |
| 1923 | Fire Prevention education in schools required by thirteen states. |

| | |
|---|---|
| 1951 | Sparky the Fire Dog created as a symbol of fire prevention for children. |
| 1965 | Multiple fires resulting from Watts riots in Los Angeles, California. After 34 lives were lost, special gear was used to protect firefighters as a defense. |
| 1967 | A fire resistive fabric, Nomex, ® came into existence. |

Relevant Studies

The majority of the scientific studies that are relevant to this project are from the late 1970's and the 1980's when OSHA promulgated the noise standard. With only a minimal number of studies conducted on the noise exposure in fire departments, much research is needed to understand and help lower firefighter noise exposure. This study provides current noise levels on the trucks and the equipment used in and around the fire department. By examining both common emergency equipment and other equipment used in the fire service such as lawn equipment, simple controls could be devised/implemented to lower noise exposure. Studies have shown that noise levels during fire-fighting tasks with some equipment were frequently at relatively high peak levels, sometimes to 120 dBA.[(4)]

In 1979, a study was conducted by the University of California at Irvine (UCI) and the California Department of Forestry (CDF) that consisted of three phases: (1) Noise dosimetry to determine exposure for a code-3; (2) Octave-band analyses for overall vehicle noise and for individual components; and (3) Audiograms to identify possible relationship between hearing loss and years in service.[(5)] The researchers concluded that there were undesirably high sound pressure levels during code-3 responses. Also, sound pressure levels were found to be in excess of OSHA limits on a regular basis. There was no correlation between years of service and loss of hearing in the small study population, but it is possible that hearing loss already observed in the younger population may have resulted from over exposure in the first three years of service.(8)

From the months of January to August in 1979 the Los Angeles City Fire Department collaborated in a study with the Center for Health Sciences at Oakland University examining hearing threshold data. Results from this study indicated that with audiometric evaluations, the Los Angeles City Fire Department showed a greater hearing loss with age when compared to a national general population.(22)

In 1980, the International Association of Firefighters requested that the National Institute for Occupational Safety and Health (NIOSH) conduct a noise evaluation on hearing loss from noise exposure. NIOSH researchers found noise levels from 99 dBA to 116 dBA with a 8-hour time weighted average of 62.8 dBA to 85.3 dBA.(9) After conducting audiometric evaluations, it was revealed that 53 of 55 (96%) full-time firefighters had detectable hearing loss.(9)

From 1981 to 1989, NIOSH conducted numerous fire department noise studies in response to requests for assistance from U.S. fire departments. These studies were accomplished by investigator, Randy L. Tubbs. The fire departments included: Memphis Fire Department; Hamilton, Ohio Fire Department; Pittsburgh, Pennsylvania Fire Department; and Newburgh Fire Department. These studies implemented a consistent methodology and had similar results. The investigator provided recommendations for each fire department. General recommendations common to each fire department included:

- Implementing a hearing conservation program including audiometric testing. This program should include pre-employment baseline audiograms and annual audiograms.

- Hearing protection should be mandated for operations that exceed a noise level of 90 dB.
- Noise absorption can be added to existing fire apparatus to isolate the firefighters from the noise sources. When used on hard surfaces of the fire vehicles, reverberant noise exposures to the personnel on the vehicles will be reduced.
- Limit the use of warning devices as much as legally possible.

Those recommendations not common to each station are addressed below.

- Noise surveys should be conducted periodically throughout the entire department to document events which have the potential for excess noise exposure.
- Warning devices should be moved away and isolated from the personnel on the vehicle. They should be placed on or below the front bumper where the vehicle will act as a sound shield from the siren and air horn noise.
- New vehicle and equipment purchases should include specifications on maximum noise levels which can be allowed in the operation of this equipment.

NIOSH investigated the Memphis, Tennessee Fire Department in 1985, in response to a request from the International Association of Firefighters (IAFF). This study was designed to examine if those firefighters assigned at the two fire stations serving the Memphis International Airport were at a greater risk of hearing loss. The investigators found that the noise data from the trucks and engines were greater at the airport stations than at the non-airport stations, but these data were not significantly different.(1)

Colorado State University conducted a study with the Poudre Fire Authority in 1989.[23] This was done by the Occupational Noise Control class under the supervision of Kenneth D. Blehm. Area monitoring was conducted on the different engines and equipment around the station, and the monitoring results indicated that the highest noise levels occurred from fire trucks during code-3. The investigators recommended that the truck windows be closed during code-3 operations, which would result in a decrease in noise of 10 to 12 decibels.

# CHAPTER 3: PURPOSE AND SCOPE

## Purpose

The Poudre Fire Authority (PFA) requested that Colorado State University conduct sound pressure level measurements on the equipment used in the PFA fire departments to determine what equipment posed hazardous levels of noise. This request demonstrated that the PFA was concerned about firefighter noise exposure and its desire to decrease the potential risk of hearing loss of firefighters.

The purpose of this research was to review firefighter noise-exposure literature and to conduct noise sampling at ten Poudre Fire Authority (PFA) fire stations to determine which pieces of equipment in the fire stations may be harmful to firefighter hearing. In addition, estimates of noise exposure were determined to calculate the noise dose of firefighters during an average shift. The noise sampling of all equipment to determine which were greater than 90 dBA will provide the PFA with the knowledge of what equipment emits hazardous noise levels that could cause damage to firefighter hearing.

By determining what equipment emits hazardous levels of noise within the fire departments, firefighters can protect themselves with proper hearing protection or implement controls to make the equipment quieter.

## Research Questions

The noise evaluation of the PFA was accomplished to answer the following research question:

Are firefighters in the PFA exposed to equipment that emits noise levels that might exceed published exposure limits and possibly lead to NIHL?

## Scope

The scope of this research included ten fire stations within the PFA. These stations included station numbers 1, 2, 3, 4, 5, 6, 7, 10, 12, and 14. Equipment evaluated for noise emission included all equipment used for fire-fighting tasks and equipment used around the stations. Equipment included lawn equipment, snow blowers, compressors, fans, saws, extrication equipment, and station emergency tones. Noise exposure estimates were collected to determine an estimated exposure during and average work shift. The noise evaluations at the stations occurred during the months of February through May 2010.

