Measurement of Exposure to Impulsive Noise at Indoor and Outdoor Firing Ranges during Tactical Training Exercises

Scott E. Brueck, MS, CIH
Chuck A. Kardous, MS, PE
Aalok Oza, MPH
William J. Murphy, PhD

Report No. 2013-0124-3208
June 2014

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Contents

The employer is required to post a copy of this report for 30 days at or near the workplace(s) of affected employees. The employer must take steps to ensure that the posted report is not altered, defaced, or covered by other material.

The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a federal agency in Tennessee. The requestors were concerned about firearms instructors' exposures to high intensity impulsive noise during tactical training exercises.

What We Did

- We measured instructors' impulsive noise exposures when training with several different firearms and weapons systems.
- We calculated the number of gunfire exposures that would be permitted per day without incurring a significant risk of hearing loss.

We measured firearms instructors' exposures to impulsive noise during live fire training exercises. When using firearms and flash bang grenades, instructors were exposed to impulsive noise levels greater than 150 decibels, which is above the NIOSH ceiling limit. Exposures were greater than recommended by some damage risk criteria. We recommended using dual hearing protection during all live fire training exercises and installing additional noise controls.

What We Found

- During most training exercises, instructors were exposed to peak sound pressure levels greater than 150 decibels. NIOSH recommends a ceiling limit of 140 decibels for peak sound pressure levels.
- Peak sound pressure levels for the Dillon M134D minigun, 12-gauge shotgun, and full-load flash bang grenade were sometimes greater than 170 decibels.
- Instructors could exceed the number of gunfire exposures permitted per day.

What the Employer Can Do

- Install noise controls at the outdoor and indoor ranges.
- Use noise suppressors on firearms, if feasible.
- Use the most protective criterion to limit the number of daily gunfire exposures
- Require use of dual hearing protection during all live fire training exercises.
- Fit test employees for the hearing protection they use.

What Employees Can Do

- Wear dual hearing protection during all live fire training exercises.

This page left intentionally blank

Abbreviations

AHAAH	Auditory Hazard Assessment Algorithms for Humans
ARU	Auditory risk units
ANE	Allowable number of exposures
CHABA	Committee on Hearing, Bioacoustics, and Biomechanics
CFR	Code of Federal Regulations
dBA	Decibels, A-weighted
Hz	Hertz
LeqA8hr	A-weighted 8-hour equivalent sound level
msec	Milliseconds
NIMS	NIOSH Impulsive-noise Measurement System
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
U.S. DOD	U.S. Department of Defense

This page left intentionally blank

Introduction

The Health Hazard Evaluation (HHE) Program received a request from the safety and health manager of a federal agency concerning firearms instructors' exposures to high intensity impulsive noise during weapons qualifications and tactical training exercises. The firearms instructors train the agency's security personnel. The safety and health manager asked the National Institute for Occupational Safety and Health (NIOSH) to characterize impulsive noise generated by several different weapon systems. The weapons were used during employee tactical training and firearms qualification exercises at indoor and outdoor firing ranges at the agency's security training complex. The agency was particularly interested in knowing peak sound pressure levels, B–duration of the impulse noise waveform, and how much weapons fire instructors could be exposed to per day.

Two NIOSH HHE Program industrial hygienists and a NIOSH research engineer visited the security training complex in June 2013. During the site visit we met with agency safety and health staff, union representatives, and firearms instructors to discuss the HHE request. We observed workplace conditions and work activities, and informally spoke with firearms instructors. We measured impulsive noise generated by several different weapons at three outdoor firing ranges, one indoor firing range, the live fire "shoothouse" facility, the tactical training facility, and the virtual training facility during tactical training exercises.

At the end of our visit, we met with employee and employer representatives. We summarized our activities, and shared preliminary observations and recommendations. In July 2013, we sent a letter to employer and employee representatives. The letter summarized our preliminary results and showed the peak sound pressure levels, the B–duration of the impulse waveform, and the allowable number of rounds of weapons fire that instructors can be exposed to per day when wearing dual hearing protection.

Methods

Impulsive Noise Measurement System

We measured impulsive noise during live firing exercises using the NIOSH Impulsive-Noise Measurement System (NIMS) and software platform. The system was designed to acquire, characterize, and analyze impulsive noise generated by weapons fire [NIOSH 2013a]. The measurement system acquired data and used a graphical interface to display the time domain waveform, one-third octave band frequency spectra, peak sound pressure level, equivalent average sound level, kurtosis, time duration, number of impulses, and temporal spacing between impulses. The system calculates potential risk to hearing based on the United States Department of Defense (U.S. DOD) MIL-STD-1474D, A-weighted 8-hour equivalent sound level (LeqA8hr) equal energy criterion, and the Auditory Hazard Assessment Algorithms for Humans (AHAAH). Additional details about NIMS and calculations using damage risk criteria are provided in Appendix A.

