Spring 2016

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Recommended Citation
Lindsey, Michael, "AN ANALYSIS OF HELMET SOUND ATTENUATION DURING ABRASIVE BLASTING" (2016). *Graduate Theses & Non-Theses*. 84.
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AN ANALYSIS OF HELMET SOUND ATTENUATION DURING ABRASIVE BLASTING

by

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A report submitted in partial fulfillment of the
requirements for the degree of

Master of Science
Industrial Hygiene Distance Learning / Professional Track

Montana Tech
2016

Abstract

During abrasive blasting, the operator is exposed to a process consisting of combined sound pressure levels from compressed air propelling an abrasive media through the hose, the abrasive striking metal substrate, the flow of breathing air inside the helmet, and the reverberation of sound inside the walls of the blast booth. The resulting noise can reach peak sound pressure levels (L_{peak}) of 128 dBA, exceeding allowable occupational exposure levels.

The objectives of this study were to investigate the noise levels produced during abrasive blasting, attempt to further quantify total noise exposure to the abrasive blast operator, and calculate combined attenuation provided by the abrasive blasting helmets and hearing protection devices. The attenuation provided by the helmets alone was directly measured during abrasive blasting operations through personal dosimetry. The attenuation provided by the helmets when used in combination with hearing protection devices was determined by applying measured attenuation data from the helmets to the attenuation data provided by hearing protection device manufacturers. Findings of the study revealed that noise levels inside the blast booth were above the OSHA permissible exposure level while noise levels inside the helmets were attenuated to within allowable levels largely on account of helmet construction. Combined attenuation provided by the helmet and hearing protection device was significant enough to reduce noise exposure to below the occupational exposure limit of 90 dBA.

Keywords: Sound attenuation, abrasive blasting helmet

Dedication

I am grateful to my Wife and Son for their unwavering support of my career and educational pursuits, especially in these feverish last few months. I also wish to thank my Mom and Uncle Dan, whose sacrifices for my education and upbringing will never be forgotten. Finally, I'd like to express gratitude to my mentor, Pete Engelbert ("Safety Pete"), who taught me what it meant to be an ESH professional.

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1. Introduction

1.1. General Abrasive Blasting Information

Abrasive blasting is a process that uses compressed air to pressurize a vessel containing abrasive media, and propel that media through a rubber blast hose where it is expelled from a nozzle during surface preparation and cleaning activities (Blair, 1975). The compressors used for industrial abrasive blasting projects are large units, delivering upwards of 800 cfm to the blast pot. The blast nozzle will discharge the abrasive at a nozzle pressure upwards of 100 psi. The nozzle is generally supported on the operator's shoulder and held within 24 inches of the operator's head (Drisko, 2002). The abrasive media can vary depending upon project requirements, but is usually a slag or mineral variety. The surfaces being blasted are almost always steel and can vary greatly from exposed bridge trusses to aboveground storage tank interiors.

The shell of the abrasive blast helmet is made of a polycarbonate plastic to provide impact protection from rebounding abrasive. The helmet is also equipped with an inner and outer face shield lens to provide additional ocular impact protection. The blast helmets have an integrated fitting to provide breathing air to the operator from the air compressor; the air is required to meet Grade D standards. The helmets have a sewn-in neck cuff that serves as a physical barrier to rebounding abrasive and particulates. Depending upon the manufacturer, the helmet will either be equipped with an adjustable headband suspension similar to a hard hat or molded foam padding similar to a football helmet. Finally, the blast helmets are equipped with a cape made of either leather or nylon to provide operator torso protection against abrasive rebound.

1.2. Abrasive Blasting Sound Pressure Levels

There have been many studies performed in the past two decades measuring the sound pressure levels generated during abrasive blasting activities outside of the blast helmet and in near proximity to the abrasive blaster. Table I summarizes the reviewed data of sound pressure levels generated during abrasive blasting simulations in other studies. It is important to note that in each study, different abrasive blasting systems were used, different abrasive blasting materials were used, the surfaces being blasted varied, and the environments in which the blasting occurred was not consistent. Nonetheless, the logarithmic sum of the sound pressure levels in each study indicates dangerous levels of noise being generated, all of which are dominated by the higher frequency spectrum.