# CHAPTER 4: MATERIALS AND METHODS

Noise sampling was conducted at 10 of the 14 PFA stations. The ten stations chosen for sampling were stations that had full-time employees. The other four stations were stations that had on-call volunteer firefighters who did not stay at the stations.

## Area Noise Monitoring

Noise sampling was conducted using a Larson Davis Sound Level Meter 824 (SLM)/octave band analyzer (Larson Davis, Provo, Utah). The SLM was both pre- and post-calibrated for accuracy and was found to be within acceptable limits for calibration (94dB and 114dB). For conducting the noise sampling, the investigator used the OSHA Technical Manual (1999) section three chapter 5 for guidance.(29) The microphone was always held at ear height and approximately one meter from the researcher.

Noise measurements were taken for all trucks and engines that were located at each fire station. Measurements were taken at the front, passenger's side, rear, and driver's side of each truck and engine while they were idling outside the station to simulate their use during a fire. The passenger and driver side samples were taken near the control areas of the truck, to simulate where a firefighter would be standing during the operation of the pumps during an actual firefighting activity. Measurements were also taken on those trucks and engines equipped with generators and pumps while these were operating at high and/or low settings. Again these samples were taken at the front, passenger's side, rear, and driver's side. In addition, measurements were taken inside of the cab of each truck while driving the distance of approximately two blocks to simulate a response to a fire. During this time, measurements were taken with the cab windows closed and with the cab windows open during code-2 and code-3 operations.

Noise monitoring was also conducted on all pieces of equipment on each truck and at each station. The truck equipment included all emergency equipment such as fans, extrication tools, and back-up alarms. The equipment at each station included air compressors, fans, lawn mowers, snow blowers, chain saws, string trimmers, and alarms inside the stations.

Noise Dose Estimates

Firefighters at the PFA work a 24-hour shift rather than a typical eight-hour shift and may be exposed to noise sources from tasks at the fire station and during an emergency response. Given the difficulty of measuring noise exposures during an emergency response, the investigator did not conduct personal noise dosimetry on firefighters to estimate firefighter noise dose during their 24-hour shift. Difficulty in conducting personal dosimetry includes limitations of the dosimetry equipment (e.g., heat-resistant dosimeters) and the unanticipated nature of emergency calls (i.e., the difficulty of attaching noise dosimeters during an actual emergency response).

However, a list of noise-producing equipment and their attendant noise levels were provided by the investigator to a PFA Captain who estimated the time of exposure for each equipment activity during a 24-hour shift and the average number of fire calls during a 24-hour shift. The list of activities and noise levels did not include the estimated noise levels encountered within a burning structure. The percent dose was calculated by the following equation:

Dose = 100 ([C(1)/T(1) + C(2)/T(2) + ... + C(n)/T(n))]

where C = Total time of exposure at a specified noise level; T = total time of exposure permitted at that level).[6].

Data Analysis

The noise data from the Larson Davis SLM were downloaded using the Larson Davis 824 software for analysis at the completion of each sampling episode from each station. Data analysis included descriptive statistics of the equivalent continuous sound pressure level (Leq) using the A-weighted scale and analysis of peak exposures. When determining statistical significance, the probability value (p-value) was to be less than 0.05. The data were analyzed with the statistical analysis software (SAS) and graphed with Microsoft Excel.

# CHAPTER 5: RESULTS AND DISCUSSION

## Engine and Truck Noise

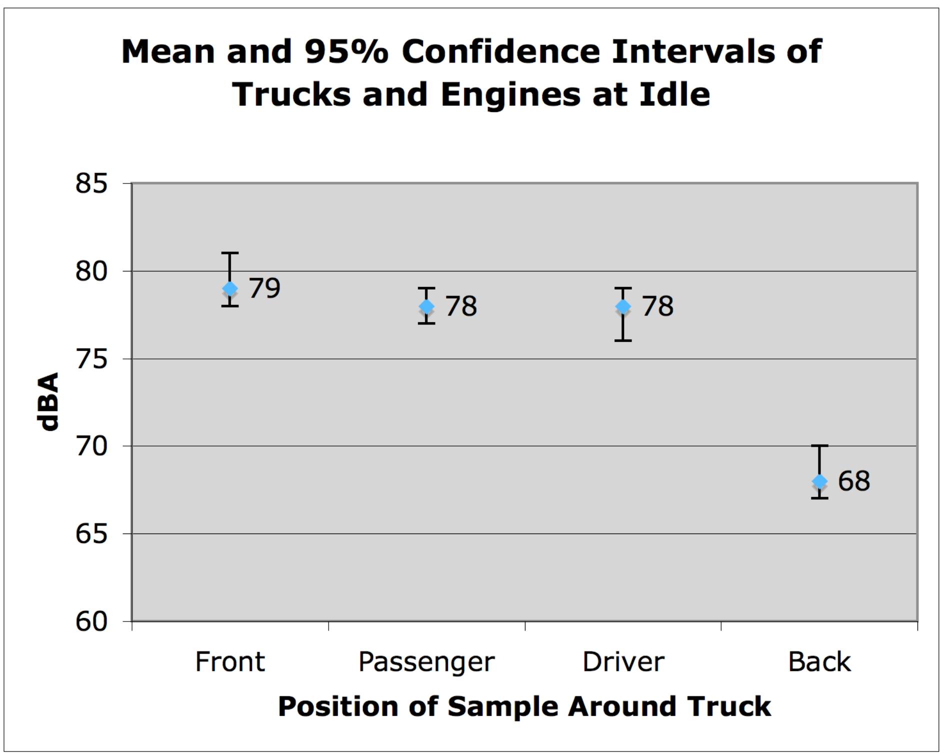
Noise monitoring data for fire engines and all types of "other trucks" were combined for statistical analyses due to the limited number of "other trucks." "Other trucks" included pick-up trucks, ladder trucks, tower trucks, and water trucks that are common to emergency response. It was also noted that there was no significant difference of noise emitted based on the age of the trucks (i.e., older vs. new models).