For each tactical training exercise we placed two or three stationary microphones on tripods within 3–4 feet of the instructor or representative instructor positions (Figure 1). We positioned the microphones at a height matching instructors' ear level (standing, sitting, or kneeling). We checked the calibration of each microphone prior to measurements. For impulsive noise measurements of the Dillon M134D Aero minigun, we placed the microphones behind the turret on the top of a modified special weapons and tactics (SWAT) vehicle at the kneeling instructor's ear level. Using the NIMS, we took several impulse noise measurements for each type of weapon or weapon system at each location to capture a representative sample of impulsive noise exposures (Figure 2). Table 1 summarizes the locations of weapons or weapons systems at each location where NIOSH took impulsive noise measurements.

Figure 1. NIOSH investigator positioning and calibrating a one-eighth inch microphone for impulsive noise measurements. Photo by HHE requestor.

Figure 2. NIOSH investigator acquiring and analyzing impulsive noise data on laptop computer using NIOSH Impulsive Measurement System. Photo by HHE requestor.

Table 1. Weapons used at each location during NIOSH impulse noise measurements

Location	Firearms or weapons system
Range 1	M240 machine gun; M249 machine gun; M4 rifle
Range 2	Dillon M134D Aero minigun with and without noise barrier
Range 3	M240 machine gun; M249 machine gun
Indoor range	M4 rifle; 9 mm pistol
Shoothouse	M4 rifle; 870 shotgun; flash bang (full-load and reduced load); Sledgehammer on door; Battering ram on door
Virtual training facility	M249 machine gun

Because of the rate of fire for some of the automatic weapons systems, one to dozens of impulsive noise exposures (i.e., gunshots) occurred during each “trigger pull.” The elapsed time for each trigger pull was approximately 1 second or less. To account for this sometimes rapid succession of gunfire impulses, we considered each trigger pull as an impulse noise exposure analogous to one round of gunfire or one impulsive noise exposure event. We combined the separate gunfire impulses per trigger pull and calculated damage risk and the allowable number of exposures (ANE) for each weapons system and each training exercise. The ANE is equivalent to the allowable number of rounds calculated for single shot weapons.

Instructors wore Moldex Pura-Fit insert ear plugs and Peltor Model MT15H69FB ear muffs. We calculated ANE assuming use of dual hearing protection with an effective attenuation of 34 decibels (dB). This is the attenuation given to this combination of earplugs and earmuffs by U.S. DOD MIL-STD-1474D.

Background on Impulse Noise and Damage Risk Criteria

Impulsive noise is considered to be more damaging to hearing than continuous sounds [Dunn et al. 1991; Starck et al. 2003]. Unprotected exposure to high intensity impulsive noise can cause acute acoustic trauma, resulting in symptoms such as ringing in the ears (tinnitus) and temporary hearing impairment [Salmivalli 1967; Mrena et al. 2002]. Permanent hearing loss may also occur from exposure to high intensity impulsive sounds that exceed a critical sound pressure level by causing direct mechanical damage to the inner ear [Ward et al. 1961; Luz and Hodge 1971].

Although military agencies in the United States and Europe have studied the effects of exposure to impulsive noise from weapons [Ylikoski 1994; Dancer et al. 1998], these studies lacked the data needed to quantify the relationship between impulsive noise and auditory damage. As a consequence, experts in the occupational, military, and scientific communities have not developed a consensus on the extent of hearing loss risk from exposures to impulsive noise.

In 1968, the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the U.S. National Research Council proposed a damage-risk criterion for exposure to impulsive noise [CHABA 1968]. The CHABA criterion was developed on the basis of measurements that could be made using available instruments at the time. The U.S. DOD criterion, MIL-STD-1474D, was based on the 1968 CHABA criterion. This standard provided a method to calculate an allowable number of impulsive noise exposures without a significant risk of hearing loss. The allowable number of impulse noise exposures varies with the use of single or double hearing protection, peak sound levels, and the B-duration of the impulse waveform [U.S. DOD 1997]. B-duration refers to the length of time that pressure fluctuations in the noise wave are within 20 dB of the peak sound pressure level. The U.S. DOD criterion does not account for the characteristics of impulsive noise such as the spectral or temporal content, or for combined exposure to continuous and impulse noise. Additionally, it does not incorporate the effectiveness of hearing protectors or the protection provided by the nonlinear acoustical reflex and the peak clipping that occurs in the middle ear [CHABA 1992]. The standard does not require hearing protection for impulses with peak pressure levels less than 140 dB.

The French Committee for Weapons Noises advocates the use of the LeqA8hr for impulsive noise exposure [DTAT 1983; Dancer et al. 1995]. It recommends a limit for unprotected ears of 85 decibels, A-weighted (dBA) for an 8-hour, A-weighted, equivalent level. Most current noise instruments are capable of measuring LeqA8hr. The criterion integrates continuous and impulsive noise and allows for the assessment of exposure to multiple impulses regardless of whether the impulse happened in the free-field or a reverberant environment. It also allows for measuring the effectiveness of hearing protectors. However, some studies have shown that the LeqA8hr method may underestimate the actual protection efficiency of certain hearing protectors by 5 to 20 dB [Dancer et al. 1995]. A NIOSH report on the LeqA8hr and other damage risk criteria highlighted the advantages of using LeqA8hr to characterize exposure to impulse noise [NIOSH 2012].

