THESIS

CONTRIBUTION OF SMALL SCALE DETONATIONS TO DAILY OCCUPATIONAL NOISE EXPOSURE

Submitted by

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ABSTRACT

CONTRIBUTION OF SMALL SCALE DETONATIONS TO DAILY OCCUPATIONAL NOISE EXPOSURE

Hazardous levels of occupational noise exposure are of great concern due to the progressive nature of hearing loss. A one-time exposure to hazardous levels of noise may result in irreversible hair cell damage that could result in permanent hearing loss. This study focused on the contribution of small scale detonations to daily noise at Sandia National Laboratories (SNL). Personal noise monitoring was conducted for eleven employees to evaluate noise exposure for an eight hour period to determine the effects of small detonations and potential risk of noise induced hearing loss. Weights of various explosive materials ranged from 18 milligrams (mg) to 275 grams (g). Sound level meters were also used to determine if peak impulse noise measurements were under the occupational exposure limit of 140 dBC. Noise evaluations were conducted in five facilities that included two indoor boom boxes, two indoor firing pads, and one outdoor firing pad.

The results of this study were used to conclude that no employees exceeded published exposure limits (85dBA, 3 dB exchange rate or 90 dBA, 5 dB exchange rate) nor at any point were employees exposed to noise levels above 140 dBC during detonations. According to SNL policy employers are required to enroll employees in a HCP if the 8-hr time weighted average (TWA) is greater than 85 dBA (3 dB exchange rate). A linear regression analysis was performed for each detonation location to determine the potential relationship between explosive weight and TWA for dosimetry results and peak levels of noise for sound level meter results. It was suggested that the relationship between explosive weight and LCPeak levels of the firing pad

(p=0.283) and outdoor firing pad (p=0.801) were not statistically significant. Further, boom box activities had a significant relationship (p=0.001) however due to small sample sizes and variation of weights it is unclear whether the difference is due to explosive weight or activity. The p-values for ACGIH criteria (p=0.092) and OSHA criteria (p=0.34) were calculated and it was found that the linear relationship between explosive weight and TWA were not statistically significant. Based on the results of this field study and small sample sizes it was not possible to determine the explosive quantity at which hearing protection should be required.

To determine the contribution of small scale detonations to daily noise exposures, noise samples that were collected during detonations were removed from employee TWAs. New TWAs were calculated and compared to the original data output. It was found that detonations increased employee ACGIH TWAs from only 1-8 dB.

Impulse noise measurements obtained in this study were used to conclude that controls currently in place, including barriers, distance, and hearing protection, were effective means to employee safety and health.

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U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

DEDICATION

For my family especially my parents whose unwavering love and encouragement gives me strength.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

CHAPTER 1: INTRODUCTION

The human ear is the organ which converts a pressure wave into a mechanical force, and then back into a pressure wave which is then converted to an electrical signal that the brain decodes as sound. The National Institute for Occupational Safety and Health (NIOSH) has estimated that 5 to 30 million workers are exposed to hazardous levels of noise. In addition, as many as 10 million workers have irreversible noise-induced hearing loss (NIH, 2008). Consequently, the necessity for regulations that help control and mitigate noise in the workplace is of the upmost importance in regards to occupational health and safety. The regulations and recommendations that are presented in this study emanate from the American Conference of Governmental Industrial Hygienists (ACGIH) and the Occupational Safety and Health Administration (OSHA).

Noise is described as the presence of any unwanted or undesirable sound and is capable of producing a variety of adverse health effects within the human body such as temporary and even permanent threshold shifts that affect a person’s ability to hear (NIOSH, 1998). Prolonged exposures to noise levels exceeding 85 decibels (dB) may contribute not only to hearing loss but to increased blood pressure and hypertension (Berger, Royster, Royster, Driscoll, & Layne, 2003). This also includes but is not limited to adverse health effects related to various organs of the body when exposed to blast overpressures which are a result of “high intensity disturbance in the ambient air pressure” (Patterson Jr. & Hamernik, 1997).

The effects of occupational impulse noise and daily activities involving the detonation of explosive materials on noise induced hearing loss (NIHL) was central to this study. Sound level meters (SLM) and personal noise dosimeters were used to determine the intensity and duration of noise exposures in the workplace to examine the potential for NIHL, which results in damage to the hair cells of the inner ear (Berger, Royster, Royster, Driscoll, & Layne, 2003). NIHL is wholly preventable, which is why it is important to address this issue with a proactive approach rather than retroactively.

This study focused on measuring personal noise exposures during small scale detonations at Sandia National Laboratories (SNL) to determine the contribution to daily noise exposures, and determining a threshold (e.g. quantity of explosives or test type) at which hearing protection is required. As one of the nation's top science and engineering laboratories addressing national security missions, the safety and health of employees are of primary importance to SNL. Activities vary daily within SNL therefore a range of explosive materials, weights, and locations of employees were recorded in this study to examine noise exposures. Exposures to explosives are a critical area of concern due to the rapid output of impulse noise emitted. The noise exposure assessment of employee activities was beneficial in determining whether or not employees are exposed to noise levels exceeding the ACGIH Threshold Limit Value (TLV) of 85 dBA and/or the C-weighted peak of 140 dB during various detonation activities. Additionally, this assessment assisted in determining the necessity of enrollment into a hearing conservation program (HCP), should the ACGIH criterion be exceeded. SNL follows the ACGIH TLVs therefore employees exposed to noise levels at or above 85 dBA 3 dB exchange rate for an 8 hour work day must be enrolled in the HCP.

CHAPTER 2: LITERATURE REVIEW

The Human Ear and Sound

The structure of the human ear is comprised of three main segments known as the outer ear, middle ear, and inner ear; all of which are used in a process to transfer sound that can be interpreted by the brain. Figure 2.1 illustrates the movement of sound through the human ear. Sound is collected by the outer ear, which is comprised of the pinna (or auricle), external auditory canal, and tympanic membrane. It is in this region of the ear that certain frequencies are either amplified or attenuated to enhance the transmission of sound. As the outer ear gathers sounds in the 2,000 to 4,000 hertz (Hz) regions the sounds are amplified by approximately 10-15 decibels (dB) thus resulting in what is considered the most hazardous region of hearing (Berger, Royster, Royster, Driscoll, & Layne, 2003). As sound exits the outer ear, it enters the middle ear through the tympanic membrane.

The function of the middle ear is to transmit sound by way of the tympanic membrane and the ossicles (or bones of the middle ear), to the entrance of the inner ear by way of the oval window. As the tympanic membrane vibrates in response to the sound waves, the ossicles (malleus, incus, and stapes) transfer the sound wave into a force wave which is amplified approximately 1.3 times. Without the function of the middle ear only $1/1000^{th}$ of acoustic energy in air would be transmitted to the inner ear fluids (Berger, Royster, Royster, Driscoll, & Layne, 2003).

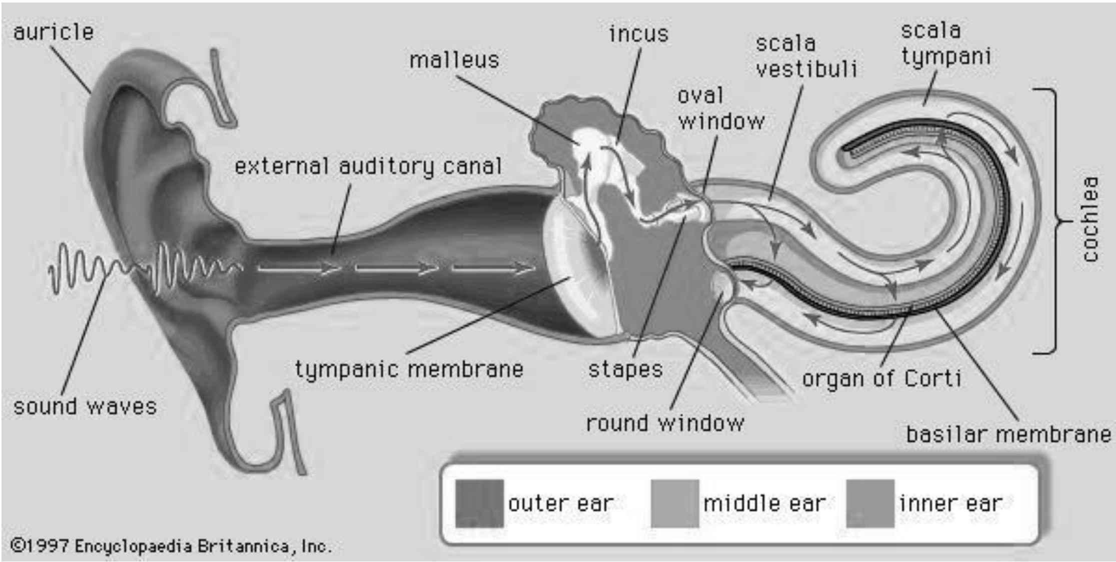

Figure 2.1 Structures of the Human Ear (Encyclopedia Britannica, 2013)

The fluid filled inner ear is comprised of the cochlea and operates to perceive sound using the Organ of Corti that rests on the basilar membrane of the cochlea. The cochlea houses approximately 4,000 inner hair cells and 12,000 outer hair cells that function to initiate neural impulses in the auditory nerve (Berger, Royster, Royster, Driscoll, & Layne, 2003). These neural impulses occur as the basilar membrane moves up or down which causes the stereocilia of the hair cells to bend. The stereocilia are the fine hairs that extend from each hair cell and vary in thickness. Thicker stereocilia resonate with high frequencies whereas thinner stereocilia resonate with low frequencies (see Figure 2.2). The pressure wave that is formed within the cochlea is converted to an electrical signal which the brain decodes as sound. If the stereocilia break (as observed with hazardous levels of noise), the damage is irreversible.