Mean noise monitoring results and 95% confidence limits calculated from noise measurements taken around the exterior of the engines and trucks while idling are presented in Table 5.1 and Figure 5.1 below. The mean noise levels were significantly different, with the highest mean noise level in front of the truck at 79 dBA and the lowest at the rear of the truck at 68 dBA. The passenger's and driver's sides showed results that were similar to the front of the trucks with 95 % confidence that the noise levels were between 76 and 79 dBA. Even though these results are below the OSHA action level of 85 dBA, to reduce their overall noise dose, it is important for firefighters to stay away from the front of the truck as much as possible and try to work toward the rear where there is a reduction of approximately 10 dBA.

Table 5.1: Mean and 95% Confidence of Noise Results for Trucks and Engines at Idle

| Location of truck | Mean (dB) | 95% Confidence (dB) | |
|---|---|---|---|
| Front | 79 | 78 | 81 |
| Passenger | 78 | 77 | 79 |
| Driver | 78 | 76 | 79 |
| Back | 68 | 67 | 70 |
| n=23 measurements at each location | | | P-value <0.0001 |

Figure 5.1: Mean and 95% Confidence Intervals of Trucks and Engines at Idle




Code-2 and Code-3 Operations

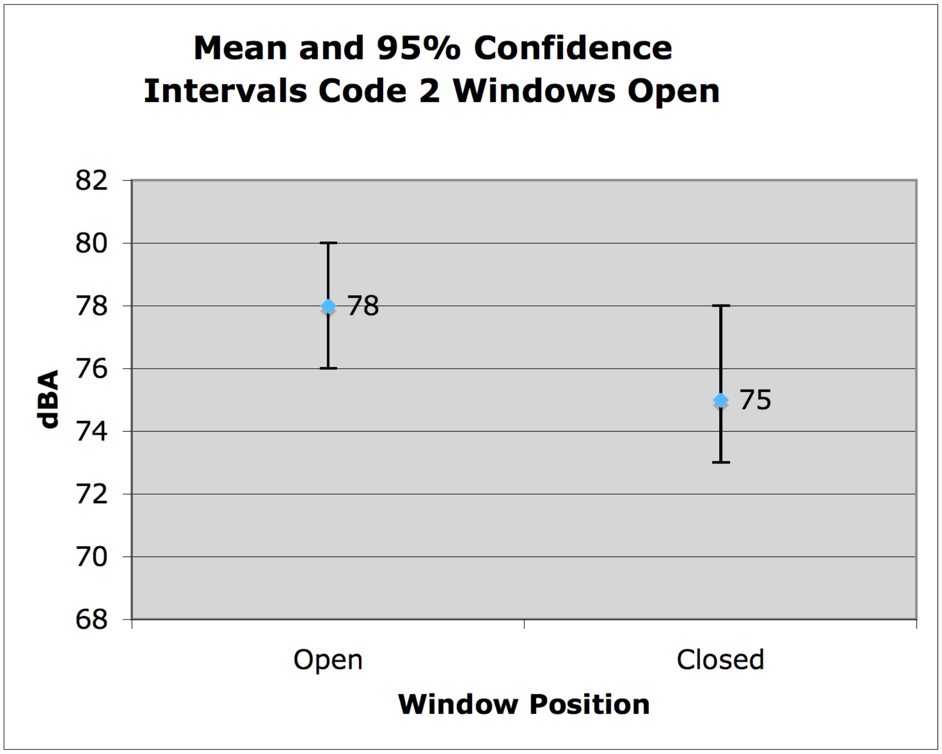
The noise monitoring results of code-2 and code-3 operations for the engines and the other trucks are presented in Tables 5.2 and 5.3 and Figures 5.2 and 5.3. The data from the engines and the trucks were analyzed together and showed that differences in noise based on the truck type was not significant, but the differences in noise based on the position of the truck windows was significant.

The mean noise values and 95% confidence values during a code-2 with the windows closed and the windows open while inside the truck are represented in Table 5.2 and Figure 5.2. The results indicated that during a code-2 operation there was no significant difference (p = 0.10188) in noise level whether the windows were closed or open. The mean noise level when the windows were closed was 75 dBA and 78 dBA when the windows were open. Even though there is only a 3 dB difference between windows closed and open positions, it is still helpful to the firefighters to keep the windows closed to reduce their overall noise dose. These values are also below the OSHA action limit of 85 dBA.

Table 5.2: Mean and 95% Confidence Intervals for Code-2 Windows Closed and Open

| Position of Windows | Mean (dB) | 95% Confidence (dB) | |
|---|---|---|---|
| Open (n=23) | 78 | 76 | 80 |
| Closed (n=25) | 75 | 73 | 78 |
| | p-value: 0.1088 | | |