The AHAAH damage risk criterion is based on an ear model developed by the U.S. Army Research Laboratory. The AHAAH model simulates the behavior of the middle and inner ear in response to high intensity impulse noise and calculates Auditory Risk Units (ARU). The AHAAH model recommends a daily dose maximum of 500 ARUs [Price and Kalb 1991]. Doses greater than 500 ARUs are predicted to produce permanent hearing loss. Other researchers recommend reducing this limit to 200 ARUs for daily or near daily occupational exposures [Fedele et al. 2013]. The model takes into account protective nonlinearities of the middle and inner ear and explains why some short impulses can cause more hearing damage than longer impulses, even when the longer impulses contain more acoustic energy than the short impulses. The model incorporates "warned" and "unwarned" conditions for calculating ARUs. The "warned" condition occurs when an individual anticipates intense noise exposures. In contrast, the "unwarned" condition occurs when an individual does not know or expect intense noise exposure. The model also incorporates use of hearing protectors for calculating ARUs.

Regulations established by the Occupational Safety and Health Administration (OSHA) and NIOSH recommendations state that no exposure to impulsive sound should be permitted if the peak sound pressure level exceeds 140 dB [OSHA 1992; NIOSH 1998]. The European Union directive 86/188, the International Organization for Standardization in ISO 1999:2013, and the American National Standards Institute ANSI S3.44-1996 also state that no exposure should be permitted above peak sound levels in excess of 140 dB [ECD 1986; ISO 1990; ANSI 1996].

The agency currently uses the U.S. DOD MIL-STD-1474D damage risk criterion to determine the allowable number of gunshot exposures per day. The U.S. DOD has proposed a revised design limit criterion for noise, MIL-STD-1474E, that uses a variant of the equivalent A-weighted sound level based on the first 100 milliseconds (msec) of an impulse ($LeqA_{100msec}$) and the AHAAH model.

Results and Discussion

In this evaluation, we assessed firing range instructors' exposures to high-intensity impulsive noise from gunfire and weapons systems during tactical training exercises. Tables B1, B2, and B3 in Appendix B show detailed results of our noise measurements and ANE for impulsive noise from each firearm or weapons system based on the three damage risk criteria with hearing protection.

Peak impulsive noise levels during shooting of the Dillon M134D Aero minigun at outdoor range 2 reached a maximum of 171.4 dB at the instructor's position next to the shooter.

Figure 3 shows the acoustic waveform and rapid succession of 42 gunfire impulses that occurred in less than 1 second during firing of the Dillon M134D. One-third octave band measurements show that the highest noise levels occurred at frequencies of 50, 63, 100, and 160 hertz (Hz). The highest peak bands correspond to the fundamental frequency and harmonics of the firing rate of the weapon. A single impulse peaks at higher frequencies, near the 1000 Hz band.