Table I - Abrasive Blasting Noise as Reported in Four Different Studies

Octave Band Frequency (Hz)	**63**	**125**	**250**	**500**	**1k**	**2k**	**4 k**	**8k**	**Log Sum**
Health & Safety Executive, 1997.	85	91	100	109	118	123	126	120	128.9
Patel & Irving, 1999.	78	79	83	90	98	107	114	120	121.2
Price & Whitaker, 1986	98	97	101	101	106	112	115	116	119.8
Environmental Medicine Unit Report, 1998.	73	82	89	97	107	111	111	107	115.5

1.3. Noise Induced Hearing Loss

Because of the omnipresence of noise, our ears and aural senses will almost always be exposed to sound. The frequency of exposures to high intensity sources of noise are increased in the occupational environment. Often the result of cumulative exposures, noise induced hearing loss may take years to fully develop. The delayed symptom onset often does not trigger an acute response by the worker to protect their hearing, limit their exposure, or evaluate their work environment (Berger, 2003). The widespread occurrence of noise induced hearing loss has been attributed primarily to lack of education on the topic, lack of individual understanding of the causal and protective mechanisms, and absence of employer controls in the occupational setting (Standard, 1996).

The effects of noise exposure extend beyond a loss of sensitivity threshold at certain frequencies. Acute noise exposure has been measured to increase cortisol levels and post-work irritability when hearing protection was not worn during a 7 day working period (Melamed and Bruhis, 1996). Therefore, the effects of NIHL can extend beyond the workplace and affect the quality of life experienced by the worker in dramatic ways.

1.4. Physiology of the Ear

The human ear is comprised of three interworking components: the outer ear, middle ear, and inner ear. The outer ear serves primarily to collect sound waves and funnel them into the ear canal leading to the tympanic membrane. Because of the shape and dimensions of the auditory canal, sound in the 2-4 kHz region are amplified by 10-15 dB making noises in this frequency range the most hazardous to hearing (Berger, 2003). This characteristic is especially important in regards to noise exposure from abrasive blasting activities because of the dominant higher frequencies as seen in Table I. Once sound travels through the external auditory canal, it reaches the middle ear in which the tympanic membrane vibrates in response to pressure fluctuations in the sound wave. These vibrations are transmitted to the ossicles which transfer the energy to the fluid-filled inner ear. The middle ear also has two muscles attached to the ossicles (tensor tympani and stapedius) which stiffen when in the presence of loud sounds reducing the transmission of low-frequency energy, 1500 Hz and below (Berger, 2003). The activation of the muscles of the middle ear can provide protection against sustained high-intensity noise often found in the industrial and construction environments.

The inner ear is relatively complex in comparison to the outer and middle ear. The movements from the ossicles are transformed into fluid pressure in the inner ear. This pressure wave generally moves through the cochlear duct and into the perilymph fluid. This pressure wave causes the round window to bulge into the middle ear. As this pressure wave descends through the cochlear duct, it sets the basilar membrane into vibration. Localized movements of the basilar membrane deflect the hearing receptor cells in which these impulses are transmitted along the cochlear nerve to the auditory cortex where sound is perceived (Berger, 2003).

The loss of hearing due to long-term high intensity noise exposure is thought to be associated with the destruction of sensory hair cells in the inner ear. Once damage to sensory hair cells occurs, it cannot be reversed and the result is noise induced hearing loss (NIHL). If NIHL is temporary it is referred to as a Temporary Threshold Shift (TSS). Four main factors contributing to the temporary loss of hearing sensitivity include: intensity level of the noise, frequency spectrum of the noise, duration of the noise exposure, and hearing sensitivity of the person exposed (Berger, 2003). Temporary threshold shifts will return to normal sensitivity in a matter of hours or days without continued exposure. If the pattern of temporary threshold shifts is repeated over a period of time, or if the initial insult is sufficiently intense, damage to the sensory hair cells will be irreparable and the hearing loss will be a permanent threshold shift.

1.5. Hearing Protection Devices

Regarded as a last resort under the hierarchy of controls, hearing protection devices (HPDs) seek to seal and block the conductance of sound in air by occluding the ear canal either internally with an earplug or externally (circumaural) with an earmuff. A third, often operation-specific option is a helmet which encases the entire head. HPD’s are generally the most popular choice for noise attenuation when other types of engineering or administrative controls are not feasible. The large interest in research and development of hearing protection began during and following World War II as a result of the tremendous hearing loss caused by military operations (Berger, 2003) and migrated into the aviation and metal industries. One of the earliest regulations pertaining to hearing conservation was Air Force Regulation 160-3, issued in 1948 and required periodic noise measurements (Dept. of the Air Force, 1948).