Figure 5.2 Mean and 95% Confidence Intervals Code-2 Windows Open and Closed

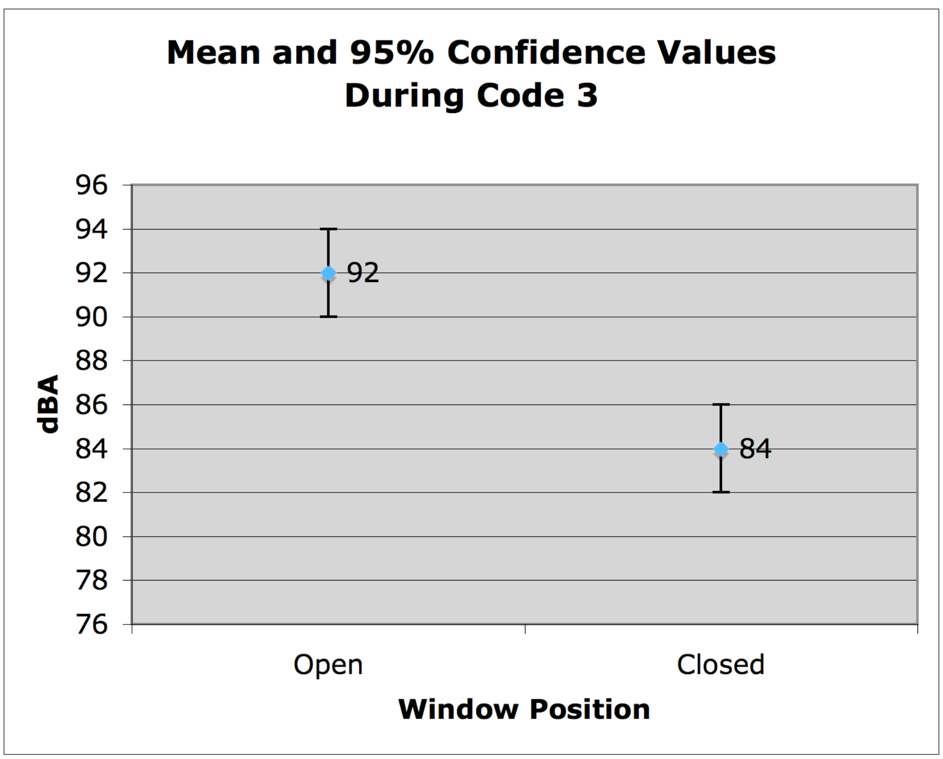



Unlike the code-2 results that did not show a significant difference in noise levels when the windows were closed or open, the code-3 noise results with windows closed or open were significantly different (see Table 5.3 and Figure 5.3). When the windows were open, there was 95% confidence that the mean fell between 90 and 94 dBA. When the windows were closed, there was 95% confidence that the mean value of 84 dBA fell between 82 and 86 dBA. There was an eight-decibel difference in the means comparing window positions, evidence that the data were statistically significant. These data illustrate the importance of window position when the trucks and engines were in code-3. During code-3 with the windows open, there was a potential exposure to hazardous noise levels, and at these levels, hearing protection must be provided and it is up to the employer to make sure the employees are wearing the protection. When the windows are closed, the mean noise value of 84 dBA is close to the OSHA action level of 85 dBA.

Table 5.3: Mean and 95% Confidence Values During Code-3

| Position of Windows | Mean (dB) | 95 % Confidence (dB) | |
|---|---|---|---|
| Open (n=24) | 92 | 90 | 94 |
| Closed (n=25) | 84 | 82 | 86 |
| | p- value < 0.0001 | | |

Figure 5.3: Mean and 95% Confidence Values During Code-3



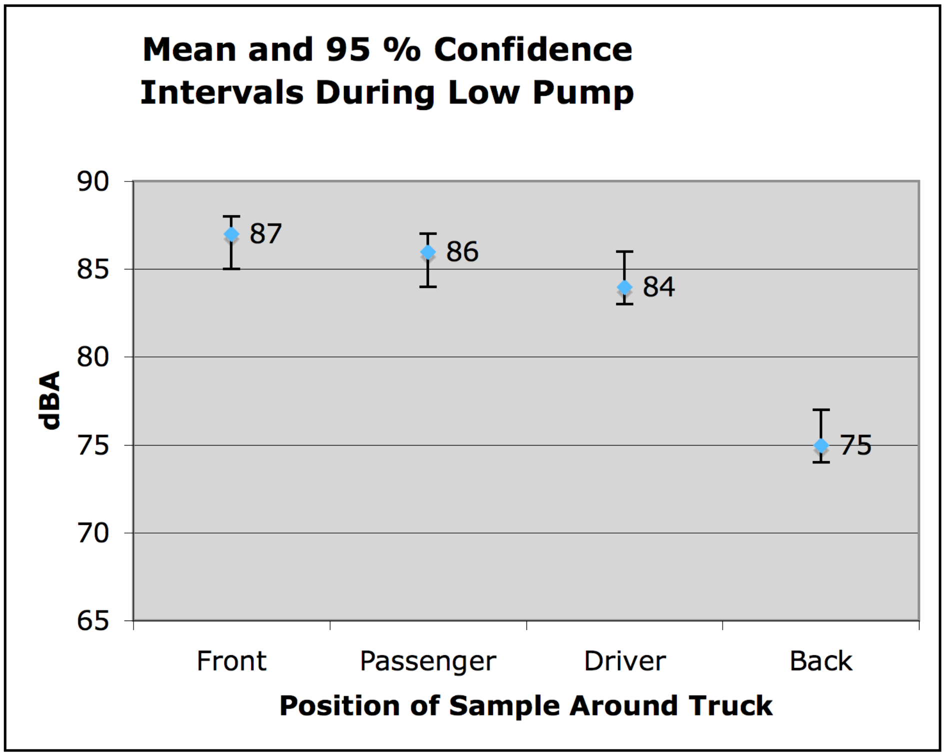

<u>Low Pump</u>

The mean and confidence limits of the noise monitoring results with the pump running at a low psi (pounds per square inch) by location of personnel around the truck are shown in Table 5.4 and Figure 5.4. The results indicated that the noise levels in relation to truck position were statistically significant. The front of the truck was the loudest with a mean of 87 dBA (85, 88). The back of the truck was the quietest with a mean of 75 dBA (74, 77). During the operation of low pump, firefighters should be either on the driver's side or the back of the trucks to try and stay below the OSHA action level of 85 dBA.

Table 5.4: Mean and 95 % Confidence Intervals During Low Pump

| Location of Truck | Mean (dB) | 95% Confidence (dB) | |
|---|---|---|---|
| Front | 87 | 85 | 88 |
| Passenger | 86 | 84 | 87 |
| Driver | 84 | 83 | 86 |
| Back | 75 | 74 | 77 |
| n= 17 measurements at each location | p-value<0.0001 | | |