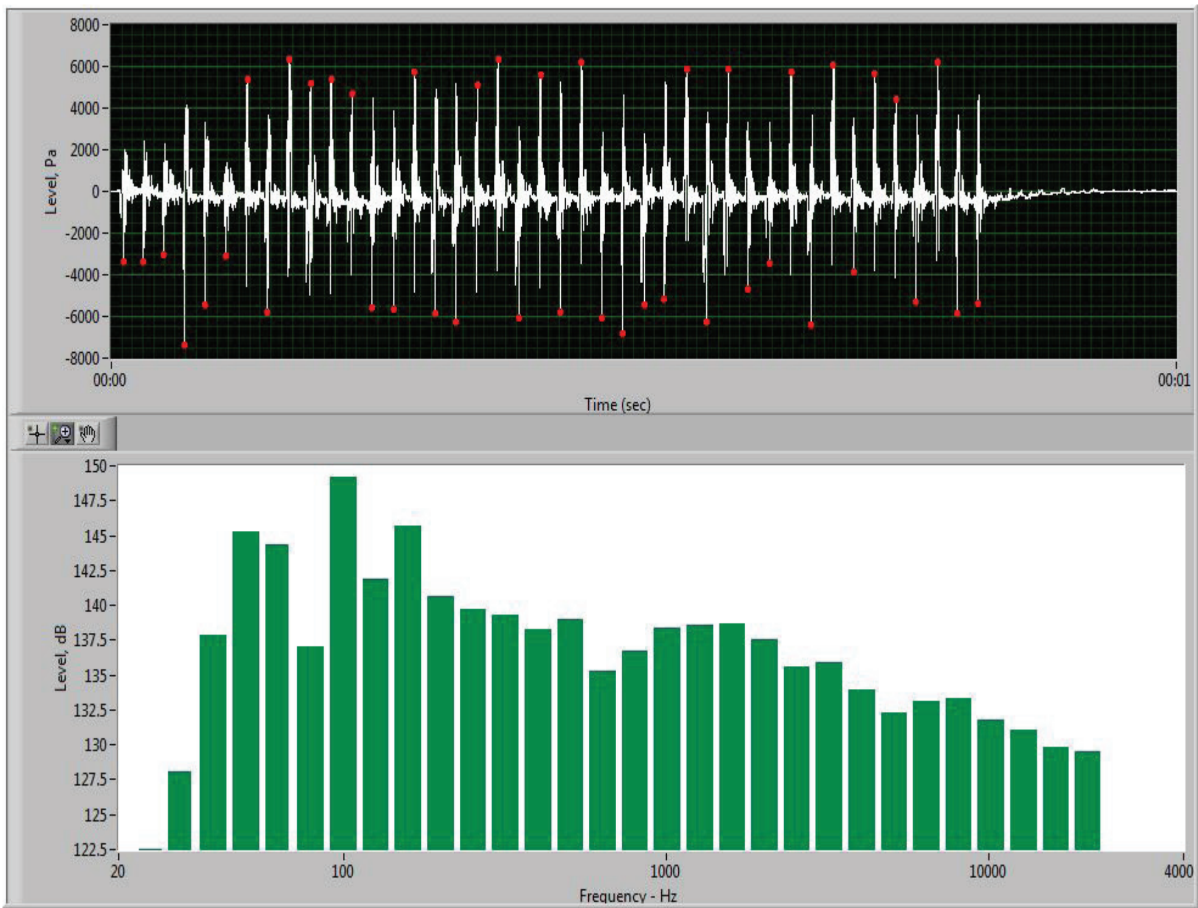

Figure 3. Screen capture of impulsive noise waveform and one-third octave band noise frequency results from NIMS display of one trigger pull from the M134D Dillon Aero minigun showing 42 gunfire noise impulses.

Depending on the damage risk criterion, the ANE (i.e. trigger pulls) for the Dillon M134D per day ranged from 5 using the AHAAH model to 276 using the U.S.DOD criterion (with dual hearing protection). To reduce instructors' noise exposures from the Dillon M134D, agency personnel positioned a wooden barrier between the gun muzzle and the shooter and instructor (Figure 4). With the barrier in place, the maximum peak sound pressure level was 160.7 dB, a decrease of about 10 dB. The ANE with the barrier in place increased to 37 based on AHAAH criterion and to 17,131 based on the U.S. DOD criterion. Additional acoustical treatment of the current barrier design could further increase attenuation of peak sound pressure levels.

Figure 4. Firing range instructor kneeling between microphones and behind a noise barrier on top of modified SWAT vehicle during firing of Dillon 134D Aero Minigun. Photo by HHE requestor.

At outdoor ranges 1 and 3, three shooters in a prone position fired their weapons simultaneously. One or two instructors usually stood 4–6 feet behind the firing line between the shooters (Figure 5) or sat next to the shooters. An additional instructor stood about 10 feet behind the shooters. Maximum peak levels at the instructor 1 position (nearest the shooters) during shooting of the M4, M240, and M249 ranged from 159–164 dB. The M249 had slightly lower peak sound pressure levels. The ANE for instructor 1 ranged from 19 using the AHAAH criterion to 412 using the U.S. DOD criterion (with dual hearing protection). Because instructor 2 stood farther away from the shooters, maximum peak sound pressure levels were less, ranging from 149–151 dB. ANE for instructor 2 was 154 using the AHAAH criterion, and > 40,000 using the U.S. DOD criterion.

Figure 5. Two instructors standing between shooters at the outdoor range. Photo by HHE requestor.

At the outdoor ranges each set of shooters usually had 16 trigger presses per live fire exercise with each weapon. Figure 6 shows the impulsive noise waveform pattern for two separate trigger presses of an M240. The impulsive noise waveform for each trigger press had seven distinct noise peaks, corresponding to seven gunshots, occurring in a timespan of approximately 0.75 seconds. The same pattern was repeated one-half a second later. Peak impulse noise levels ranged from 2000 to 3000 pascals (160–164 dB). Noise levels at all frequencies higher than 100 Hz were above 120 dB. However, at 1250 and 1600 Hz noise levels were 130–135 dB. Acoustical treatment of the underside of the corrugated metal roof and the wall behind the shooters might reduce some of reverberant noise during shooting.

Based on the AHAAH criterion, instructor 1 would exceed ANE after observing only two sets of shooters (assuming 16 trigger presses per set of shooters), but could observe about 25 sets of shooters before ANE was exceeded using the U.S. DOD criterion. At the instructor 2 position, an instructor would exceed the ANE after observing 9 sets of shooters based on the AHAAH criterion, but would not exceed the U.S. DOD criterion during a workday because the ANE was greater than 40,000.