Earplugs are most widely available in foam, pre-molded, formable and semi-insert varieties and provide noise attenuation when they are placed into the ear canal to form a seal. Earmuffs are most commonly constructed as molded plastic ear-cups that seal around the ear using foam or fluid-filled cushions. The cups are lined with acoustic foam to absorb high frequency energy within the cup, greater than 2 kHz (Berger, 2003). Helmets are designed primarily for impact protection but can also provide beneficial amounts of hearing protection because the inherent design of the helmet encloses a substantial portion of the head. In higher frequencies, helmets can provide attenuation beyond the bone-conduction limits experienced with traditional hearing protection devices like earplugs and earmuffs (Berger, 2003).

1.5.1. Measuring Attenuation

Before a hearing protection device can be assigned a noise reduction rating (NRR), the sound level attenuation of the device must be measured. The two most common methods of measuring attenuation are the Real-Ear-at-Threshold (REAT) method and the Microphone-in-Real-Ear (MIRE) method.

Virtually all available manufacturers’ reported NRR data have been derived from the REAT method and follow ANSI/ASA S12.6-2008 Method for Measuring the Real-Ear Attenuation of Hearing Protectors. It is also the procedure required by the EPA to obtain data for the computation of NRR. Under this method, the subject performs a behavioral audiometric assessment without the hearing protection device and then performs a second audiometric assessment with the hearing protection device. Measures are based upon the determination of the difference between the "open threshold" and the "occluded threshold". An advantage of the REAT method is that it measures both the ear conduction and bone conduction sound pathways (Berger & Kerivan, 1983).

The alternative method to REAT is the Microphone-in-Real-Ear (MIRE) method using a microphone for direct measurement. This involves measurements being made in the ear canal with and without the hearing protection device inserted, or with one in the ear canal and one outside the hearing protection device. The difference between the two measurements becomes the sound attenuation in dB (Berger, 2003).

1.6. Bone Conduction

In addition to air conduction, sound pressure waves can be transmitted via vibrations in the skull called bone conduction. There are three processes contributing to bone conduction: First, the inner ear in which vibration of the temporal bone encasing the cochlea directly stimulates the cochlea; second, the ear canal wall vibrates and causes a pressure change in the ear canal; third, the movements of the ossicles cause additional stimulation of the cochlea (Khanna et al, 1976).

Even if the hearing protection device selected was perfectly effective in blocking sound paths from air leaks, eliminating HPD vibration in the ear canal, and material transmission of vibrations sound pressure energy could still reach the inner ear via bone conduction. In order to attenuate sound transmitted via bone conduction the body must be isolated from the sound/vibration source in some way (Berger, Kieper, & Gauger, 2003). This flanking of the HPD is most significant in the higher frequencies; however, the level of sound reaching the ear through bone conduction is approximately 40-50 dB below the level of air-conducted sound (Berger, 2003).

In an earlier study measuring the individual and combined attenuations of flight helmets, foam earplugs, and ear muffs (Berger, Keiper, and Gauger, 2003), bone conduction transmissions were found to have decreased in the higher frequencies as the skull was afforded isolation by the helmets that full enclose the skull. The study also noted that lower frequency attenuation was provided primarily by the use of the foam earplugs. As can be seen in Figure 1, the combined attenuation provided by ear plugs and ear muffs increase approximately 5 to 6 dBA per octave until reaching the limit imposed by bone conduction of approximately 40 dBA. It is then possible that an appropriately designed helmet that encapsulates the skull, when used in combination with foam insert earplugs, can provide the necessary attenuation of both higher and lower frequency noise sufficient to protect against noise induced hearing loss during abrasive blasting operations.

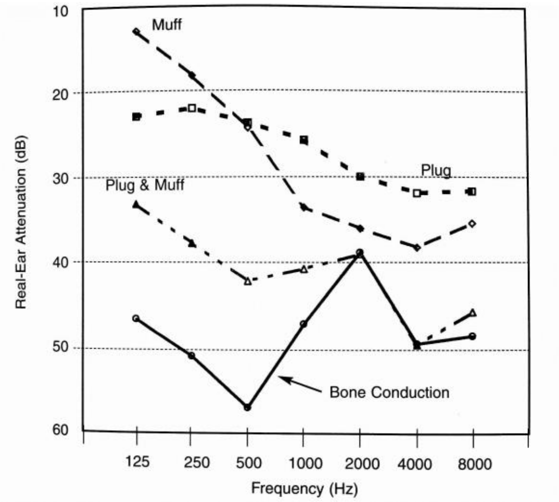

Figure 1 - Bone Conduction limits to HPD attenuation. From Berger, 2003 pp 397.