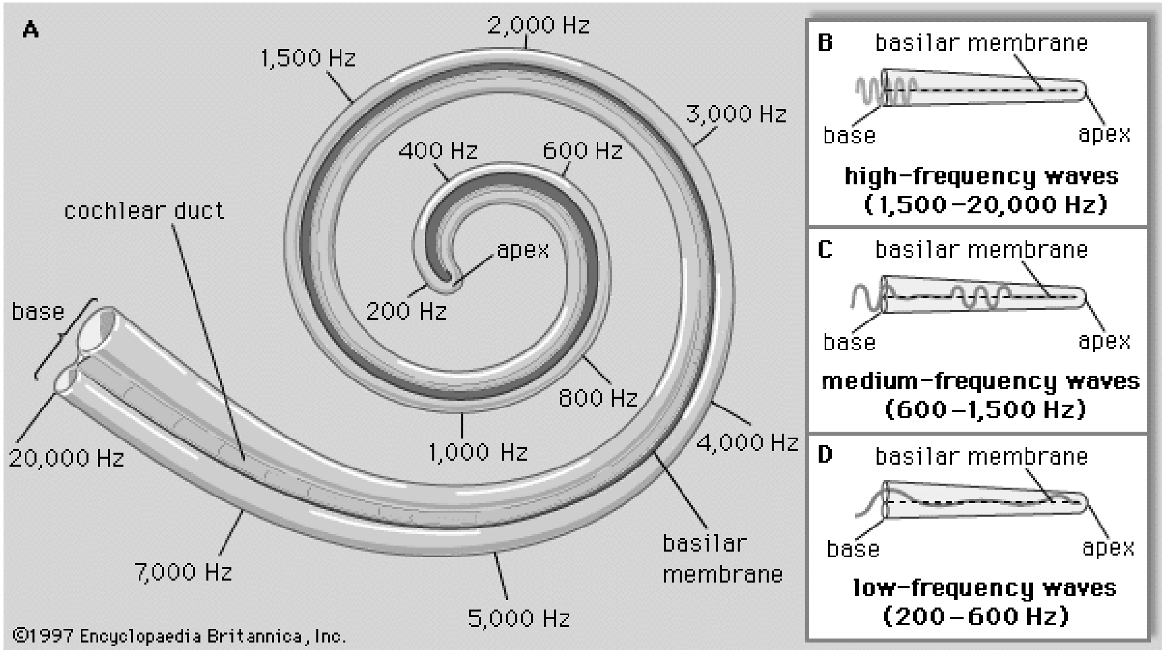

Figure 2.2 Frequencies of the Basilar Membrane (Encyclopedia Britannica, 2013)

<u>Noise Induced Hearing Loss</u>

NIHL is of great concern in today's society as it is one of the leading occupational diseases (Lynch & Kil, 2005). It can be caused by simply one exposure to an impulse sound or over many (NIDCD, 2012). Exposure to noise may lead to a temporary threshold shift (TTS) which is a decrease in hearing sensitivity that returns hearing within minutes or hours of exposure. A permanent threshold shift (PTS) on the other hand, results in irreversible hearing loss (HL) (NIOSH, 1998). Shone et al. (1991) used mice of the CBA/CaJ strain known to have age-related HL (known in humans as presbycusis) to demonstrate that those with HL are more susceptible to PTSs than those mice without evidence of HL. To determine the sensitivity of HL, the mice underwent an electrophysiological assessment to examine baseline sensitivity to noise. The mice were exposed to 101 dB for 45 minutes and post-noise thresholds were evaluated one hour and one week following the noise exposure. Mice were then euthanized to determine the distribution of hair cell loss. The researchers noted that the anatomical pattern of hair loss seen in this strain of mice is comparable to human presbycusis. This study was useful because it recommends that increased measures should be taken to protect individuals with age-related HL from further cochlear damage that could result in a PTS.

Threshold Limit Values

Threshold limit values (TLVs) for noise that are relevant to this study are from guidelines published by ACGIH. The TLVs are pertinent because they were established to "protect the median of the population against a noise-induced hearing loss exceeding 2 dB after 40 years of occupational exposure for the average of 0.5, 1, 2, and 3 kHz" (ACGIH, 2012). These guidelines are not intended to protect all workers in every situation but rather, "represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect on their ability to hear and understand normal speech" (ACGIH, 2012).

The values listed in Table 2.1 represent the TLVs for noise to which workers may be repeatedly exposed without adverse effects on human hearing (ACGIH, 2012). The duration of exposure should never exceed the TLVs presented.

The sound pressure level (SPL) is measured by using either a SLM or a noise dosimeter set at an A-weighted network with a slow meter response. The ACGIH noise-exposure criterion for an 8-hour workday is a sound level of 85 dBA with a 3 dB exchange rate. In other words, for every 3 dB increase above 85 dBA the allowed duration is cut in half (Berger, Royster, Royster, Driscoll, & Layne, 2003). Likewise, the TLV is exceeded when the dose is more than 100% on a noise dosimeter set for a criterion level of 85 dBA with a 3 dB exchange rate for an 8-hour work day (ACGIH, 2012).

Table 2.1 Threshold Limit Values for Noise (ACGIH, 2012)

	Duration per Day	Sound Level dBA
Hours	8	85
	4	88
Minutes	30	97
	15	100
Seconds	1.76	127
	0.88	130
	0.44	133
	0.22	136
	0.11	139

Hearing Conservation Program

The permissible exposure limits (PELs) set forth by OSHA are enforced to assure employees do not exceed 90 dBA with an exchange rate of 5 dB for an 8-hour TWA. OSHA's HCP found in 29CFR1910.95(c)(1) was established and employers are required to administer a continuing, effective HCP should "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" (OSHA, 1999). Employees should receive audiometric testing at no cost if they are exposed to an action level of 85 dB (5dB exchange rate) or higher for an 8-hour TWA. This includes a baseline audiogram, annual audiogram, and training (OSHA 3074, 2002). Employers must also provide employees with hearing protection with a variety of at least two different types (i.e., ear plugs and ear muffs). The use of personal protective equipment (PPE), however, is the last line of defense in protecting workers from hazardous noise exposures. Employees who show a standard threshold shift (STS) (a decrease in hearing acuity of 10 dB or more at 2,000, 3,000, and 4,000 hertz) must be fitted or refitted with sufficient hearing protection

(OSHA 3074, 2002). The difference between the OSHA PEL and OSHA HCP is that unlike the PEL which requires employee noise exposure to be less than 90 dBA with a 5 dB exchange rate, the HCP requires actions be taken at the OSHA action level of 85 dBA or a dose of 50%. For the purpose of this study entrance to the HCP is required at SNL if the ACGIH TLV (85 dBA, 3 dB exchange rate) is exceeded.

Sound Level Meters and Dosimeters

A basic SLM is used to measure and assess noise exposure in a surrounding environment by sensing acoustic pressure to record sound levels (Berger, Royster, Royster, Driscoll, & Layne, 2003). The SLM data are used to evaluate the need for engineering controls to abate the noise as necessary. There are a wide variety of SLMs to choose form that vary based on types. These types are known as 0, 1, 2, and special type (S) and are designated to represent different functions (Berger, Royster, Royster, Driscoll, & Layne, 2003). Though these types differ regarding how and where they are to be used, they all consist of a microphone, a frequency selective amplifier, and an indicator which are used to measure SPLs in decibels (NIOSH, 1998).

Unlike SLMs, noise dosimeter microphones are attached in an employee's hearing zone to evaluate continuous levels of noise to determine an employee's TWA or noise dose (NIOSH, 1998). To assure the noise measurement equipment functions properly, a pre- and post-calibration must be performed to determine the accuracy of the reading by emitting a specified SPL and frequency into a microphone (Berger, Royster, Royster, Driscoll, & Layne, 2003). Dosimeters contain several settings including threshold levels, exchange rates, crest levels, and weighting. Threshold levels represent standard noise level (dB) and vary based on the agency that publishes them. When a noise level increases by the decibel value of an exchange rate, the duration time is cut in half. The weighting uses a filter to help determine how loud a noise level is. A-weighting most closely depicts how a human ear hears whereas C-weighting includes low frequencies which better depicts high noise levels than the A-weighting scale. Crest factors are used to specify the accuracy a sound measurement tool when measuring peak levels of noise.

Relevant Studies

In a study by Patterson Jr. and Hamernik (1997), injury to the inner ear from blast overpressure was analyzed to determine structural and functional changes in the auditory system. Blast overpressure was categorized in this study as a "high intensity disturbance in the ambient air pressure." The focus was directed toward military personnel who were exposed to various categories of blast overpressure including sounds exhibited from firing heavy weapons and the detonation of explosives and munitions with peak overpressures that ranged from 160-175 dBC. Histological data analysis of chinchillas exposed to different impulse intensities were used to determine threshold shifts. Chinchillas were used due to the similar function of inner- and outer-ear sound transfer as seen in humans. The researchers determined the greater exposures resulted in greater threshold shifts, which also showed an increase in hearing loss over the first 6-12 hours following the exposure. Missing or damaged sensory cells were counted along the basilar membrane to quantify the results. The data were extrapolated to compare chinchilla data to the human ear. The results revealed the sensitivity of the human ear which, when affected in an unprotected state, damages the basilar membrane of the inner ear, the tympanic membrane and conductive structures of the middle ear.

Researchers collaborated with the Singapore Armed Forces to conduct a series of audiometric tests to determine the effectiveness of their hearing conservation program (Teo, Chia, Tan, & Ali, 2008). Pure tone audiometric assessments and questionnaires were performed at the beginning and end of military training, and one year into vocational military training (Teo, Chia, Tan, & Ali, 2008). Researchers of this study were concerned with the level of impulse noise to which military personnel were exposed and thus wanted to determine the effectiveness of hearing protection. The researchers concluded that hearing thresholds did not exceed a difference of 25 dB in either ear, which is defined as hearing loss by OSHA, however the threshold shifts may have been significant. The researchers concluded that the threshold shifts may be temporary or permanent but did not elaborate nor provide an examination of the degree of cochlear damage. The results led the researchers to conclude that the implemented performance and safety measures were adequate in protecting soldiers against NIHL thus justifying the importance of a safety and health environment wherever employees are exposed to harmful noise levels (Teo, Chia, Tan, & Ali, 2008). The researchers did not examine or correlate the amount of ammunition or explosive material used during this time.

Mice were used by Kujawa and Liberman (2009) to examine the results of neural degeneration in ears with temporary noise-induced threshold shifts. The researchers exposed mice, contained in cells within a cage, to 100 dB SPL for two hours. Results showed that 24 hours following the exposure neural damage was clearly evident. After a two week waiting period response thresholds returned to normal and remained in this state 8-16 weeks later (Kujawa & Liberman, 2009). Although response thresholds returned to pre-exposure values, the loss of neurons in cochlear regions was evident, thus suggesting “neuronal loss in high-frequency regions” (Kujawa & Liberman, 2009). The researchers concluded that although federal standards and guidelines by OSHA, NIOSH, and ACGIH are implemented to prevent permanent threshold shifts, temporary threshold shifts may be progressive and result in long-term damage to the human auditory system (Kujawa & Liberman, 2009).

In a 2007 impulse noise monitoring study at SNL, impulse noise associated with free radiating detonations within fire pads was measured. The impulse noise from five detonations was recorded with masses ranging from 40 gr to 833 gr of net explosive weight. Noise levels were obtained at the employee control stations approximately 30 ft away and were consistent despite mass variation. Maximum values reached by sound pressures on an A-weighting scale with a slow meter response (LASmax) ranged from 131 dBA to 137 dBA whereas the maximum values reached by the sounds pressure on a C-weighting scale (LCPeak) were between 165 dBC and 169.9 dBC. Following data analysis it was concluded that all members of the workforce who were present in laboratories directly adjacent to the firing pad enclosures during detonations and those not resident in these laboratories, but routinely present during detonations, be enrolled in the SNL Hearing Conservation Program. Eight-hour personal noise samples were not taken during this study. Annual requirements resulting from the study were audiometric testing, training, and use of proper hearing protection.