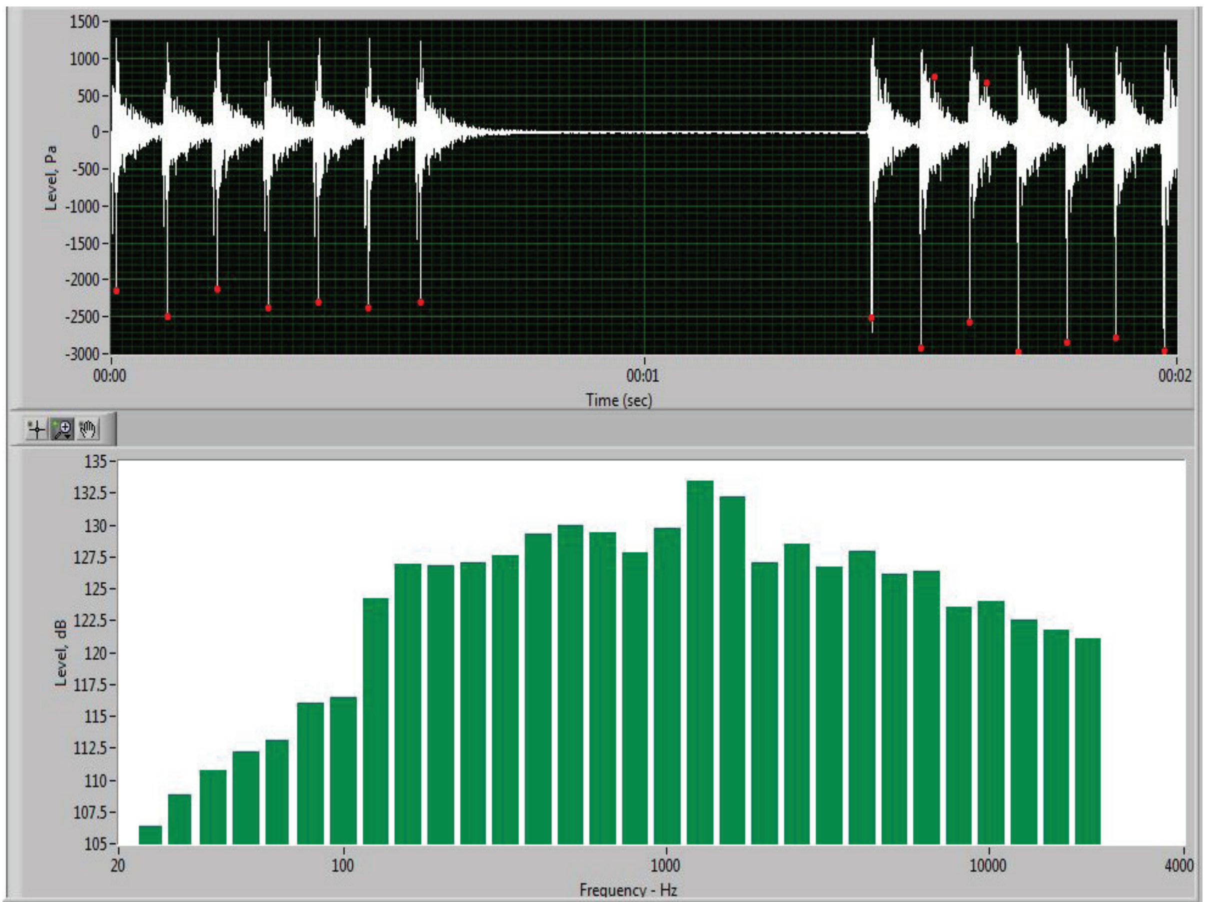

Figure 6. Screen capture of impulsive noise waveform and one-third octave band noise frequency measurement results from NIMS display showing two trigger pulls of M240 rifle.

At the indoor range, shooters used M4 rifles and 9 mm pistols at distances of 50 yards, 25 yards, and 5 yards from range targets (Figure 7). During our evaluation, 14 shooters fired weapons simultaneously at the 50-yard and 25-yard positions. However, the number of shooters can vary from ten to twenty. Shooters fire weapons from standing, kneeling, and prone positions. On a typical day, each shooter fires 75 rounds from the M4 rifle and 50 rounds from the 9 mm pistol. For the 50-yard and 25-yard exercises, instructors stood about 6 feet behind the firing line and shooters. Maximum peak sound pressure levels at the instructor position were approximately 152 dB for the M4 rifle and 146 dB for the 9 mm pistol. Maximum peak levels increased to about 160 dB for 5-yard training exercises. This increase in peak levels is most likely because the instructors stand within an arm's length distance from the shooter for the 5-yard exercises. Additionally, instructors were exposed to more reverberant noise because the shooters were relatively close to the walls and ceiling of the nearby bullet trap.

Figure 7. Live fire exercises using M4 rifle from kneeling position at 50 yard position. Note the NIMS microphone at the instructor position behind the firing line. Photo by HHE requestor.