1.7. Hearing Conservation Regulation

The Occupational Safety and Health Administration mandated the Department of Labor’s noise regulation in 1972 setting a PEL of 90 dBA with a 5-dB exchange rate and required reduction of noise levels to the PEL by engineering or administrative controls. Hearing protection devices were required if sound levels were above the PEL, and a hearing conservation program for employees exposed above the PEL. OSHA issued a Hearing Conservation Amendment in 1981and revised it in 1983 with specific requirements for noise measurement, audiometric testing, employee education and recordkeeping.

It is important to note that OSHA has separate regulations for General Industry and Construction. The General Industry regulations will cover most civilian employees working in industrial and manufacturing settings, but does not cover other federal groups such as Dept. of Defense, MSHA, or Dept. of Energy. The Construction regulations have not been amended to include a detailed hearing conservation program. The EPA has estimated that in order for there to be no risk of noise induced hearing loss from noise exposure, the permissible exposure limit would have to be as low as 75 dBA as an 8 hour time weighted average (EPA, 1974).

1.8. Report Objectives

The objective of this study was to investigate the noise levels produced during abrasive blasting, attempt to further quantify total noise exposure to the abrasive blast operator, and calculate combined attenuation provided by the abrasive blasting helmets and hearing protection devices. In order to assess the adequacy of the helmet, the approximate risk to the abrasive blaster must be quantified and the appropriate control measures such as administrative, engineering, or personal protective equipment can be implemented.

It is hypothesized that the constant sound pressure levels in the blast booth and the time weighted average sound pressure level will exceed OSHA’s 90 dBA Permissible Exposure Limit (PEL). It is further believed that the construction of the blast helmet will have significant impact upon the ability of the helmet to attenuate sound, especially higher frequency sound pressures. Finally, it is postulated the estimated combined attenuation achieved by wearing a hearing protection device in addition to the blasting helmet will diminish sound the operator’s exposure to sound pressure levels to below the 90 dBA PEL mandated by OSHA.

2. Methods and Measurement

2.1. Participants

A journeyman painter that was part of a shop operation from an industrial coatings company had volunteered to have personal dosimetry conducted while abrasive blasting. The painter was male, and regularly performed abrasive blasting as part of his daily activity. He was provided the dosimetry results to help confirm the hazardous levels of noise exposure and assist in his selection and continued use of hearing protection devices.

2.2. Equipment

During abrasive blasting a survey of sound pressure levels was collected at various points around the blast operator using a 3M Quest SoundPro Type I sound level meter with an integrated octave band filter and equipped windscreen. Sound pressure levels inside and outside of the blast helmets and the resulting time weighted average exposures were measured using 3M Quest DLX Type II dosimeters. The dosimeters were attached to the participant's belt and one microphone was inserted into the helmet and secured as close to the hearing zone of the ear as possible while the second microphone was attached to the outside of the blast helmet, adjacent in proximity to each other as seen in Figure 2. (The circled area shows the external microphones and approximate positions of where the internal microphone would have been installed). Wind screens were installed on both dosimeter microphones. Both instruments were received with certificates of lab calibration and were field verified with the 3M Quest QC-10 Calibrator set to 1 kHz at 114 dB.

Figure 2 - Nova 2000 Blast Helmet (left) and Bullard GenVX Blast Helmet (right) with dosimeter microphones installed.

During abrasive blasting, the participants wore NIOSH Type CE respirators, commonly referred to as blast helmets. Two different helmets were utilized for comparison: the Nova 2000 and the Bullard GenVX. Each helmet was equipped with a nylon cape and was supplied breathing air through a 3/8” airline fed by an air compressor. Because of common fittings on the airline assembly, the entire breathing air system from the compressor through the multi-stage filters and carbon monoxide monitor was able to be left intact for both helmets. All that was necessary was for the blast operator to connect the airline to the helmet’s regulator. This common assembly also ensured a consistent volume of air being supplied to the blast helmet, and thereby less variability in background noise produced by the flow of air. A number seven blast nozzle was connected to the blast hose which is considered to be a relatively standard size selection and a coal slag abrasive commonly referred to in the industry as “Black Beauty” was utilized on steel plates during the abrasive blasting period.