CHAPTER 3: PURPOSE AND SCOPE

Purpose

The purpose of this study was to determine the contribution of noise exposures of workers employed at SNL in Albuquerque, New Mexico during small scale detonations using personal noise dosimeters and sound level meters. Personal noise dosimetry measurements on the A-weighted scale are to most accurately measure noise and its effect on the human ear (NIOSH, 1998). Dosimeters were used to measure employee noise exposure for an eight hour period to determine the potential overexposure of 85 dBA with a 3dB exchange rate during small scale detonations. The noise exposures and distance to the noise exposures were collected and noise exposures were compared to OSHA PEL and ACGIH TLVs. According to SNL policy employers are required to enroll employees in a HCP if the 8-hr TWA is greater than 85 dBA (3 dB exchange rate). The results of this assessment are used to determine if employees require enrollment into a hearing conservation program should the ACGIH criterion be met. This study provides SNL with the average noise levels of small scale detonations so that management can make an informed decision concerning the noise mitigation of those tasks that are shown to pose a hearing loss risk. Future subjects will benefit from the results of this study in determining the need for training, hearing protection, and enrollment in the HCP via SNL Medical.

Hypothesis and Research Questions

The hypothesis for this study was that employees who are intermittently exposed to small scale detonations activities for an eight hour work day exceed the ACGIH TLV TWA of 85dB 3 dB exchange rate for an eight hour work day. In addition, it was hypothesized that the noise to which employees are exposed to increases concurrently with weight of explosive materials. Also, the contribution of small scale detonations increases employees' ACGIH TWAs.

The evaluation of the small scale detonations will be used to answer the following:

1. Do SNL employees' 8-hour noise exposures exceed published exposure limits during small scale detonations?

2. At what threshold (e.g., quantity of explosives or test type) is hearing protection required?

3. Do the contributions of small scale detonations affect employees' overall daily noise exposure?

Scope

This research was conducted in June, July and August, 2012, during routine employee activities involving small scale detonations. Small scale, in this study, refers to 6 types of detonating material with a net explosive weight ranging from 18mg to 275g. The noise evaluations were conducted in 5 facilities; 2 indoor boom boxes, 2 indoor firing pads, and 1 outdoor firing pad. Permission was obtained to solicit subjects only from employees authorized to participate in work-related detonations. Personal noise exposures were measured using noise dosimeters during routine employee activities. Participants in the study were all adults, employed by SNL. The study population was not limited to gender or race, however due to SNL requirements, all participants were adults over the age of eighteen. General area noise measurements were collected with a SLM to characterize the noise levels for each detonation. Employees wore hearing protection (ear muffs) during firing pad activities.

CHAPTER 4: METHODS AND MATERIALS

Site Selection

Managers of the appropriate organizations at SNL that conduct explosive operations were contacted for solicitation of employees in this study. Due to the nature of this study, subject participation was contingent on the agreement that no noise monitoring was to be performed during classified work activities.

Employee Recruitment

SNL employees who coordinate and perform explosive operations on-site were contacted daily to determine the availability for participation. Communication with employees was made in accordance with the Colorado State University Institutional Review Board (IRB) and Research Integrity and Compliance Review Board, which included a discussion of the purpose of the research and sampling methods used. Volunteers in this study were also assured that all identifiable research records would be kept private to the extent allowed by law. The employee, Environmental Safety and Health Coordinator, SNL Medical, and managers of the employees' organizations were notified of the results on behalf of SNL. Employees then signed and dated their consent to participate in the research study. All data collection was performed in June, July and August of 2012.

Personal Noise Monitoring

Personal noise exposure levels were measured using Quest Technologies NoisePro Model DLX (Oconomowoc, WI) dosimeters to determine the employees' 8-hour noise exposures during small scale detonation activities. The dosimeters were pre-calibrated to assure accuracy according to the manufacturer's standards. Prior to collection, a one sample t-test was conducted using data from a study (Engard, 2009) that measured football stadium employee noise levels during which a cannon was fired numerous times. The one sample t-test was used to determine that a sample size of 20 individuals would be sufficient to obtain 90% probability of rejecting the hypothesis. Noise sampling procedures were followed per the OSHA Technical Manual, TED1-0.15A, Section III, Chapter 5. The dosimeters were programed with the parameters located in Table 4.1 so that the results could be compared to ACGIH and OSHA PEL noise criteria. The thresholds for the OSHA HCP are also listed however for the purpose of this study the data were compared to ACGIH TLVs due to SNL policy.

Table 4.1 NoisePro DLX Dosimeter Measuring Parameters

	ACGIH	OSHA PEL	OSHA HCP
Weighting	A	A	A
Range	70-140 dB	70-140 dB	70-140 dB
Response	SLOW	SLOW	SLOW
Exchange Rate	3 dB	5 dB	5 dB
Threshold	80 dB	90 dB	80 dB
Criterion Level	85 dB	90 dB	90 dB
Criterion Time	8	8	8
Upper Limit	115 dB	115 dB	115 dB

Prior to any work being performed by the employee, the microphone of the dosimeter was attached to the employee's shirt lapel as close as possible to the person's hearing zone. Workers were shadowed throughout the workday and a noise dosimetry log was maintained while the dosimeter was running. An example of this log can be found in Appendix A. Collected data included the number of explosive shots fired, the weight of explosive material used per shot, location of employee during detonation, and any activities that would otherwise interfere with the data collection (i.e., disturbing the microphone). Employees who left SNL during their lunch break were relieved of the dosimeter during this time. Upon arrival back to work activities, the dosimeter was re-attached to the employee. The dosimeter was kept running for employees who remained on-site. At the end of the workday, the Quest Model DLX dosimeters were post-calibrated to determine if the calibration remained unvaried. Employee TWAs were calculated by the dosimeters to adjust for an 8 hour sampling period.

Area Monitoring

A 2250 Bruel and Kjaer (B&K) (Naerum, Denmark) hand held SLM was used to measure peak levels of noise (crest factor of 10 dB) during detonations. Proper use of the SLM was followed using the OSHA Technical Manual (1999) in TED 1-0.15A. A B&K 4189 microphone was used and was pre- and post-calibrated to assure accuracy of the equipment.

During detonations, the type of explosive material, weight, location of the employee, and time of the detonation peaks were recorded (see Appendix B for Area Noise Monitoring form). Measurements were taken at employee control stations for approximately 5 seconds per shot. Per SNL protocol, a verbal countdown was performed prior to detonation. After the shot was fired, the 2250 SLM provided the output needed for data collection, including a visual graph which was used to detect the highest peak obtained during each shot. The Max Peaks (dBC) were recorded at the highest peak which was obtained by recording the exact time of the detonation and correlating this number with the peaks shown on the B&K 2250. The data were then analyzed to determine employee noise exposure.

Description of Detonation Activities

Employees were monitored for hazardous noise exposures during seven different activities. Three boom box activities were observed that included (1) igniter testing, (2) lighting of pyrotechnic actuators, and (3) primer shots. Igniters are Electro Explosive Devices (EEDs) that contain pyrotechnic material to perform a specific job. Pyrotechnic actuators are also EEDs and were used in tests to produce an explosive output. The pyrotechnic materials used were low explosives that deflagrate rather than detonate. In other words, these materials burned rapidly with heat in a reaction that was sub-sonic rather than super-sonic. Primer shots, unlike igniters, are not EEDs and require a mechanical input to set it off rather than electrical energy. This process is similar to that of a pistol that contains a pin with a spring tensioned behind it. When the tension is released the pin hits the primer to set it off thus creating noise, which was monitored in this study.

Three different activities were monitored in the indoor firing pad that included (1) a cook-off experiment, (2) detonation of C4, and (3) detonation of pentaerythritol tetranitrate (PETN). A cook-off experiment was performed in an indoor firing pad using a net explosive weight to estimate at what point a material will detonate. Activities utilizing C4, PETN, and urea nitrate (outdoor firing pad) were used in several activities for various tasks.

Statistical Analyses

The data analysis for this study was conducted using MINITAB Student Release 14.11.1 Statistical Software for Education. The data were separated into five different categories prior to statistical analysis; ACGIH TLV TWA, OSHA PEL TWA, boom box SLM results, indoor firing pad SLM results, and outdoor SLM firing pad results. Each category was placed in a scatterplot fitted with a regression line to visually depict the fit about the line. A linear regression was performed depicting TWA (for dosimetry results)/LCPeak (for area monitoring) as the response and net explosive weight as the predictor. R^2 values were observed to determine the relationship between weight and noise. P-values >0.05 were found to have no significant linear relationship.

CHAPTER 5: RESULTS

Personal Noise Dosimetry

Although twenty samples were required to help assure statistical power, a total of eleven personal noise dosimetry samples were taken on SNL employees during forty-two, small-scale detonations to determine if their noise exposures exceeded ACGIH and OSHA criterion levels. The noise monitoring results were used to conclude that none of the employees were overexposed to noise based on ACGIH criteria (85 dBA, 8-hour TWA) or OSHA criteria (90 dBA, 8-hour TWA). Employees were under the ACGIH criterion level of 85 dBA, therefore, no enrollment into the HCP was required. In addition, none of the employees were overexposed to the ACGIH and OSHA peak noise exposure limits of 140 dB during detonations.

Personal noise dosimeter measurements were obtained during various detonation activities including primer shots, lighting of pyrotechnic actuators, a cook-off detonation, detonation of PETN, and detonation of urea nitrate. The dosimetry results presented in Table 5.1 are sorted by location of detonation activities. Due to technical difficulties, the dosimeter worn by employee 8 did not provide the OSHA PEL or dose %. Five locations were used in this study: two boom boxes housed inside a laboratory, two indoor firing pads with a steel door that is closed during detonations, and an outdoor firing pad at a remote location on-site.

The following depicts the location of employees at the time of the detonations while wearing dosimeters:

- Employees 1 and 2 were approximately 19 feet (ft) away from detonations that utilized the boom box for lighting of pyrotechnic actuators (7 detonations) and primer shots (8 detonations) for a total of 15 detonations.
- Employees 6 and 7 were approximately 30 ft away from detonations that were performed in an indoor, single firing pad including PETN (1 detonation). Employee 4 was approximately 30 ft away from two PETN detonations. Employee 5 was located approximately 50 ft away from the noise source in a laboratory adjacent to the firing pad during the two PETN detonations.
- The cook-off activity (1 detonation) performed by employee 3 was located in a different indoor firing pad within the same building and was approximately 50 ft from the noise source. Employee 3 used audio speakers that were connected to the firing pad to aid in experimental activities; therefore the primary source of noise was obtained through the speakers.
- Employees 8-11 who used the outdoor firing pad for detonating urea nitrate (10 detonations) were stationed inside a control room within a concrete bunker adjacent to the firing pad. Measurements were obtained approximately 100 ft away from the noise source. Shots were viewed via a computer monitor and included audio from computer speakers.