Using the U.S. DOD criterion, the ANE was 40,000 for most of the training exercises at the indoor range, except for an ANE of 6,651 for shooting the 9 mm pistol at the 5-yard position. Using the AHAAH criterion, the minimum ANE was 91 for live fire exercises at the 25- and 5-yard positions. At the 50-yard position the instructor's minimum ANE was 149 for the M4 rifle and 476 for the 9 mm pistol. The indoor range had concrete floors and did not have acoustical treatment on the walls and ceiling. Installing acoustical treatment could reduce some of the reverberation from gunfire but may not have a substantial impact on the ANE for instructors because of their close proximity to the shooters. However, at the 50-yard position it may be possible to install three-sided enclosures behind the firing line for instructors to stand in during shooting.

Live fire training exercises in the shoothouse simulated tactical scenarios in rooms of various sizes and configurations inside a building (Figure 8). Shooters used M4 rifles and Remington model 870 12-gauge shotguns. Additionally, full-load and reduced load flash bang grenades were used for some exercises. Peak sound pressure levels during shooting of the M4 rifle reached about 163 dB when fired in a doorway, but were about 3 dB less when fired in a walkway or hallway. The 12-gauge shotgun reached peak levels of about 172 dB when fired in a doorway and about 155 dB when fired in a hallway. Using the AHAAH criterion, the minimum ANE for the M4 rifle was 5 and for the shotgun was 95. Using the U.S. DOD criterion, the ANE was more than 11,000 for the M4 rifle and more than 2,500 for the shotgun.

Figure 8. Two shooters firing M4 rifles in the shoothouse, with an instructor standing in the doorway. Photo by HHE requestor.

The full-load flash bang grenades generated peak sound pressure levels ranging from 158–172 dB. Figure 9 provides an example of the impulse noise waveform and octave band noise frequency from a full-load flash bang grenade. The wave form was characterized by a very large initial impulse followed by several reverberant impulses of rapidly diminishing energy over the next 0.5 second. Full-load flash bang grenades generated higher peak sound pressure levels than reduced load flash bang grenades discharged at the same location. However, even reduced load flash bang grenades generated peak levels of 151.1–168.8 dB. The highest peak levels occurred when the flash bang devices were exploded in doorways. Peak sound levels were lower when the grenades were exploded in the middle of the room and in the walkway. These differences in peak levels are most likely related to greater reverberation of the explosion shockwave because of the close proximity of the wall and door frame. The minimum ANE for the flash bang grenades ranged from 47 using the AHAAH criterion to 551 using the U.S. DOD criterion.