2.3. Procedure

2.3.1. Process Description

The work to be performed during this survey was abrasive blasting of one-quarter inch thick steel panels to clean and prepare for coating application. Each panel was laid horizontally on a cart and was transported into the blast booth. A coal slag blast media commonly referred to as “Black Beauty” was used with a number seven nozzle. The gauge on the abrasive blast pot registered 100 psi of air pressure being sent to the abrasive blast nozzle. This is characteristic of a typical setup and scope of work to be performed inside the blast facility. The nozzle was manually operated by the blaster who wore a Type CE supplied air respirator with nylon cape, foam earplugs, and leather gloves. The activity period sampled is typical for the facility in which the abrasive blast operator will spend approximately six hours performing abrasive blasting. The rest of the shift is negligible exposure below the 80 dB threshold consisting of breaks, or equipment inspection and staging not involving significant noise sources.

2.3.2. Noise Dosimetry

The noise dosimeters were field calibrated in accordance with the manufacturer’s instructions using the specified calibrator prior to sampling and after sampling. The dosimeters were set to A scale weighting, Slow response, 5 dB exchange rate, and 90 dB criterion level. A 90 dB threshold (OSHA PEL) was also set. The dosimeters were attached to the participant’s belt, the microphone wires run up the participant’s back to minimize entanglement, and one microphone secured inside the abrasive blast helmet next to the ear using the provided alligator clip while the other microphone was secured to the outer helmet lens casing using the provided alligator clip. The two microphones were positioned as adjacent to each other as allowable to capture the most accurate attenuation that may be provided by the helmet. The identical procedure was completed for both types of helmets; each helmet was worn by the blaster for approximately three hours. A visual inspection was conducted when the opportunity allowed to ensure that each dosimeter's microphone was still in place and had not moved or shifted during abrasive blasting. Dosimetry was collected during the entire abrasive blasting work period. The type of blast helmet was changed at the midpoint of the shift from the Bullard GenVX model to the Nova 2000 model when the abrasive blast operator had completed surface preparation of the first set of panels and was preparing for the next set of panels.

2.3.3. Sound Level Meter Survey

The sound level meter was calibrated in accordance with the manufacturer's instructions using the specified calibrator prior to sampling and after sampling. The sound level meter was set to A scale weighting, slow response, 5 dB exchange rate and 1/1 octave band analysis. A windscreen was equipped on the sound level meter. The survey began once the operator commenced abrasive blasting of the panels and took readings at pre-measured locations within the blast booth. Because of the inherent risks of being near an abrasive blast stream, the surveyor donned personal protective equipment including: coveralls, gloves, and an air fed-helmet with cape. The sound level meter was held by the surveyor at a full, extended arm's length away from the surveyor's body to prevent—to the extent possible—casting an acoustic shadow or reflective interference. Once the sound survey was complete, the surveyor exited the blast booth and watched the blasting operation through an observation port.

3. Results and Discussion

3.1. Sound Level Meter Survey

As shown in Table II, the sound pressure levels generated during abrasive blasting were quite substantial with 120 dBA recorded 5 feet from the blast operator. As expected based on the literature search discussed in Section 1.2, the overall sound pressure level was dominated by higher range frequencies. Doubling the distance from the source did provide an approximate 6 dB decrease in sound pressure level to 114 dBA. The measured SPLs indicate that hearing protective devices will be required to be used by personnel performing abrasive blasting to provide protection against high intensity sound pressure levels.

Table II - Sound Survey Readings

Location	**63 Hz**	**125 Hz**	**250 Hz**	**500 Hz**	**1 kHz**	**2 kHz**	**4 kHz**	**8 kHz**	**Log Sum (dBA)**
5 ft right of blaster	78.2	79.1	83.5	90.6	98.1	107.7	114.3	118.8	120.4
10 ft right of blaster	79.0	83.3	89.8	97.6	100.8	107.2	111.7	109.3	114.8
5 ft behind blaster	76.5	78.3	81.9	89.2	98.4	107.1	112.5	118.2	119.5

When compared in Table III, the results of the author's survey are near identical in range with data collected by Patel & Irving (1999) using both human as well as Head and Torso Simulator with pink noise being measured at the helmet in a laboratory setting and are slightly higher than Price and Whitaker (1986) in which levels inside and outside of a range of helmets were measured during blasting in the field. The author's survey results are also lower than the results reported by the Environmental Medicine Unit Report (1998) and the Health and Safety Executive (1997).