Table 5.1: Personal Noise Dosimetry Results

Employee	Location	Activity	Weight, g	ACGIH TWA, dBA	ACGIH Dose, %	OSHA PEL TWA, dBA	OSHA PEL Dose, %
1	Boom Box	Primer Shots	0.176 *	74	7.336%	51	0.428
2	Boom Box	Lighting of Pyrotechnic Actuators	0.154 *	77	15.680%	59	1.285
3	Indoor Firing Pad	Cook Off	25	72	5.007%	45	0.191
4	Indoor Firing Pad	PETN	54 *	76	11.860%	57	0.995
5	Indoor Firing Pad	PETN	54 *	82	50.180%	68	4.925
6	Indoor Firing Pad	PETN	150	73	5.897%	50	0.416
7	Indoor Firing Pad	PETN	150	79	23.770%	63	2.32
8	Outdoor Firing Pad	Urea Nitrate	842 *	70	3.479%	-	-
9	Outdoor Firing Pad	Urea Nitrate	375 *	73	5.898%	48	0.312
10	Outdoor Firing Pad	Urea Nitrate	375 *	78	20.490%	60	1.574
11	Outdoor Firing Pad	Urea Nitrate	842 *	71	3.690%	46	0.238

*Represents combined weights of multiple detonations in a single eight-hour work shift

The measured 8-hour TWAs of employees using the SNL enforced ACGIH criterion of 85 dBA with a 3dB exchange rate are displayed in Figure 5.1. As indicated in the graph (with the inserted line at 85 dBA), all employees had 8-hour TWAs less than 85 dBA and therefore were not required to participate in the HCP.

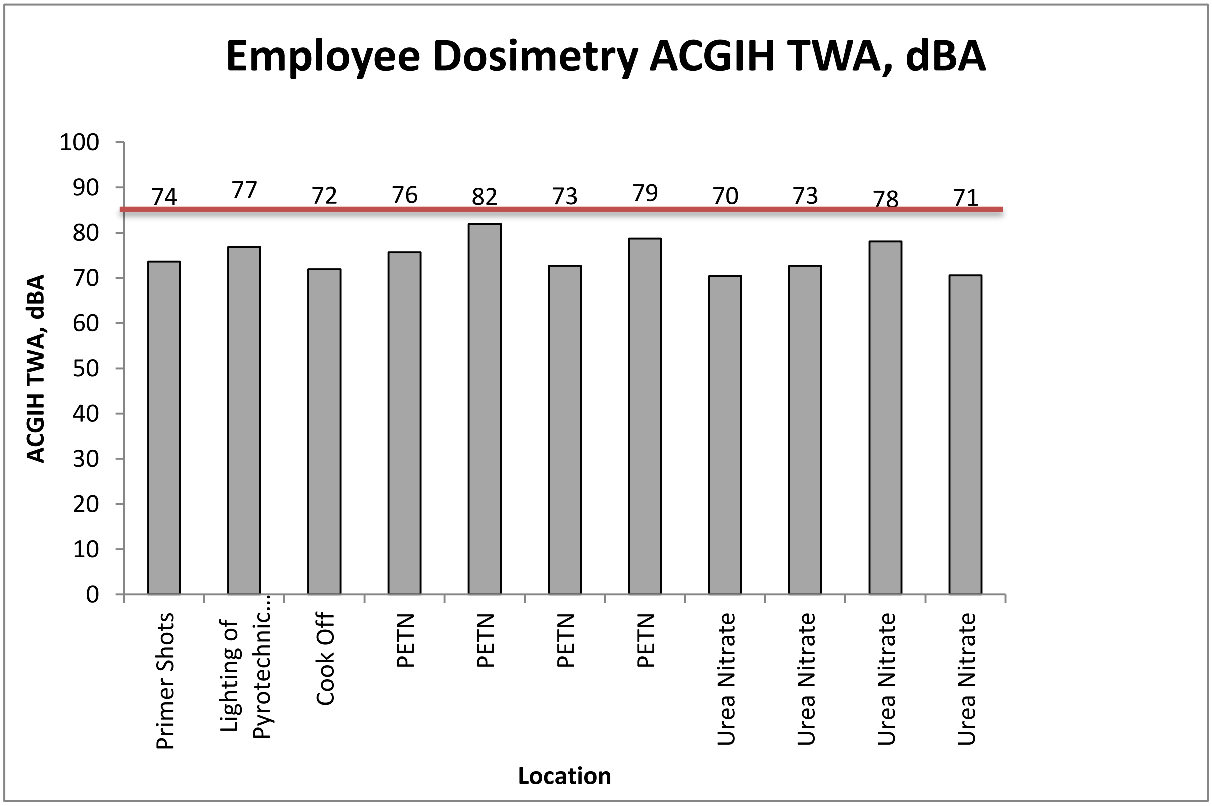

Figure 5.1 Employee Dosimetry Results Compared to ACGIH TWA, 85 dBA

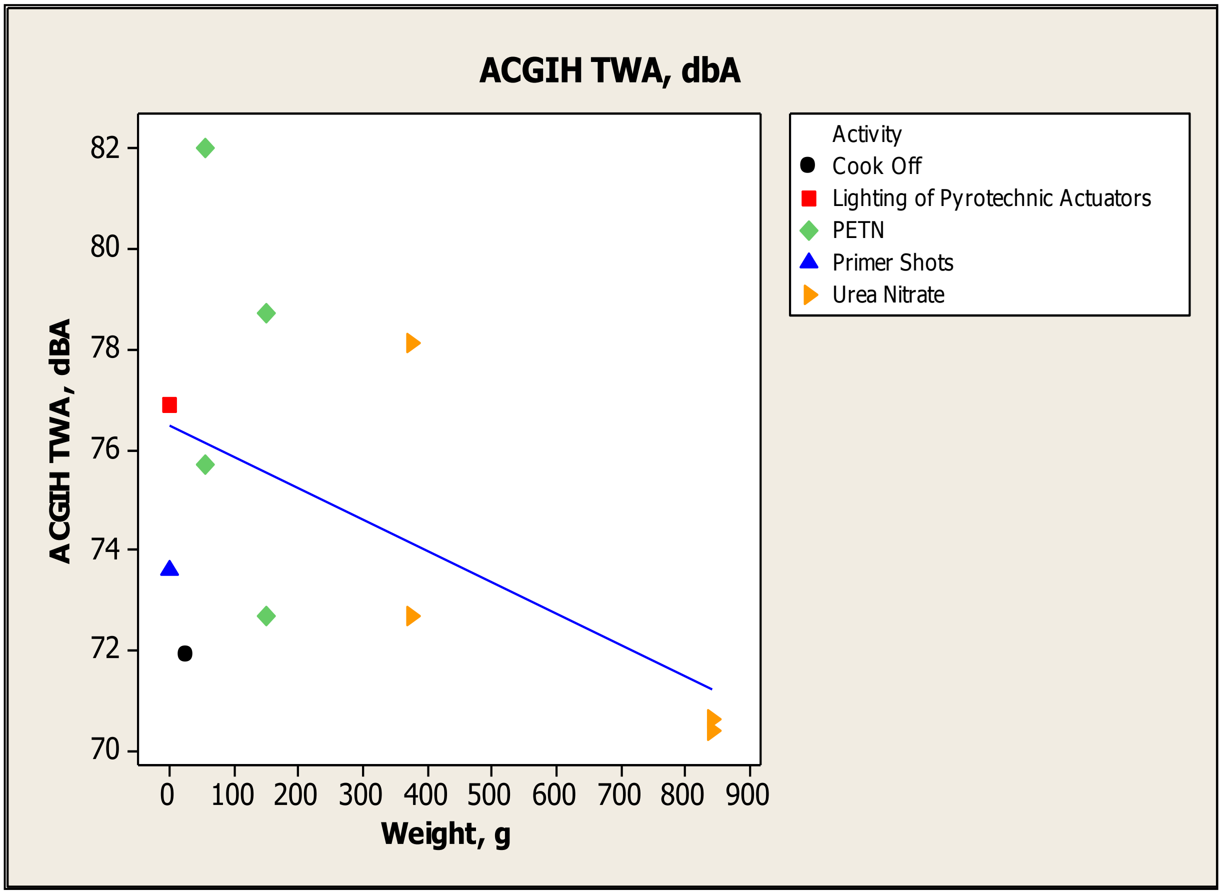

Figure 5.2 Scatterplot of Personal Noise Dosimetry Results per ACGIH TWA criteria

The relationship between the weight of explosive materials and the ACGIH TWA is illustrated in the scatterplot in Figure 5.2. A linear regression was performed to determine the significance of the relationship. A p-value of 0.092, which is >0.05, was calculated and it was determined that there was no significant linear relationship between explosive weight and ACGIH TWA. The R^2 value was calculated and it was determined that only 28.4% of the variability in ACGIH TWA may be explained by weight. The results may differ had a greater sample size been utilized. Eleven samples were collected however twenty samples were required.

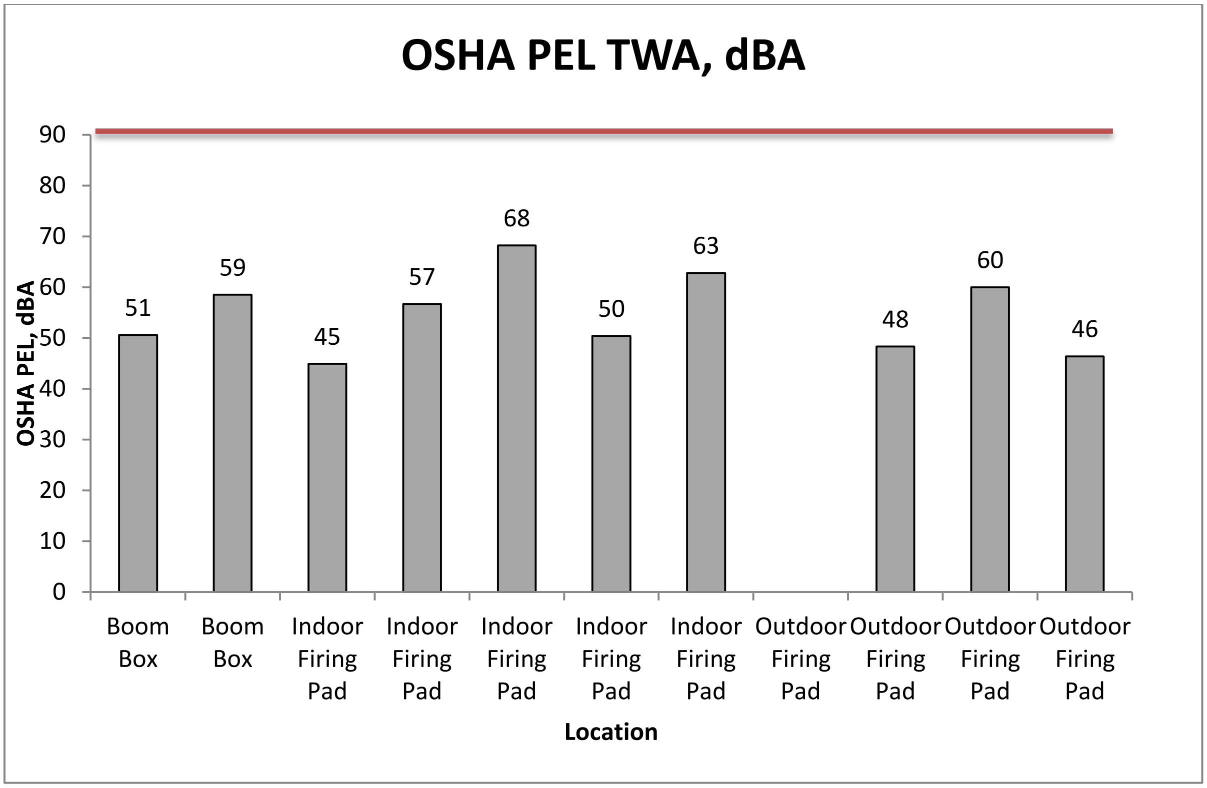

Figure 5.3 Employee Dosimetry Results Compared to OSHA PEL, 90 dBA

The employee 8-hour TWA dosimetry results per the OSHA PEL of 90 dBA with a 5 dB exchange rate are displayed in Figure 5.3. Employees 1-7 and 9-11 were well below 90 dBA. Employee 8 was excluded from this figure due to technical difficulties with the dosimeter which did not provide the output for the OSHA PEL TWA.