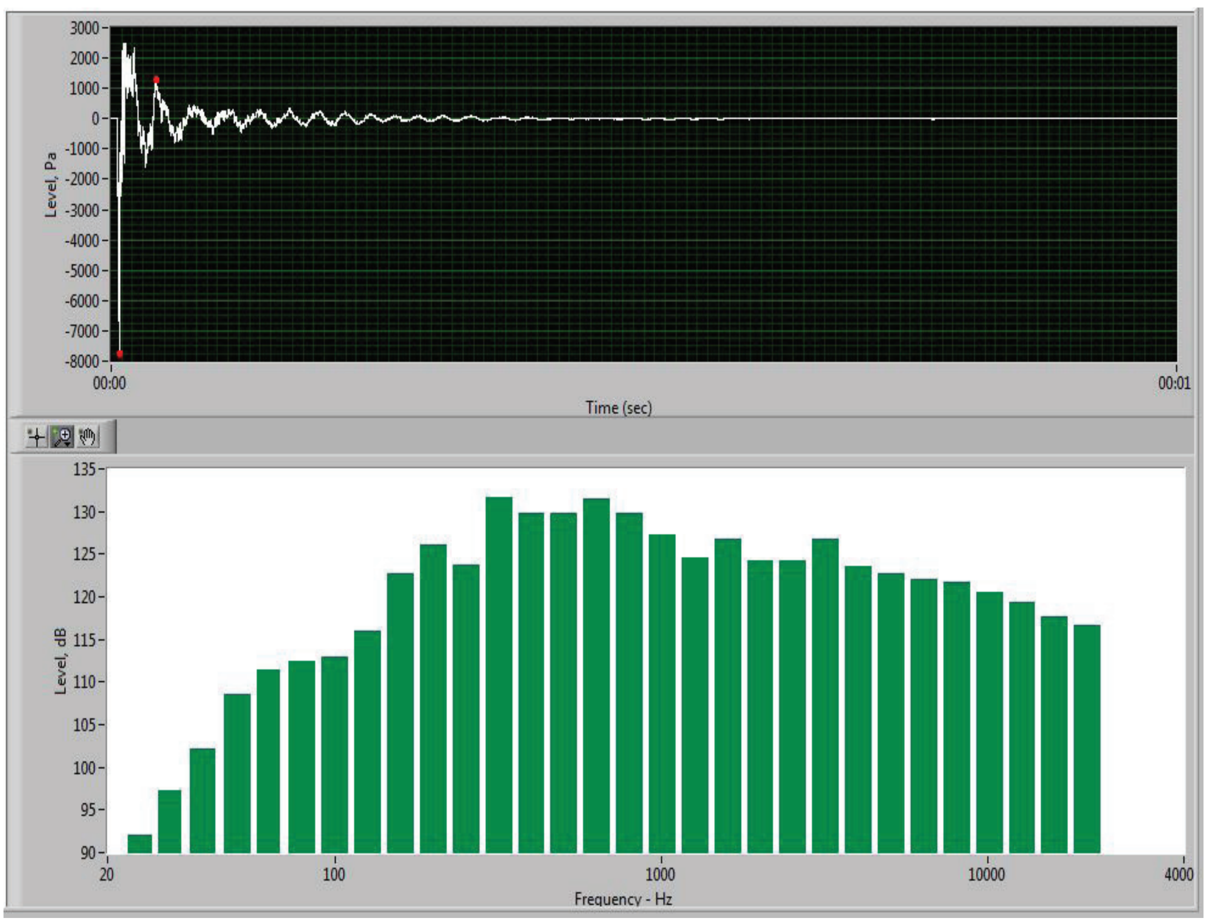

Figure 9. Screen capture of impulsive noise waveform and one-third octave band noise frequency measurement results from NIMS display of a full-load flash bang grenade.

Our results showed that the AHAAH model was the most conservative criterion (most protective against hearing loss) and the U.S. DOD MIL-STD-1474D (currently used by the agency) was the least protective. Results for the LeqA8hr criterion fell between the other criteria. We calculated damage risk estimates for instructors using dual hearing protection and assumed a combined attenuation for earplugs and earmuffs of at least 34 dB, as prescribed by the damage risk criteria in U.S. DOD. On the basis of the U.S. DOD criterion and use of dual hearing protection, instructors would not likely exceed the calculated ANE during any of the live fire exercises. However, on the basis of the AHAAH criterion, instructors would likely exceed the ANE for live fire exercises using the Dillon M134D (with or without the barrier), and for the weapons used at the outdoor ranges and shoothouse. Using the equal energy criterion, instructors would exceed the ANE at the Dillon M134D if the barrier were not used. If ANE were calculated using single hearing protection instead of dual protection, instructors would exceed ANE for nearly all of the weapons and live fire exercises, except for exercises in the virtual training facility.

We observed a few instances at the outdoor ranges of instructors only using single hearing protection. We also observed that not all insert hearing protection appeared to be deeply inserted into the ear canal, as recommended by hearing protector manufacturers. Additionally, employees can appear to have hearing protection properly inserted, but the hearing protectors still may not fit effectively. Lack of proper insertion can substantially reduce the ability of the hearing protectors to attenuate noise. NIOSH has developed a hearing protector fit test system [Murphy 2014] to help ensure proper selection and fit. Methods and systems for fit testing of hearing protection are available from several manufacturers.

Recent NIOSH research on hearing protectors for impulsive noise exposures has shown that the combination of ear plugs and muffs worn by instructors can attenuate noise levels by 36–49 dB, if properly fitted and worn [Murphy et al. 2012; NIOSH 2013b]. If this attenuation was achieved, noise levels at the ear of firearms' instructors could be reduced to below the impulse noise exposure limit of 140 dB established by OSHA, and recommended by NIOSH, ANSI, ISO, and the EU. Greater noise attenuation of hearing protection should also increase the calculated ANE. Although NIOSH research has shown that hearing protectors are capable of attenuating more noise than the attenuation levels used for damage risk criteria calculations in this report, these higher levels of noise attenuation cannot be assumed and hearing protector attenuation should be verified through fit testing. Sound can also be transmitted to the inner ear through the skull (bone-conduction), bypassing the hearing protector entirely and effectively limiting the attenuation to about 41 dB.

Conclusions

Firearms instructors were exposed to impulsive noise levels greater than 150 dB for most of the weapons and weapons systems used during indoor and outdoor live fire training exercises. Thus, instructors were exposed above the occupational exposure limit of 140 dB. The Dillon M134D and flash bang grenades generated peak levels greater than 170 dB. Calculation of ANE for live fire exercises using the U.S. DOD currently used by the agency showed that instructors wearing dual hearing protection would not exceed the ANE permitted on a typical day. In contrast, calculations using the AHAAH criterion showed that instructors would likely exceed the ANE permitted for most of the weapons or weapon systems used. The U.S. DOD has proposed a revised standard that incorporates a variant of the LeqA8 criterion and the AHAAH damage risk model.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the agency to use a labor–management health and safety committee or a working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations.

Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. If feasible and legally permissible, attach noise suppressors to firearms to reduce peak sound pressure levels.
2. Continue to use the noise barrier for all exercises with the Dillon M134D.
3. Install acoustical materials and panels to the canopy and walls at the outdoor firing ranges and to the barrier used for exercises using the Dillon M134D.

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Use the LeqA8hr or the AHAAH model to determine the amount of gunfire instructors can be exposed to per day.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of personal protective equipment requires a comprehensive program and a high level of employee involvement and commitment. The right personal protective equipment must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, personal protective equipment should be used until effective engineering and administrative controls are in place.