Table III - Comparison of Abrasive Blasting Noise as Reported in Multiple Studies

Octave Band Frequency (Hz)	63	125	250	500	1k	2k	4 k	8k	Log Sum
Health & Safety Executive, 1997.	85	91	100	109	118	123	126	120	128.9
Patel & Irving, 1999.	78	79	83	90	98	107	114	120	121.2
Price & Whitaker, 1986	98	97	101	101	106	112	115	116	119.8
Environmental Medicine Unit Report, 1998.	73	82	89	97	107	111	111	107	115.5
Results from this study, 5 ft from operator	**78**	**79**	**84**	**91**	**98**	**108**	**114**	**119**	**120**

These differences are most likely on account of the differences in the type and setup of the blasting equipment or sound simulator, location, and other variables such as air pressure, media, and substrate. The placement of the microphone, type of sound level meter, and response settings would also have had an effect upon the results. All surveys do indicate the sound pressures being dominated by higher frequency wavelengths during abrasive blasting. The minimal differences between the studies are also representative that the respective study authors were unable to identify specific design features of the blast helmets that could be correlated with higher attenuation properties.

As illustrated in Figure 3, the results of this study closely parallel the results of Patel and Irving's (1999) study, and also reflect the dominant high frequency profile of abrasive blasting common to all of the other studies.

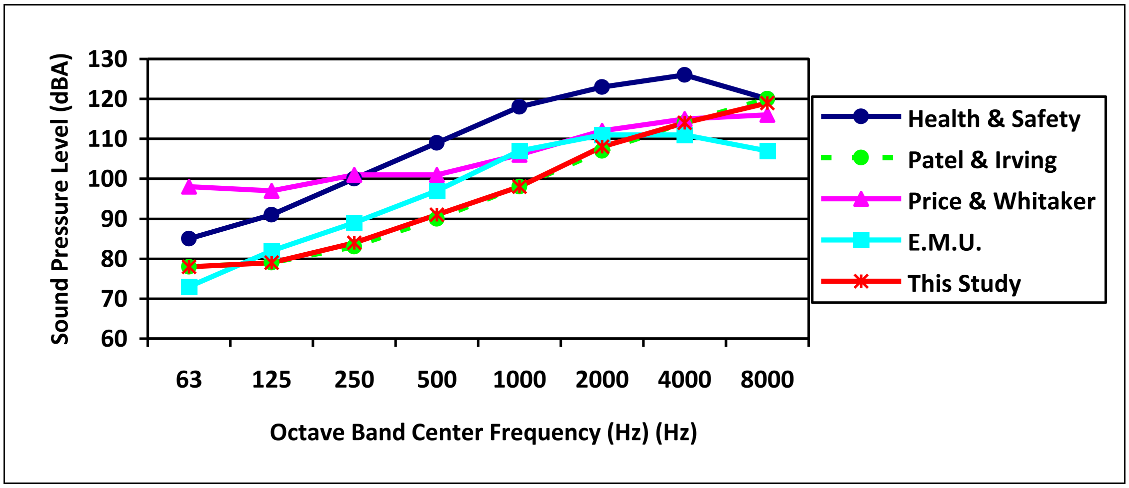

Figure 3 - Plot of Abrasive Blasting Noise Surveys

3.2. Noise Dosimetry Readings

Personal sampling data was collected inside the blast helmet to provide a more accurate assessment of sound pressure levels experienced by the abrasive blaster. Dosimetry was also collected immediately outside of the blast helmet to measure possible attenuation that may occur as a result of helmet construction and design features. As can be seen in Table IV, noise dosimetry performed provides evidence that attenuation of sound pressure levels is provided by the abrasive blasting helmets. The Bullard GenVX and Nova 2000 helmets demonstrate 18 dBA and 20.9 dBA respectively.

Table IV – Estimated Helmet Attenuation

Helmet Model	Exposure Time (Hr)	Lavg (dBA) Exterior Dosimeter	L_{avg} (dBA) Interior Dosimeter	Estimated Helmet Attenuation (dBA)
Bullard GenVX	3:27	112.6	94.6	18.0
Nova 2000	3:15	111.4	90.5	20.9

It was hypothesized that because of the construction of the helmets, the design of the Nova 2000 containing significantly more foam padding than the Bullard GenVX would allow the Nova helmet to absorb more sound than the GenVX helmet. While the Nova helmet did attenuate more noise than the Bullard helmet, it was not as pronounced a difference as initially expected. From the manufacturer's data, the reported NRR for the Bullard GenVX was 30.7 dBA (Bullard, 2013) and the Nova 2000 was 25.6 dBA (Hamill, 2010). However, only an approximate 2.9 dBA difference in attenuation provided by the helmets was calculated based upon the L_{avg} recorded by the dosimeter. Despite the differences between manufacturer and measured data, the L_{avg} inside both blast helmets was measured to exceed the 90 dBA PEL criteria from OSHA indicating that if the operator was unprotected during his work shifts, noise induced hearing loss could occur. The results also indicate that the operator should be enrolled as part of a hearing conservation program by the employer.