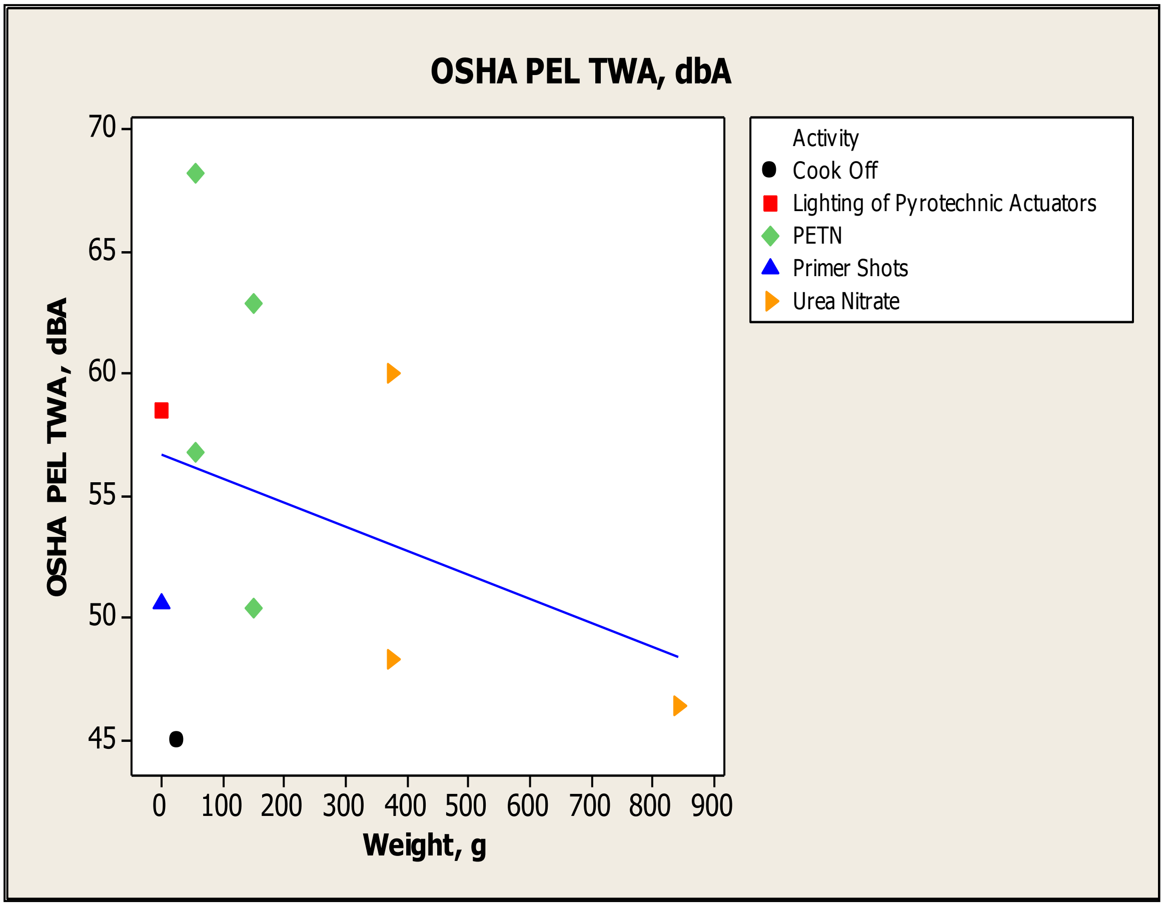

Figure 5.4 Scatterplot of Personal Noise Dosimetry Results per OSHA PEL TWA criteria

As illustrated in the scatterplot in Figure 5.4, the data points were not well fitted to the regression line. With a sample size of ten individuals (twenty were required the linear relationship between explosive weight and OSHA PEL TWA was not significant ($p = 0.34$). The R^2 value was calculated and it was determined that only 11.4% of the variability in OSHA PEL TWA may be explained by weight.

Boom Box SLM Results

The results of the area peak noise measurements for detonations contained within an indoor boom box (see Table 5.2) ranged from 71 dBC to 104 dBC. SLM measurements were taken near the hearing zone of employees performing igniter testing, who were approximately 3 ft from the noise source. The mean peak noise exposure for igniter testing activities was 73 dBC. Employees performing primer shots and lighting of pyrotechnic actuators in a different boom box were approximately 19 ft from the noise source. The mean peak noise exposure for primer tests was 100 dBC and 116 dBC for lighting of pyrotechnic actuators. LCPeak levels presented in Figure 5.5 were well below the ACGIH and OSHA peak noise exposure limits of 140 dBC.

Table 5.2 SLM Area Noise Data for Boom Box Activities

Project	Location	Activity	Weight, mg	Laeq, dBA	Lcpeak, dBC
1	Boom Box	Igniter Testing	18	55	71
2	Boom Box	Igniter Testing	18	53	75
3	Boom Box	Lighting of Pyrotechnic Actuators	22	92	115
4	Boom Box	Lighting of Pyrotechnic Actuators	22	93	115
5	Boom Box	Lighting of Pyrotechnic Actuators	22	92	114
6	Boom Box	Lighting of Pyrotechnic Actuators	22	92	115
7	Boom Box	Lighting of Pyrotechnic Actuators	22	94	117
8	Boom Box	Lighting of Pyrotechnic Actuators	22	94	117
9	Boom Box	Lighting of Pyrotechnic Actuators	22	94	117
10	Boom Box	Primer Shots	22	72	90
11	Boom Box	Primer Shots	22	77	95
12	Boom Box	Primer Shots	22	78	99
13	Boom Box	Primer Shots	22	77	99
14	Boom Box	Primer Shots	22	77	99
15	Boom Box	Primer Shots	22	78	100
16	Boom Box	Primer Shots	22	79	100
17	Boom Box	Primer Shots	22	78	101
18	Boom Box	Primer Shots	22	79	102
19	Boom Box	Primer Shots	22	80	102
20	Boom Box	Primer Shots	22	80	103
21	Boom Box	Primer Shots	22	81	103
22	Boom Box	Primer Shots	22	78	104