Figure 5.4 Mean and 95 % Confidence Intervals During Low Pump



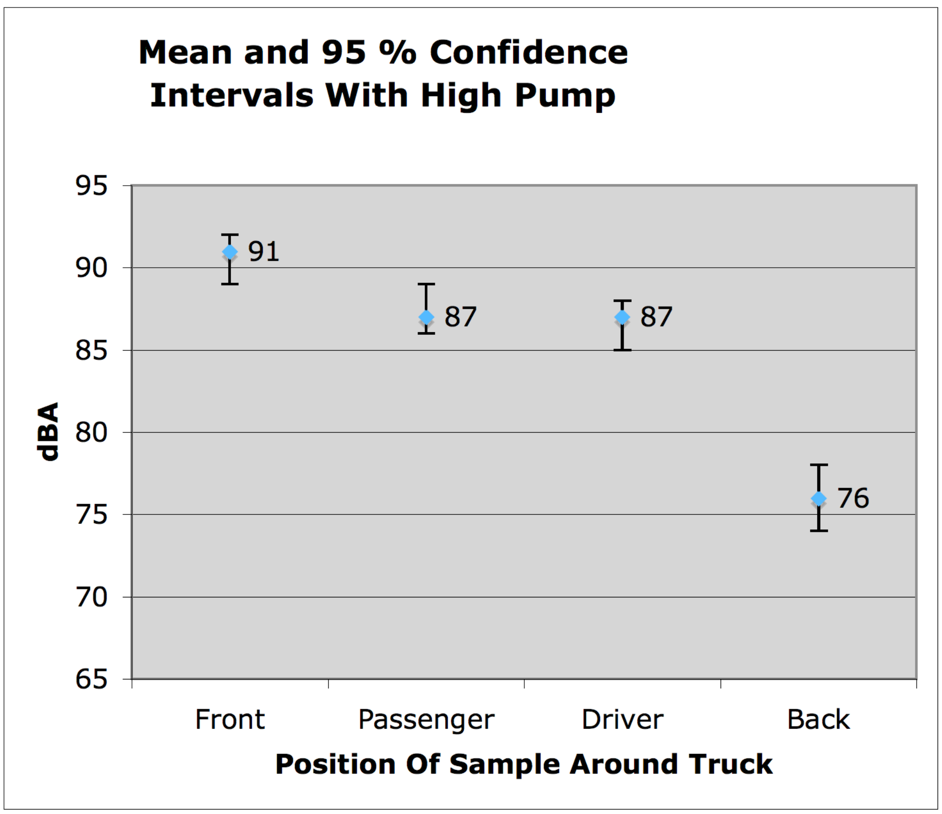

<u>High Pump</u>

Trucks and engines were also sampled in four locations with the pump running at high psi and the results are shown below in Table 5.5 and Figure 5.5. When the trucks and engines had the pump running at high psi, the difference in noise levels based on the location was statistically significant. The back of the truck had a mean noise level of 76 dBA (74, 78), which was the quietest of the four locations around the truck. The front of the truck was the loudest with a mean of 91 dBA (89, 92). The noise levels at the passenger and driver's sides of the truck both had a mean of 87 dBA (85, 89). Compared to the OSHA action level of 85 dB, all of these locations except the back of the truck exceeded the action level.

Table 5.5 Mean and 95 % Confidence Intervals with High Pump

| Location of Truck | Mean (dB) | 95% Confidence (dB) | |
|---|---|---|---|
| Front | 91 | 89 | 92 |
| Passenger | 87 | 86 | 89 |
| Driver | 87 | 85 | 88 |
| Back | 76 | 74 | 78 |
| n=11 measurements for each location | p-value< 0.0001 | | |

Figure 5.5 Mean and 95 % Confidence Intervals with High Pump



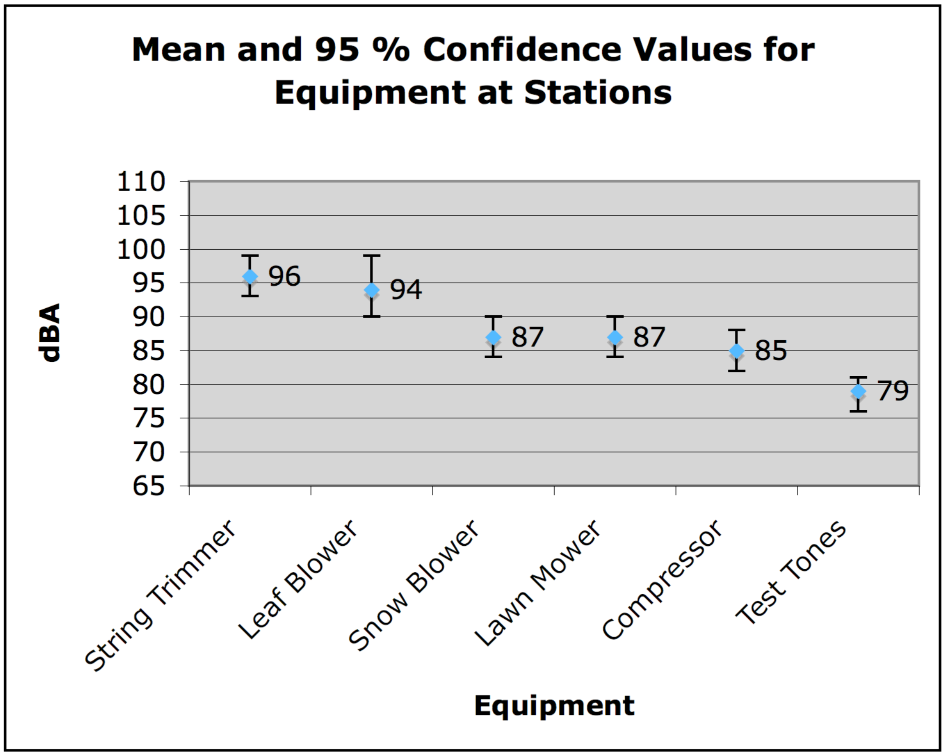
Equipment at Stations

Table 5.6 and Figure 5.6 below show the mean noise values and the 95% confidence intervals for the equipment at the stations. The mean noise levels ranged from 85 dBA to 96 dBA, with confidence intervals of 82 up to 99. All of these means were either at or above the OSHA action level. Test tones, the alarms that signal the firefighters that there was a call, had a mean of 79 dBA (76, 81).