Using the octave band SPL data measured with the sound level meter to compare against the manufacturer's stated attenuation data for each helmet, an estimate of attenuation can be derived for each center frequency of the octave band. As can be seen in Figure 4 for both the GenVX and Nova 2000 helmets, the attenuation provided by the helmet is most substantial in the higher band frequencies above 2000 Hz. This degree of attenuation at higher frequency bands is significant not only because of the tendency of higher frequencies sound pressures to be transmitted via bone conduction but also because of the characteristic of the auditory canal to amplify higher frequency sound. In combination with the design of the Nova 2000 helmet to use foam padding rather than a suspension design as in the GenVX, it is possible that considerably less energy was transmitted via bone conduction.

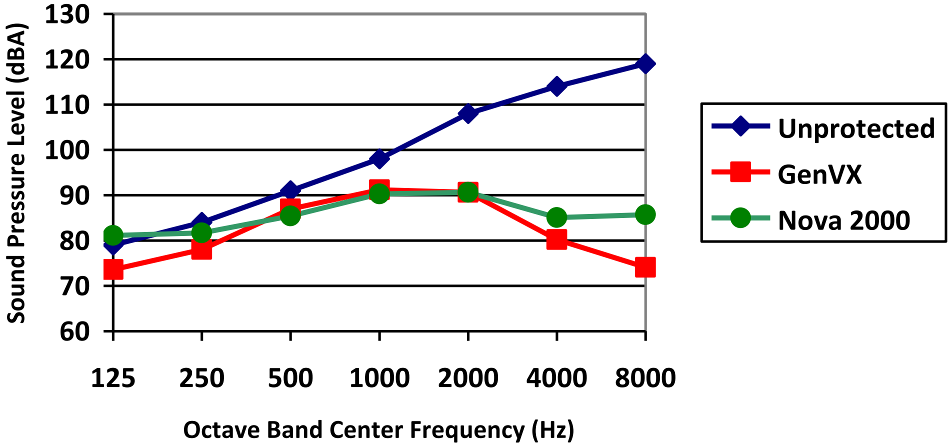

Figure 4 - Estimate of Attenuated SPL during Abrasive Blasting

Using the data obtained from in-helmet dosimetry compared against the data obtained from outer-helmet dosimetry, an actual measured attention value can be obtained. When considering the ear-plugs worn by the abrasive blast operator while wearing either abrasive blast helmet, a combined attenuation value can be determined for each helmet. In both instances, the combination of abrasive blast helmet and earplugs provided significant attenuation to reduce the exposure to not only below the 90 dBA threshold, but below the 85 dBA Action Level under the Hearing Conservation Amendment. Table V provides a comparison of predicted and measured attenuations provided by the abrasive blast helmet and earplugs.

Table V- Comparison of Predicted vs Measured Attenuation

Helmet Type	**Bullard GenVX**	**Nova 2000**
Manufacturer Stated NRR (with C Weighting Adjustment)	30.7 dBA – 7 = 23.7	25.6 dBA – 7 = 18.6
Measured Helmet Attenuation	112.6 – 94.6 = 18 dBA	111.4 – 90.5 = 20.9 dBA
Estimated Exposure with Helmet + Plugs (NRR = 33) [OSHA Method w/ 50% Correction Factor]	94.6 - [(33-7)/2] = 81.6 dBA	90.5 – [(33-7)/2] = 77.5 dBA

3.3. Limitations of Study

One of the foremost confines of this study was the limited sampling events from which to record data, measure attenuation, and conduct further evaluation of the blast helmet design and construction. Multiple sampling events examining a variety of helmets from different manufacturers would be the ideal method to obtain validity and accuracy in the data results. Another concern is that of the abrasive blast operator's shift, the sampling event for each helmet only comprised approximately half of the shift. If dosimetry could be conducted for full shift periods of abrasive blasting with each helmet, a more accurate L_{avg} and resulting helmet attenuation could perhaps be obtained for each helmet.

The sound level meter placement was approximately 5 feet away from the abrasive blaster. Because a true measurement was not taken directly at the source with the sound level meter equipped with octave band analyzer, the accuracy of the source measurement may be slightly lower resulting in a slightly lower overall sound pressure level. Mounting the sound level meter on a fixed tripod or utilizing a remote microphone would help increase the accuracy of this measurement at the source.