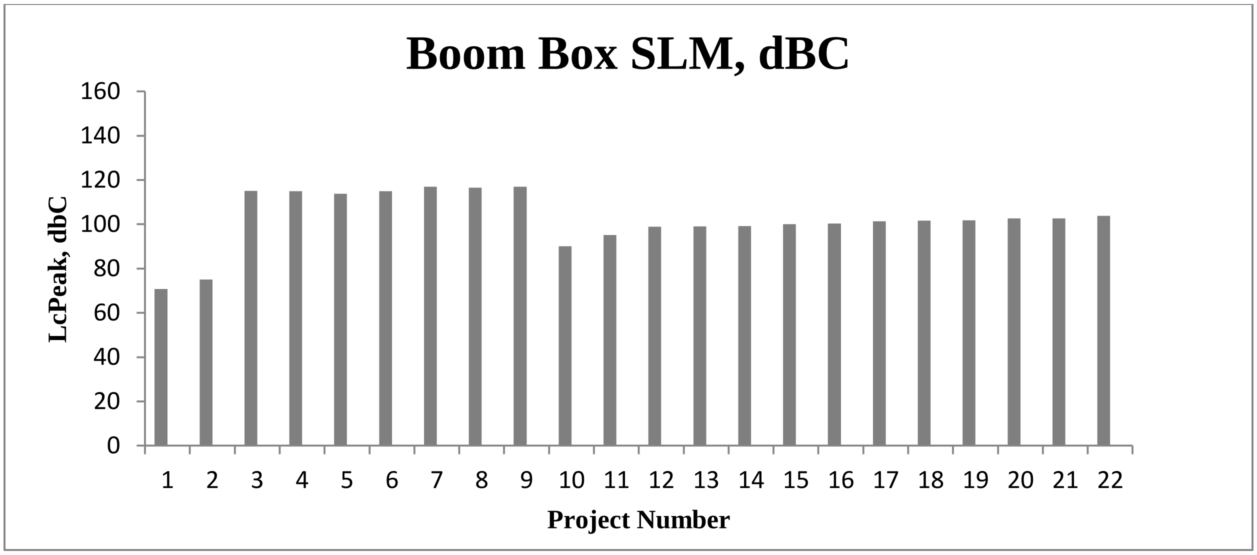

Figure 5.5 Boom Box SLM, LCPeak

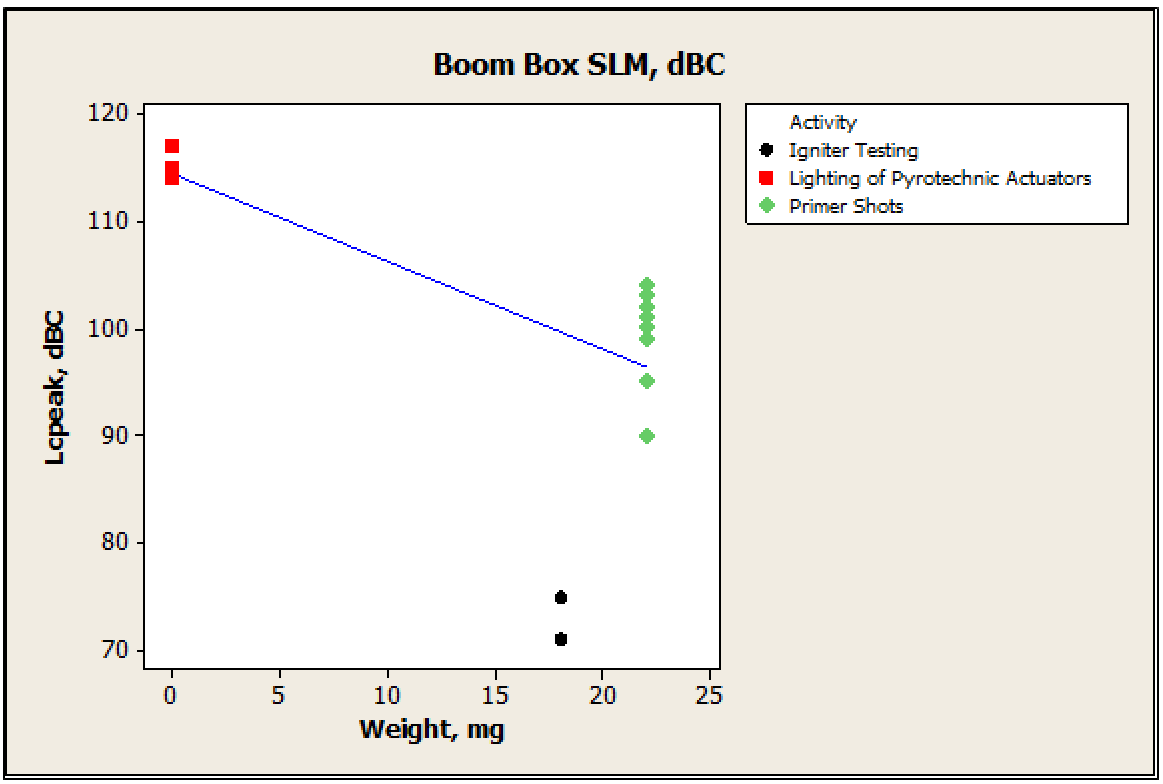

Figure 5.6 Scatterplot of SLM Boom Box LCPeak

The relationship between the explosive weight and the LCPeak for activities within a boom box is illustrated in the scatterplot in Figure 5.6. A straight line regression was performed and a p-value of 0.001 was found, which was used to determine that there was a significant linear relationship between the weight of explosives and the LCPeak. However only two different weights are present, representing three different shots therefore it was difficult to determine if the difference was due to Weight or Activity.

Indoor Firing Pad SLM Results

The SLM area noise measurements for indoor firing pad activities in Table 5.3 are listed by increasing weight. LCPeak levels ranged from 99 dBC to 132 dBC (distance to the noise sources can be found in Appendix C). As displayed in Figure 5.6, all detonation noise levels were below the 140 dBC TLV. The relationship between explosive weight and the LCPeak for firing pad activities are presented in Figure 5.8. Following a linear regression analysis it was determined that the p-value was 0.283 which suggests that there was no significant linear relationship between explosive weight and LCPeak with a sample size of 19 detonations. The R^2 value was presented and only 6.7% of the variability in the LCPeak may be explained by weight.

Table 5.3 SLM Area Noise Data for Indoor Firing Pad Activities

Project	Location	Activity	Weight, g	Laeq, dBA	Lcpeak, dBC
1	Indoor Firing Pad	PETN	4	95	115
2	Indoor Firing Pad	C4 Detonations	5	74	102
3	Indoor Firing Pad	C4 Detonations	5	97	117
4	Indoor Firing Pad	C4 Detonations	5	113	132
5	Indoor Firing Pad	C4 Detonations	20	78	104
6	Indoor Firing Pad	C4 Detonations	20	99	118
7	Indoor Firing Pad	C4 Detonations	20	112	131
8	Indoor Firing Pad	Cook Off	24	81	99
9	Indoor Firing Pad	C4 Detonations	40	79	106
10	Indoor Firing Pad	C4 Detonations	40	92	113
11	Indoor Firing Pad	C4 Detonations	40	100	121
12	Indoor Firing Pad	PETN	50	101	122
13	Indoor Firing Pad	C4 Detonations	100	78	111
14	Indoor Firing Pad	C4 Detonations	100	102	122
15	Indoor Firing Pad	C4 Detonations	100	105	124
16	Indoor Firing Pad	PETN	150	93	111
17	Indoor Firing Pad	C4 Detonations	275	85	112
18	Indoor Firing Pad	C4 Detonations	275	105	127
19	Indoor Firing Pad	C4 Detonations	275	110	129

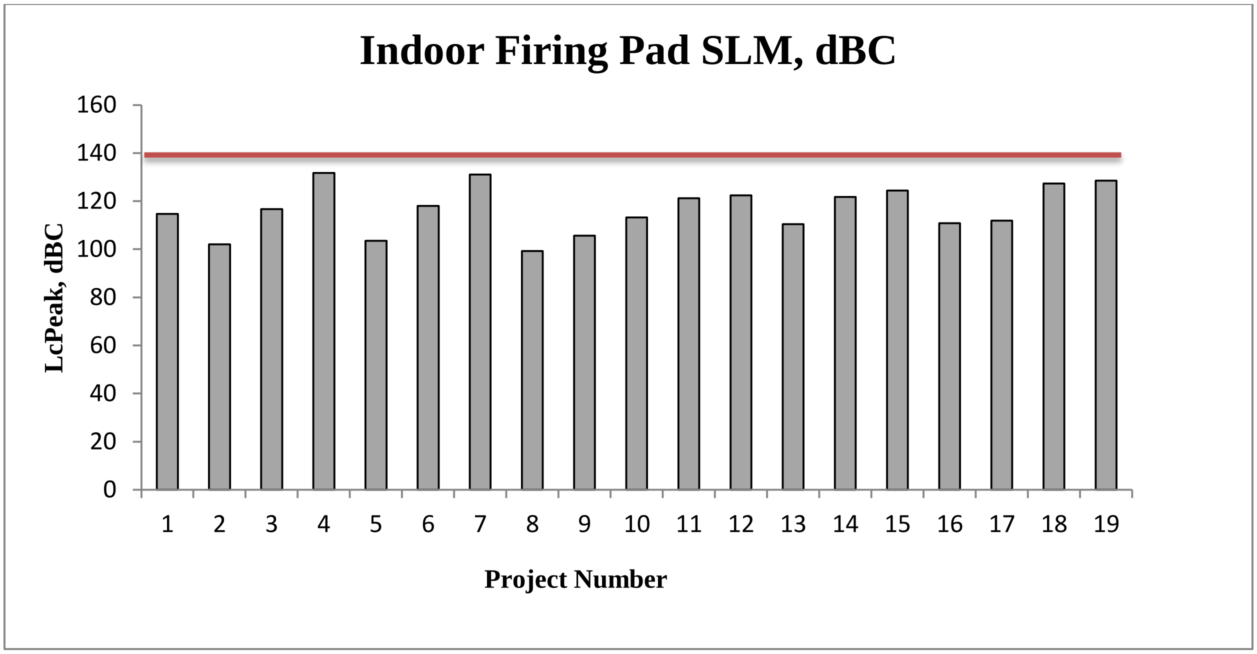

Figure 5.7 Indoor Firing Pad SLM, LCPeak

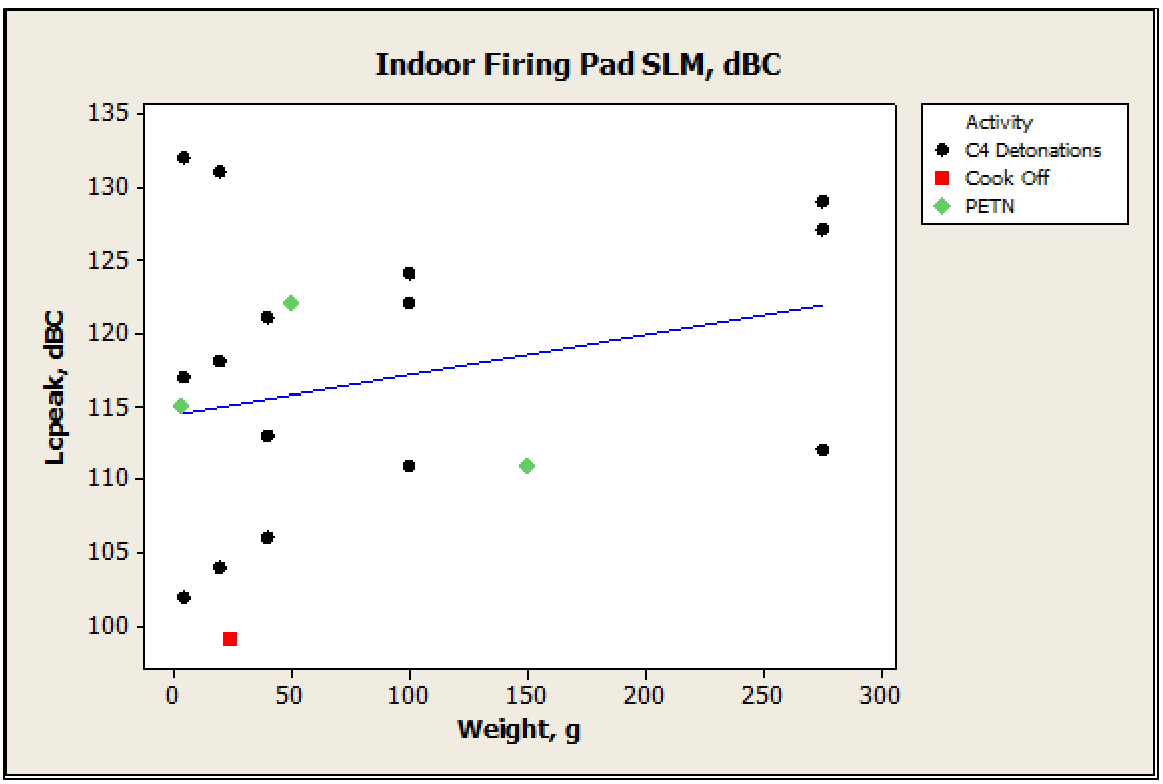

Figure 5.8 Scatterplot of SLM Indoor Firing Pad LCPeak

Outdoor Firing Pad SLM Results

The LCPeak results for outdoor firing pad activities can be found in Table 5.4 and are arranged by increasing weight. Measurements were taken inside a control room within a concrete building adjacent to the firing pad, which was approximately 100ft away from the noise source. Shots were viewed via a computer monitor and included audio from computer speakers. As indicated in Figure 5.9, all measurements were less than the ACGIH and OSHA peak noise exposure limits of 140 dBC TLV. Based on the results of a linear analysis with a sample size of 10 detonations, there was no significant linear relationship between weight and LCPeak (p-value = 0.801). The R^2 value was presented and only 6.2% of the variability in the LCPeak may be explained by weight.