Table 5.6 Mean and 95 % Confidence Values for Equipment at Stations

| Equipment | Mean (dB) | 95% Confidence (dB) | |
|---|---|---|---|
| String Trimmer (n=7) | 96 | 93 | 99 |
| Leaf Blower (n=3) | 94 | 90 | 99 |
| Snow Blower (n=7) | 87 | 84 | 90 |
| Lawn Mower (n=7) | 87 | 84 | 90 |
| Compressor (n=9) | 85 | 82 | 88 |
| Test Tones (n=9) | 79 | 76 | 81 |

Figure 5.6 Mean and 95 % Confidence Values for Equipment at Stations



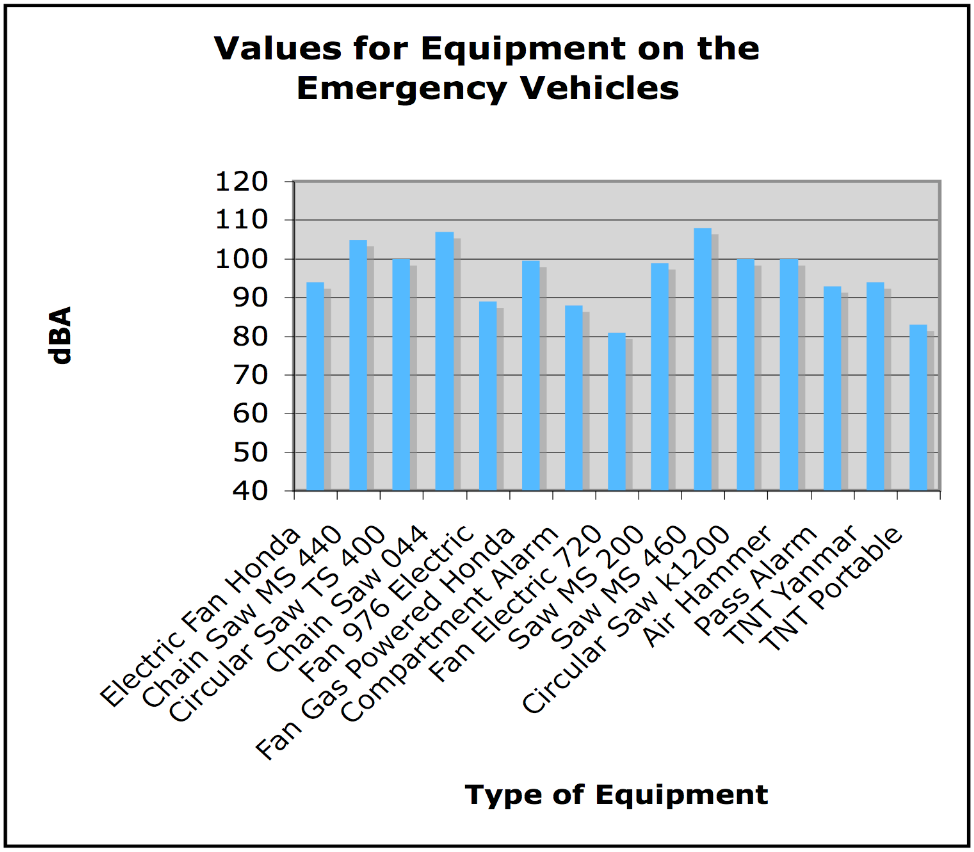

Equipment on Trucks

Samples were taken on the equipment found on the emergency response vehicles (trucks and engines) and the mean noise levels are shown in Table 5.7 and Figure 5.7. The equipment ranged in mean noise values from 81 dBA to 108 dBA. Since one measurement was taken for the majority of the equipment the LEQ value was used. The equipment for which two or three measurements were taken, the mean value was used. All equipment except the electric fan 720 were over the OSHA action limit of 85 dBA, therefore, hearing protection should be provided when using these pieces of equipment. Emergency equipment used in instances such as car accidents, jaws of life, are called TNT equipment in the fire department, these are powered by a generator and firefighters may not be able to distance themselves from the generator depending on the length of the electrical for the piece of equipment. Equipment such as the air hammer is powered by an air pack that is carried on the firefighters' backs or is located beside them. These configurations also pose difficulty in firefighters distancing themselves from the noise source.

Table 5.7 Mean Values for Equipment on the Emergency Vehicles.

| Equipment on trucks | Mean (dBA) |
|---|---|
| Electric Fan – Honda (n = 2) | 94 |
| Chain saw-STIHL- MS 440 (n=2) | 105 |
| Circular saw- STIHL- TS 400 (n=2) | 100 |
| Chain saw –STIHL- 044 (n=2) | 107 |
| Fan -976- Electric (n=1) | 89 |
| Fan- Gas Powered- Honda –GX 200- (n=2) | 100 |
| Compartment Alarm (n=1) | 88 |
| Fan – Electric- Super vac- 720 (n=1) | 81 |
| Saw –STIHL- MS-200 (n=1) | 99 |
| Saw- STIHL- MS 460 (n=1) | 108 |
| Circular Saw- Mark II- k1200 (n=1) | 100 |
| Air Hammer- Pakhammer (n=1) | 100 |
| Pass Alarm (n=1) | 93 |
| TNT Yanmar (n=1) | 94 |
| TNT Portable (n=1) | 83 |

Figure 5.7: Mean Values for Equipment on the Emergency Vehicles.




Estimated Noise Dose

The estimated noise doses as listed below in Table 5.8 are based on a typical 24-hour shift in the PFA. The estimated times of exposure for each task were provided by the PFA Captain of Station 1for firefighters working at Station 1. Station 1 was chosen for these estimates since it is, on average, the busiest of all the stations in Fort Collins, CO. Thus, these estimates can be generalized as the worst-case exposures in the PFA. An average noise dose of 48.7% was calculated for the 24 hour shift , which may vary depending on the amount of downtime and other activities firefighters experience during the shift. Dose was calculated using the OSHA criterion level of 90 dBA and an exchange rate of 5 dB. The downtime decibel level was calculated by averaging the noise levels of sleep (30dBA), normal conversation(60 dBA), noisy office (80 dBA), and kitchen noise. By using the calculation available by the Canadian Centre for Occupational Health and Safety the calculated allowable TWA for a 24-hour shift is 77dBA.[24]

There are a few steps to calculate the noise dose for each task. First step is to figure the total duration for how long each task occurs in minutes and then convert this time into hours. By using the data taken during sampling the noise level for that task could be added to the table. Then by using the table G16-A on the OSHA website the dB reading from during sampling can be found on the table to see what the recommended time spent at the noise level is.[26] The noise dose for each task was then: durationof hours exposed/ reference duration (in hours)

It should be noted, however, that the estimated noise doses do not include the mean noise levels that are experienced by firefighters while inside a burning structure. To the author's knowledge, these noise data have not been published, presumably because of the difficulties discussed earlier in collecting such noise data. Therefore, the average estimated noise dose may increase when firefighter noise monitoring data become available and are included in the noise dose estimate.