The placement of the microphone was also a concern for the dosimeter. From a technical practice standpoint, the microphone of the dosimeter should be as close to the hearing zone of the abrasive blast operator as possible to obtain a true reading of the sound pressure level, generally within 30 cm (Berger, 2003). While this study did achieve such placement, a critical portion of measuring the attenuation provided by the helmet was being able to place the internal and external dosimeter microphones as close together as possible but the construction of each helmet provided a unique mounting challenge. Ultimately, a difference of a few centimeters may not have a dramatic impact upon the study but the question of precision must still be addressed. It is also important to consider the impact of the reflective plane created by the outer shell of the blast helmet on the outer dosimeter microphone.

The inability to measure bone conduction of sound pressure levels is also considered a limitation in this study because of the lack of analyses that can be provided for attenuation based on helmet construction, and further clarify the hypothesized efficacy of the helmet foam liner. Further method research will be required to confirm the efficacy of the helmet attenuation data.

Finally, the Quest dosimeters did not have an octave band analyzer. This limitation is now viewed as particularly important with the consideration that the construction of the helmet may have had significant impact upon sound attenuation across the spectrum, especially at higher frequencies. To truly measure the attenuation provided by the helmet, especially at the dominant higher frequency spectrum, a dosimeter equipped with an octave band analyzer would be viewed as essential.

3.4. Recommendations for Further Research

It is recommended that one of the above-proposed means of placing the sound level meter closer to the hearing zone of the abrasive blast operator either on a tripod or remotely be utilized to obtain a truer measurement of sound level data. It is also recommended that dosimetry be performed with a dosimeter equipped with an octave band analyzer to separate the frequencies of the sound generated during abrasive blasting and further analyze which frequencies are most attenuated by the design and construction of the abrasive blast helmets.

As a method of further quantifying attenuation provided by the combination of abrasive blast helmet and earplugs, it is recommended to use a more specific attenuation measurement method such as MIRE in which a microphone is inserted into the operator's ear canal during actual abrasive blasting activities. It is believed this field data would add more precise measurements of the operator's actual exposure than lab simulations that other studies have performed using Head and Torso Simulators.

4. Conclusion

This report examined sound pressure levels produced during abrasive blasting activities, refined the sound pressure level across octave band frequencies, and examined sound level attenuation provided by abrasive blast helmets, earplugs, and their combined attenuation.

Measurements taken inside the blast booth were well above OSHA’s 90 dBA threshold and could exceed OSHA’s PEL for noise exposure if the blast operator did not utilize a secondary hearing protection device during the work shift. These noise exposures could also contribute to noise induced hearing loss if engineering controls, administrative controls, or personal protective equipment were not implemented. The measured and calculated attenuation values provided by the abrasive blast helmets were more conservative than the stated manufacturer ratings for the two abrasive blast helmets studied. Sound survey and personnel dosimetry data were used in combination with manufacturer NRR for earplugs to further quantify the exposure to abrasive blast operators. It has been determined that, when used appropriately during a work shift, both devices can provide a combined attenuation sufficient to reduce the operator’s exposure to below OSHA’s PEL and aid in the prevention of noise induced hearing loss.

Measured sound pressure levels obtained in the blast booth did exceed 120 dBA and the TWA sound pressure levels could easily exceed OSHA’s 90 dBA PEL. The blast helmets tested also demonstrated the ability to attenuate sound generated during abrasive blasting, especially sound in the higher frequency bandwidth. Comparatively, the design of the Nova 2000 blast helmet to utilize a dense foam liner with circumaural ear pads inside the helmet did provide nearly 3 dBA more sound attenuation than did the Bullard GenVX helmet designed with a plastic helmet suspension liner. Because of the dominant higher frequency sound profile for abrasive blasting, this attenuation is believed to occur in the higher frequency spectrum where bone conduction of sound pressure levels takes place. The continued use of dense foam liners with circumaural ear pads is recommended as a design feature in blast helmets to provide greater operator protection to noise generated during abrasive blasting processes.

This study has demonstrated that the attenuation achieved by wearing a hearing protection device in addition to the blasting helmet will diminish sound the operator's exposure to sound pressure levels to below the 90 dBA criterion level mandated by OSHA. However, it is clear that further research is needed to determine methods to quantify and reduce bone conduction to increase operator safety. Further, this study emphasizes the need to examine the abrasive blasting process and protective equipment to reduce noise generated during abrasive blasting and equipment to increase operator protection.

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