Table 5.4 SLM Area Noise Data for Outdoor Firing Pad

Project	Activity	Weight, g	Lcpeak, dBC
1	Urea Nitrate	106	106
2	Urea Nitrate	118	116
3	Urea Nitrate	118	116
4	Urea Nitrate	125	104
5	Urea Nitrate	125	105
6	Urea Nitrate	125	118
7	Urea Nitrate	125	118
8	Urea Nitrate	125	107
9	Urea Nitrate	125	106
10	Urea Nitrate	125	115

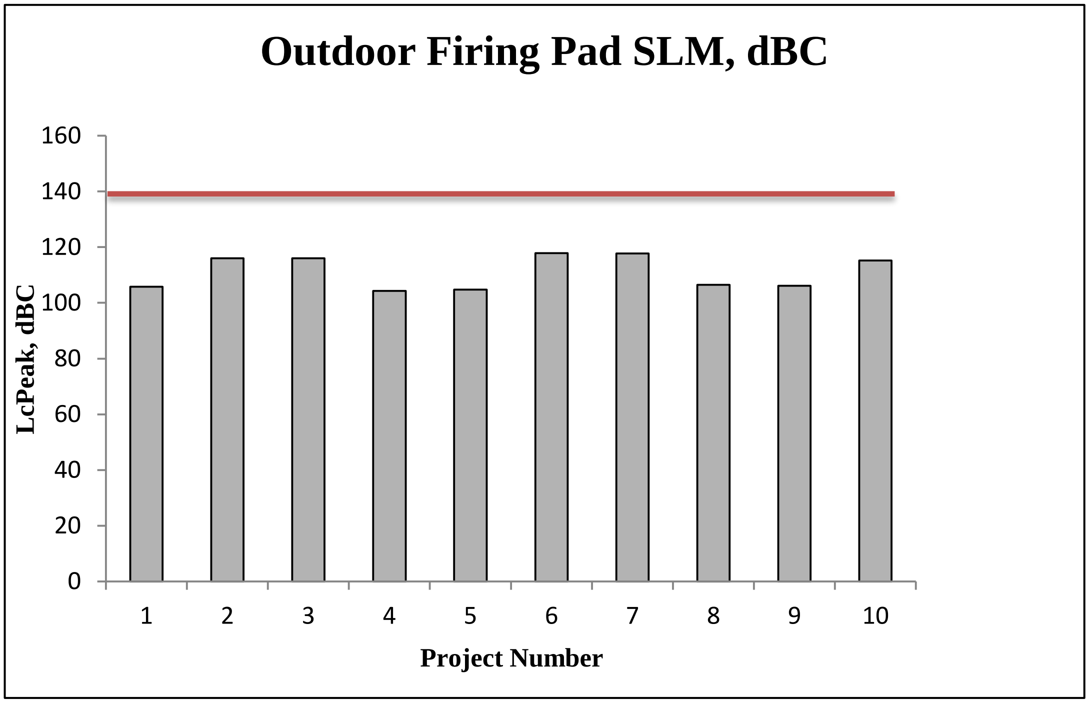

Figure 5.9 Outdoor Firing Pad SLM, LCPeak

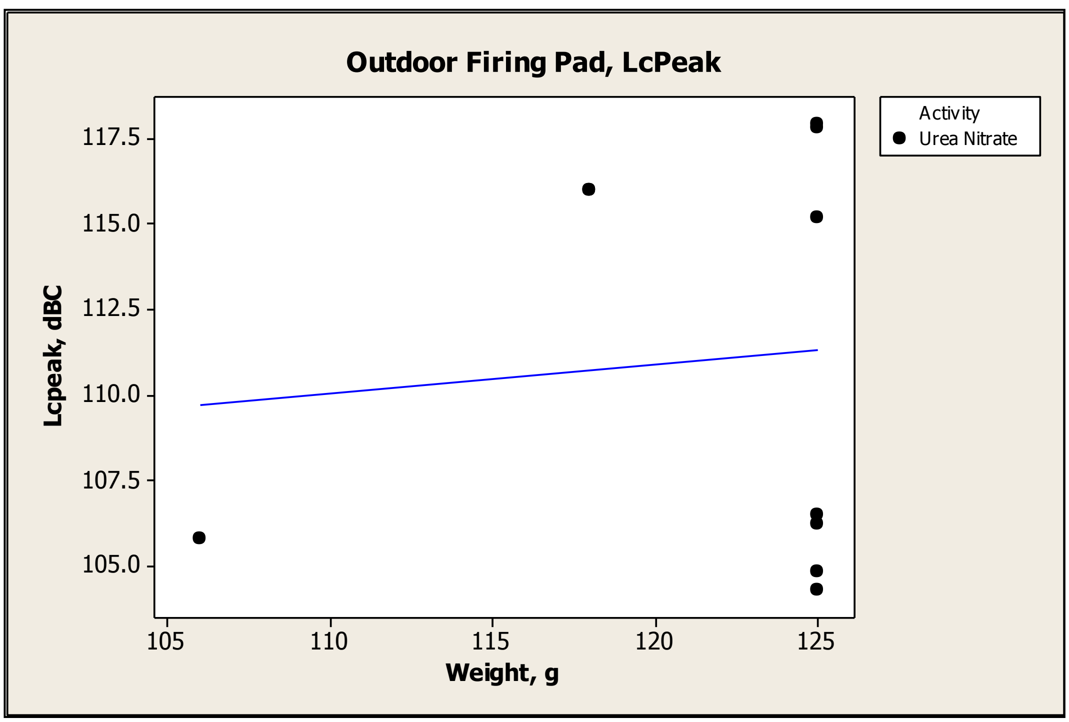

Figure 5.10 Scatterplot of SLM Outdoor Firing Pad LCPeak

Contribution of Small Scale Detonations

The overall noise exposures presented in Table 5.5 display the TWAs (not adjusted for an 8 hour sampling period) for employees during small scale detonations. The noise exposures during detonations were removed from the data and the new TWAs were calculated utilizing equations 5.1 and 5.2 to determine the contribution of detonations to overall noise exposures. The data output for Employee 4 did not report the ACGIH average sound level (Lavg) and is therefore omitted from Table 5.5.

Table 5.5 Contribution of Small Scale Detonations to ACGIH TWAs

	With Detonations		Without Detonations	
Employee	TWA	Dose %	TWA	Dose %
1	71	3.79	71	4.21
2	70	3.33	69	4.81
3	70	3.04	70	3.16
4				
5	81	36.13	78	20.46
6	72	5.53	70	3.34
7	77	15.77	75	9.18
8	72	5.46	69	2.32
9	78	19.83	70	2.86
10	77	15.30	71	3.78
11	73	5.63	68	2.09

Equation 5.1 ACGIH Noise Dose Calculation

$$\text{ACGIH } L_{avg} = 85 + \left(10 \log_{10} \frac{D\%}{12.5\,T}\right)$$

Where, $L_{avg\ ACGIH}$ = average noise level
D% = dose percentage

Equation 5.2 ACGIH TWA Calculation

$$\text{ACGIH TWA} = 10\log\left(\frac{D}{100}\right) + 85$$

Where, TWA = time weighted average
D = dose

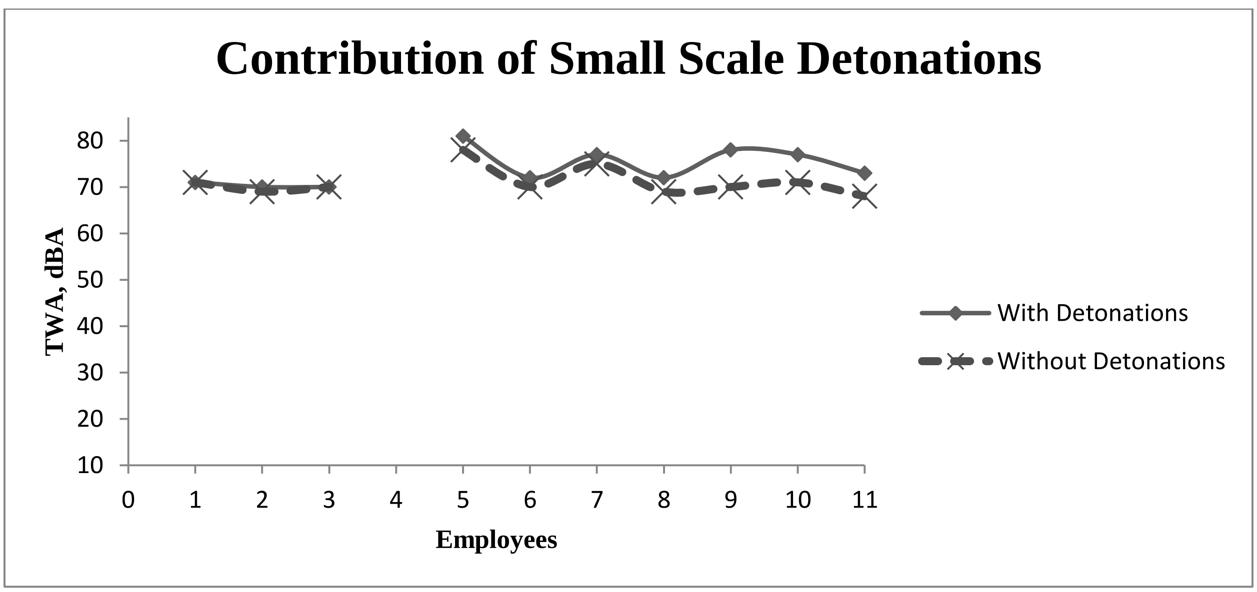

Figure 5.11Contributions of Small Scale Detonations

CHAPTER 6: DISCUSSION

The hypothesis for this study was three-fold predicting that (1) employees who were intermittently exposed to small scale detonations for an eight hour work day exceeded the ACGIH TLV TWA of 85dB for an eight hour work day; (2) the noise to which employees were exposed increased concurrently with the weight of explosive materials; and (3) the contribution of small scale detonations increases employee ACGIH TWAs. Based on the results of this study, employees exposed to detonation noise did not exceed ACGIH/OSHA criteria for an eight hour work day, nor were they exposed to impulse noise levels greater than 140 dBC during detonations. Furthermore, the noise to which employees were exposed did not appear to increase concurrently with the weight of explosive materials. Also, after a comparison of calculated ACGIH TWAs without detonation noise data, the contribution of small scale detonations increased employees' TWAs from only 1 to 8 dB.

Additional noise that contributed to employee noise exposure involved typical processes that precede and follow detonations. This includes preparation work such as assembly of detonation material. Prior to detonations within the indoor firing pad, an audible siren located outside of the building is turned on. If employees are located near the siren, elevated noise levels may be apparent. After employees have assured the appropriate safety protocols have been followed, a verbal (3-2-1) countdown is performed resulting in elevated noise levels. Following detonations, it is typical work practice to clean up left over debris. Various methods are used that include, but are not limited to, vacuum pumps, a fire hose that discharges water, and leaf blowers, which also resulted in elevated noise levels.