Table 5.8: Estimated Noise Dose

| Task | Duration (Minutes) | Duration in hours | Noise level (dB) | % Dose Calculation | %Dose |
|---|---|---|---|---|---|
| Code-2 | 100 | 1.67 | 78 | 1.67/42 | .04 |
| Code-3 | 70 | 1.17 | 92 | 1.17/6.1 | .192 |
| Station Tones | 3.75 | .063 | 79 | .063/36.8 | .001 |
| Compressor | 5 | .083 | 85 | .083/16 | .005 |
| Pass Alarm | .33 | .006 | 93 | .006/5.3 | .001 |
| Fan 720 | 3 | .05 | 81 | .05/27.9 | .002 |
| Chainsaw 440 | 3 | .05 | 105 | .05/1 | .05 |
| Circular saw | 3 | .05 | 100 | .05/2 | .025 |

| | | | | | |
|---|---|---|---|---|---|
| Honda fan-gas | 3 | .05 | 100 | .05/2 | .025 |
| Saw MS 200 | 3 | .05 | 99 | .05/2.3 | .022 |
| Saw MS 460 | 3 | .05 | 108 | .05/.66 | .076 |
| Air Hammer | 3 | .05 | 100 | .05/2 | .025 |
| Down Time | 1239.92 | 20.7 | 56.25 | 20.07/861 | .023 |
| Total | 1440 | 24 | --- | ---- | 48.7% |

Results of Original Research Questions

The evaluation of the Poudre Fire Authority was used to answer the following research question:

1. Are firefighters in the PFA exposed to equipment that emits noise levels that might exceed published exposure limits and possibly lead to NIHL?

Firefighters are exposed to relatively loud pieces of equipment (i.e., greater than 85 dBA) that contribute to their daily noise doses. However, based on the estimated, average time-of-use for each piece of equipment used during a 24-hour shift, firefighter overall, estimated noise dose using the equipment in this study did not exceed 100% (i.e., firefighters were not overexposed to noise). Given the variability that is inherent to the time-of-use of the equipment and the difficulty in taking personal noise measurements over an entire shift, the estimated noise dose for a 24-hour shift will vary from the researcher's estimate of 48.7%. It can be assumed that these loud pieces of equipment contribute to NIHL since firefighters have been shown to have excessive NIHL when compared to the general population. Since current technology does not allow for the measurement of noise during actual firefighting events, firefighters may have the potential to exceed published noise exposure limits during a 24-hour shift in contrast to the results of noise dose in this study.

Another factor to take into account is that when the firefighters are not engaged in emergency calls or are not using equipment around the fire station, they are exposed to relatively quiet noises associated with sleeping, talking, watching TV, or cooking; which are classified as down time and may consume as much as 20 hours in a 24 hour shift.

Downtime noise exposures (estimated at 56 dBA), allow for the recovery of the hearing mechanism.

Based on the noise monitoring results of this study and the estimated time of exposure, the use of the equipment certainly adds to firefighter noise dose, but did not result in overexposure to published exposure limits. When additional noise exposure data become available and are factored into the estimated noise doses, the firefighters may have the potential to exceed published noise exposure limits.

## Discussion

Consistent with previous studies, a code-3 operation resulted in significantly higher noise levels than a code-2 operation, and during a code-3 operation, the noise levels were significantly different based on the position of the windows.(23,1,2) These results were expected based on a previous study that indicated that the highest noise measurements were during code-3 operations.(8)

The measured sound pressure levels in this study that exceeded 85 dBA included code-3 operations with windows open (92 dBA); front and passenger sides of the trucks when the pump was on low psi (87, 86 dBA); front, passenger, and drivers sides of the truck when pump was at high psi (91, 87, and 87 dBA); all pieces of equipment except test tones, the electric fan 720, and the TNT portable. The study conducted by Colorado State University (CSU) in 1989 with the PFA reported noise measurements of 103 dBA to 114 dBA emitted from the chain saws. (23) Some of the chain saw measurements are similar to the current study in that the decibel levels in this study for the chain saws range from 99dBA to 108dBA. In addition, the CSU study reported that the noise levels from firefighter trucks with the pumps running ranged from 81 to 102 dBA on the emergency vehicles.[23] This data range is also consistent with samples taken during this study.

When examining the noise levels emitted from the four positions around the trucks, the highest noise levels were associated with the equipment location on the truck. The front of the truck was consistently the loudest, (87dBA and 91dBA), due to the engine noise and the air movement into the radiator and fans within the engine compartment. It was observed that the harder the truck was running, the louder the noise emitted from the front of the truck. The quietest, (76 dBA and 75 dBA), areas were the backs of the trucks which did not house equipment that would generate additional noise. The backs of the trucks were also the furthest point from the areas of the truck that were generating noise. The driver and passenger, (87 dBA, and 85 dBA), sides of the trucks were consistent in noise levels due to the presence of the generators.

Results from the equipment used at the fire stations showed noise level measurements ranging from 81 dBA to 108 dBA. Thirteen of the 15 pieces of equipment had measured noise levels greater than 85 dBA. Therefore, it is highly recommended that firefighters wear hearing protection devices while using these pieces of equipment to lower their risk of NIHL.

The different saws that were measured all resulted in a range measured noise levels, (99 dBA to 108 dBA), and the different fans that were measured also resulted in similar measured noise levels. These results are consistent with the noise measurements conducted by Blehm (1989) for the similar pieces of equipment.[23]

Noise measurements were also taken during the operation of lawn and snow-removal equipment,(79 dBA to 96 dBA). These sources of firefighter noise exposure have not been identified in the literature as contributors to firefighter noise dose, presumably since they are used not on a regular basis or for emergency use. The noise emitted from these pieces of equipment was measured from 87 dBA to 96 dBA. The measured noise level results of this study for specific types of equipment were found to be similar to the results from NIOSH.[1,2,3]

Based on the estimated time-of-use for the equipment measured in this study and the estimated downtime for PFA firefighters during a 24-hour shift, a dose of 48% was calculated based on the OSHA criterion level of 90 dBA and an exchange rate of 5 dBA. As shown in Table 5.7 there are many tasks that occur during the 24-hour shift of a PFA firefighter. Although an overexposure to noise was not predicted in this study based on the measured equipment noise levels and time of use, it is acknowledged that all PFA firefighter noise sources were not taken into account (e.g., noise encountered during firefighting activities within a burning structure). However, it can be assumed that the noise dose to PFA firefighters from the measured equipment may contribute to NIHL since studies have shown that firefighters have elevated NIHL as compared to the general population.[22,8,1,2]

One cause that may contribute to the elevated NIHL experienced by firefighters is the lack of hearing protection being worn by firefighters during emergency calls or fires when loud equipment is used. Emergency or firefighting activities significantly vary in time, thus influencing the amount of time that noisy equipment is used which contributes the daily firefighter noise dose. In addition, firefighter exposure to code-3 sirens may vary greatly depending on the time it takes to arrive at the emergency site. Some emergency sites may involve a five to ten minute drive, whereas others may take 15 to

45 minutes.   Firefighter activities at a site and the response time to a site will both affect the noise dose experienced by firefighters.