Personal Noise Dosimetry

Although twenty samples were required eleven employees volunteered to participate in noise monitoring during routine detonation activities. The dose percentages reflected in Table 5.1 were calculated and it was concluded that all employees, except Employee 5, were under the 50% dose required for enrollment into the HCP. After further review of Subject 5's noise dosimetry log, it was noted that the employee was whistling throughout the work day, thus producing excess noise near the microphone of the dosimeter. Subject 5 was located in an adjacent laboratory to the indoor firing pad and was not exposed to noise greater than 105dBC during detonations. Subjects 7 and 10 displayed the second and third highest doses with ACGIH doses of 23.77% and 20.49%. Subject 7 was participating in activities involving the indoor firing pad, however further review of the dosimetry log revealed that the explosive preparation process generated more noise to the employee than the actual detonation. Subject 10 was located inside a concrete building while shots were fired on the outdoor firing pad and was never exposed to noise levels above 87dBC during detonations. The clean-up process exposed the employee to elevated levels of noise due to the use of a fire hose and leaf blower, at which time hearing protection in the form of ear plugs were used.

Scatterplots were used to determine the fit of the line to evaluate the relationship between weight of explosives and the ACGIH and OSHA 8-hour TWAs. The p-values for ACGIH criteria ($p=0.092$) and OSHA criteria ($p=0.34$) were used and it was found that the linear relationship between weight and TWA were not significant. Based on these results and due to small sample sizes, it was not possible to predict the maximum net explosive weight employees may use to maintain a TWA below 85 dBA.

Area Noise

The results of the area noise samples taken with the SLM were used to conclude that employees engaged in activities involving boom boxes, the indoor firing pad, and outdoor firing pad were less than 140 dBC during detonations. LCPeak values involving boom box activities ranged from 71-104 dBC using 18 mg and 22 mg of explosive weight. Noise levels with this amount of explosive weight did not display concerning levels of noise. A scatterplot of the results revealed an interesting outcome and provided a significant linear relationship between the weight of explosives and the LCPeak (p=0.001). These results however only represent two different weights that were present, thus making it difficult to account whether the difference was due to weight or activity.

Area noise samples taken within the indoor firing pad ranged from 99-129 dBC. Location during measurements varied based on activity and location of employee, but the noise exposures remained consistently under 140 dBC (see Appendix A for approximate distance measurements taken during detonation activities). The cook-off activity that was conducted was approximately 50 ft away from the employee however, barriers (concrete walls) were in place to protect the employee from hazardous noise exposures. Due to the nature of the experiment, the employee watched the explosions via a computer monitor with speakers in a control room. Speaker volumes were increased to detect the sparks that precede the explosion; therefore the primary source of noise was exhibited through the computer speakers rather than the actual detonation. The highest levels of noise were detected during the detonation of C4, which occurred in 5 increasing increments (5 g, 20 g, 40 g, 100 g, and 275 g). SLM measurements were taken at the primary area of concern which was in an adjacent firing pad approximately 20 ft away with peak noise levels reaching 132 and 131 dBC (Projects 11 and 14). It was noted that during the time of explosion a siren was engaged to alert workers of the detonation, which may have contributed to the SLM reading. The weights of the explosive material for all indoor firing pad activities were used in a linear regression in Minitab to determine the relationship with LCPeak levels. It was found that the relationship between weight of explosives and LCPeak levels was not significant ($p=0.283$) which may be attributed to a small sample size. The lack of significance did not sanction further interpretation regarding the maximum explosive weight allowed to maintain noise levels under 140 dBC.

Outdoor firing pad activities were consistent with regards to activity and distance from the noise source (~100ft). Employees were well protected within the concrete bunker adjacent to the firing pad with measurements ranging from 104-118 dBC. Explosions were viewed on a computer monitor and included speakers that contributed to the noise exposure within the control room. A linear regression determined that the relationship between the weights of explosives and LCPeaks were not significant ($p=0.801$). Therefore it was not feasible to determine the amount of explosive material that should be used to maintain LCPeak levels below 140 dBC.

<u>Contribution of Small Scale Detonations</u>

The TWAs (not adjusted for an 8 hour sampling period) that were calculated following the removal of noise data from detonations were compared to overall noise exposures. It was found that the contribution of small scale detonations increased employee ACGIH TWAs from only 1-8 dB. The greatest contribution of noise from detonations occurred during outdoor firing pad activities (Employees 8-11) which involved detonations of urea nitrate and increased overall noise exposures up to 8 dB. Employees were located within a concrete bunker and utilized computer speakers to listen to the detonations occurring on the firing pad outside. The volume of the computer speakers was not recorded therefore it is difficult to distinguish whether the increase in overall noise exposure was from the detonations of urea nitrate or the volume of the computer speakers, which contributed to the detonation noise. Employees 4-7 were involved with PETN detonations. A 3 dB difference was found after calculating the new TWA without detonation noise for Employees 5. A 2 dB difference was found after calculating the new TWAs for Employees 6 and 7. The cook-off experiment performed by Employee 3 and primer shots performed by Employee 1 did not alter the employees' TWAs. The TWA calculated for Employee 2 decreased by 1 dB following the removal of detonation noise data.

Study Limitations

The most noteworthy limitation for this study was collecting sufficient amount of data to determine relationships between net explosive weight and TWA/LCPeak measurements. The power analysis required 20 dosimetry samples however only 11 samples were collected. The amount of data collected was determined solely by the necessity of explosive operations at SNL during June, July, and August of 2012. Consistency of day to day activities was also a key limitation which prevented multiple measurements to be taken for any one activity. This study was a field study to determine actual employee noise exposure during normal, routine activities rather than an experimental noise study that would have required an interruption in normal activities. The collection of data was also dependent on the nature of the work being performed, which in a few cases did not permit the use of dosimeters or the SLM due to the sensitivity of the experiment. A larger sample size would be beneficial to determine, for example, the true relationship between weight and LCPeak for boom box activities which displayed a significant relationship ($p=0.001$). An additional limitation for this study was that the preparation and clean-up of each detonation appeared to produce more noise than the detonation itself therefore it was difficult to distinguish if dose percentages were attributed to preparation work or detonation activities.

CHAPTER 7: CONCLUSION AND FUTURE WORK

The evaluation of the small scale detonations at SNL were used to answer the following research questions:

1. *Do SNL employees' 8-hour TWA noise exposures exceed ACGIH and OSHA published noise exposure limits during small scale detonations?*

   The author of this study rejected the hypothesis that SNL employees who are intermittently exposed to small scale detonations activities for an eight hour work day exceed the SNL enforced ACGIH TLV TWA of 85 dBA (3 dB exchange rate) and the OSHA PEL TWA of 90 dBA (5 dB exchange rate) for an eight-hour work day. The author also found that employees' exposures did not exceed the ACGIH and OSHA peak noise exposure limits of 140 dBC during detonation activities. In addition, employees were not required to enroll into the HCP because noise exposures did not exceed the SNL criterion, which follows the ACGIH TLVs (8-hour TWA greater than 85 dBA 3 dB exchange rate or 50% dose). Thus, impulse noise levels measured in this study were used to conclude that the noise controls such as barriers, distance, and hearing protection, currently in place at SNL, were an effective means of protection to employee hearing.

2. *At what threshold (e.g., quantity of explosives or test type) is hearing protection required?*

   Due to the lack of a significant linear relationship between explosive weight and noise TWAs/LCPeaks, the noise to which employees were exposed may or may not increase concurrently with weight of explosive materials. Based on the results of this study, it was not feasible to determine at what threshold (quantity of explosive material) hearing protection is required. Had the relationship between net explosive weight and TWA/LCPeak been significant with the appropriate number of samples (at least 20), mathematical equations may have been performed using the equation about the regression line to determine explosive quantity thresholds.

3. *Do the contributions of small scale detonations affect employees' overall daily noise exposure?*

The author of this study rejected the hypothesis that the contribution of small scale detonations affects employees' overall daily noise exposure (not adjusted to an 8 hour sampling period). Although a 5-8 dB drop was calculated (to exclude detonation noise) for employees utilizing the outdoor firing pad, noise exposure during detonations included amplified noise from computer speakers which were wired to the outdoor firing pad. Employees using the indoor firing pads and boom boxes achieved a 1-3 dB drop after the new TWAs were calculated which excluded detonation noise exposures.

Future Work

The impulse noise to which employees were exposed appear to have no trend regarding mass quantity, therefore it would be wise to question if the difference in sound pressures may be attributed to other factors such as the supersonic speed of shock waves and/or distance to the noise source (Brinkmann, 2000). It would be prudent to investigate audio levels of noise emitted from computer speakers which aide employees in detonation activities. Audio levels as well as employee distance from speakers should be evaluated to determine elevated noise levels. Future work would include factoring in additional variables such as velocity and greater sample sizes to better determine the effects of impulse noise during detonation activities.

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APPENDIX A

NOISE DOSIMETRY

Person Conducting Sampling: ______________________________ Date ______________________________

Building(s)/Room(s) ____

Activity/Task(s): ____

Instrument Make/Model/SN: ______________________________ Calibrator SN: ________________

Worker #, Name, org	Dosimeter SN	Pre-Cal	Post-Cal	Start Time	Stop Time	Total Time	Lave (dBA)

Exposure Controls and PPE

Describe Task and Activities Sampled/Additional Notes:

NOISE DOSIMETRY LOG

Activity/Machine (include location if applicable)	Start Time	Stop Time

APPENDIX B

AREA NOISE MONITORING

Person Conducting Sampling: ________________________ Date ______________________

Building(s)/Room(s): ____

Activity/Task(s): ____

Sound Level Meter Make/Model/SN: ____

Microphone Make/Model/SN: ____

Calibrator Make/Model/SN: ____

Pre Calibration: _____________ Post Calibration: __________

Activity/Machine (include location if multiple building/rooms are identified above)	Duration (hr:min)	Laeq (dBA)	Max L (dBA)	Max P (dBC)

Describe Activities, Conditions, Noise Source (s), Engineering Controls, PPE:

APPENDIX C

Table C.1 Approximate Distance during Indoor Firing Pad Activities

Project	Activity	Weight, g	Approx. Distance from Noise, ft	Lcpeak, dBC
1	PETN	4	20	115
2	C4 Detonations	5	40	102
3	C4 Detonations	5	30	117
4	C4 Detonations	5	20	132
5	C4 Detonations	20	40	104
6	C4 Detonations	20	30	118
7	C4 Detonations	20	20	131
8	Cook Off	24	50	99
9	C4 Detonations	40	40	106
10	C4 Detonations	40	30	121
11	C4 Detonations	40	35	113
12	PETN	50	20	122
13	C4 Detonations	100	40	111
14	C4 Detonations	100	30	122
15	C4 Detonations	100	35	124
16	PETN	150	20	111
17	C4 Detonations	275	40	112
18	C4 Detonations	275	30	127
19	C4 Detonations	275	35	129