Another area of concern is the use of “headsets” that include a microphone for firefighter communication.  When firefighters are responding to an emergency call, they wear headsets which  are supposed to protect them from the noise of truck.  However, the headsets have a built-in microphone for communication, which, if elevated over the noise from the truck, could contribute to excessive noise exposure.  In addition, the headsets also amplify siren and other background noise from the truck, for example, the noise generated from wind traveling over the microphone from open windows.

<u>Study Limitations</u>

The primary limitations of this study in predicting firefighter noise dose during a 24-hour shift were: (1) the estimated firefighter time-of-exposure to the noise-measured equipment, and (2) the lack of noise-exposure data from actual emergency responses in the noise-dose calculation.   Firefighter noise exposure times to the equipment evaluated in this study can vary widely depending on the number of emergency calls during a 24-hour shift and the time to complete other tasks within the fire stations.   Each call and emergency response has its own unique characteristics based on the severity of the incident.   Also, the number of emergency calls can vary between the PFA stations. Some PFA stations are located in areas that receive relatively more emergency calls, such as Stations 1 and 3, and other stations are located in more remote areas that receive relatively less calls.

The estimated times of exposure to equipment were solicited from the PFA Station One Captain who has more than 25 years of service with the PFA, thus, these are the best estimates of exposure times for Station One at this time. However, without actually monitoring a sufficient number of full-shift firefighter noise exposures, the estimate of a 48.7% dose may vary on a day-to-day basis.

Secondly, without the equipment capability to measure the noise doses accumulated by firefighters inside burning structures during firefighting activities, it is not possible at this time to account for the contribution of noise to firefighter noise dose during firefighting within a burning structure. Thus, personal noise dosimetry was not conducted since: (1) current monitoring devices are not able to withstand firefighting conditions (e.g., excessive heat and physical forces); and (2) personal dosimetry would hamper firefighter response time (attaching and activating noise dosimeters to firefighters during an emergency response).

# CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

PFA Firefighters in this study were found to be potentially exposed to relatively high levels of equipment noise for different tasks throughout the PFA fire departments. The equipment noise exposure was estimated to contribute a noise dose of 48%. However, since there were numerous tasks that have to be considered into the calculation of firefighter noise dose during a 24-shift, there remains significant variability in the daily noise exposure.

The truck equipment measured in this study is used depending on the severity of the emergency call, so there is variability in noise exposures between shifts and also between stations. However, by identifying the level of noise emissions for the truck equipment and the estimated time of use, a noise dose can be calculated for the shift. However, since firefighters are not always on calls and the calls may or may not require sirens and horns then it is difficult to estimate the exposure for each shift.

When the firefighters are on a call, the trucks remain in idle mode. When calls consist of a house fire or accident, equipment on the trucks need to be used, requiring the generator and pumps to operate. This study demonstrates the difference in the noise levels depending on where the firefighter is located around the truck. The front of the truck was consistently the loudest with the back of the truck the quietest. By identifying the noise levels for each side of the truck, firefighters can be more aware of where they are standing around the truck and possibly back the truck up to a scene rather than driving forward to help reduce the noise levels.

## Recommendations

Strategies to lower the noise exposure for firefighters encompass the trucks, the station itself, equipment at the station, and equipment on the trucks. Even though the exposure may be reduced since the shifts are 24 hours in duration, there are still items that should be addressed to lower the immediate exposure while conducting certain tasks.

1. When buying new trucks, the trucks should have air conditioning. The PFA firefighters communicated that they travel in the trucks with the windows open because they get hot while wearing all of their equipment. In-truck air conditioning would cool the firefighters and allow them to keep the windows in a closed position, resulting in a lower noise exposure, especially during the code-3 operations.

2. For the trucks that do not have air conditioning, windows should be left in the closed position during code-3 as much as possible.

3. Hearing protection should be worn when using fans and saws during operation.

4. When applicable, longer cords for equipment that needs to be hooked up to a generator should be considered. This will help distance the firefighters from the noise source.

5. When filling air tanks, hearing protection should be worn.

6. Training should be conducted concerning the noise levels to which firefighters are exposed and the effects that these noise levels have on their hearing.

7. The fire department should consider purchasing an audiometer to conduct hearing tests on-site.

## Future Research

This study has shown that PFA firefighters have the potential for noise exposures to relatively loud pieces of equipment during a 24-hour shift. Further, based on the estimated times of use for the various pieces of equipment, equipment use alone may contribute nearly 50% of the noise dose experienced by firefighters. PFA firefighter noise exposures are also dependent on the number and severity of calls that are received during a shift.

Studies conducted in the 1980's showed similar noise-monitoring results as in this study.[23,1,3] Future studies should include personal sampling over the 24 hour shift during different times of the year for the development of noise-exposure tables that represent a full year. This would provide a more accurate exposure estimate. It is also recommended that cohorts of firefighters of different age groups be evaluated for hearing loss over a period of time, five to ten years, to examine the correlation between hearing loss and firefighter noise exposure.

Future studies should also evaluate at the noise associated with the microphones and headsets used throughout the fire department. The volume of the microphones could be increased to levels that may harm firefighter hearing if they are trying to hear directions over a fire. While riding in the truck, the headsets can amplify the wind and siren if the windows are open. These noises, in addition to firefighter communication, could pose hazardous levels of noise.

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