1. Require instructors to use dual hearing protection for all live fire training exercises.
2. Perform hearing protector fit testing to determine the noise attenuation of the hearing protectors used by instructors.

Appendix A: Methods

For measurements using the NIMS system, we connected four 1/8-inch condenser pressure microphones (GRAS model 40DD) and four 1/4-inch preamplifiers (GRAS model 26AC) to two 2–channel power modules (GRAS model 12AA) using LEMO® cables. The outputs from the two–channel power modules were connected to a National Instruments (model NI–4432) universal serial bus data acquisition board using BNC coaxial cables. The data acquisition board operated at a sampling rate of 102.4 kilohertz. The data acquisition board was connected to a laptop using a USB 2.0 cable. The NIMS program operated using the National Instruments LabVIEW Runtime 2011 64 bit (for Windows 7 or higher) software and National Instruments DAQMX 93.5 device drivers, and the Microsoft.Net or Visual C redistributable package. We calibrated each microphone using a Brüel and Kjær model 4228 piston–phone calibrator.

We calculated damage risk and maximum ANE to gunfire using three different damage risk criteria. The NIOSH artificial head fixture was not available at the time of the site visit to measure attenuation of actual hearing protectors used by instructors. Therefore, for damage risk calculations, we used previously measured values for the single and double hearing protectors that instructors used [Garinther and Hodge 1971; NIOSH 2013b].

U.S. Department of Defense Criterion MIL-STD-1474D

We calculated the allowable number of impulsive noise exposures per day using the following equation [U.S. DOD 1997]:

$N1 = 10^{X}$ where,

$X = 1/5\ [177 - L + 6.64 \log_{10} 200/T]$

$N2 = 20 \times N1$

N1 = allowable number of impulse exposures/day (single protection),
N2 = allowable number of impulse exposures/day (double protection),
L = measured peak sound pressure level, in dB,
T = measured B–duration in milliseconds (msec), if B > 200 msec, use B = 200 msec.

To calculate the allowable number of exposures per day for the shooters and instructors wearing hearing protection, we divided N2 by the number of impulses in each exposure.

MIL-STD-1474D Definitions and Assumptions

A. A single exposure consists of either
   1. a single impulse for non-repetitive systems (systems producing not more than one impulse per second, e.g., single shot rifle or shotgun, or
   2. a burst for repetitive systems (systems normally producing more than one impulse per second, e.g., automatic weapons. For repetitive systems such as the Dillon Aero M134D and M240/M249 belt–fired machine guns, the B–duration is calculated by multiplying the average B–duration of every impulse in a “gunfire burst” by the number of impulses in the first 200 millisecond of that burst, as specified in section 5.4.2 of MIL-STD-1474D.

B. The maximum permissible number of exposures per day provided in Table 4–I of MIL-STD-1474D (40,000) was used when the calculated allowable number of rounds exceeded those shown in the table.

A-weighted 8-hour Sound Equivalent Level (LeqA8hr) [DTAT 1983; Dancer et al. 1995]

Following measurements of gunfire noise exposures, the NIMS provided LeqA8hr values for single or multiple shot exposures. Because instructors wore hearing protectors, we reduced the LeqA8hr by 29 dBA for single protection or 34 dBA for double protection [Garinther and Hodge 1971]. More recent NIOSH research indicates that greater hearing protector reductions are possible, ranging from 26–39 dB for single protection and 36–49 dB for double protection [NIOSH 2003; 2013b]. However, for this report, we used the 29 dB and 34 dB values because they represent a more protective measure of instructors’ potential risk.

We calculated the allowable number of impulsive noise exposures per day on the basis of the LeqA8hr criterion by using the following formula:

Allowable number of exposures = $10^{[85-(\text{LeqA8hr with Hearing Protection Device [HPD]}/10]}$

Where, LeqA8hr with HPD = LeqA8hr value from NIMS – 34 dBA of attenuation for dual hearing protection (or 29 dB for attenuation of single protection)

Ear Modeling Method – Auditory Hazard Assessment Algorithms for Humans (AHAAH) [Price and Kalb 1991; Price 2007]

The AHAAH ear modeling technique is based on an ear model that explains the behavior of the middle and inner ear in response to high intensity impulse noise [Price and Kalb 1991]. Following gunfire measurements, the NIMS provided ARU values calculated on the basis of dual hearing protection and “warned” noise exposure conditions because instructors anticipated high impulse gunfire. We calculated the allowable number of impulsive noise exposures per day by dividing the model maximum allowable ARU (i.e., 200) by the number of impulses per exposure.

Appendix B: Tables

Table B1. Peak sound pressure levels, damage risk, and allowable number of exposures at outdoor ranges 1, 2, and 3

Weapon/Location	Peak level (dB)	Number of impulse exposures per trigger pull or impulsive event	U.S. DOD criterion MIL-STD-1474D		Equal energy criterion LeqA8hr		AHAAH Auditory Risk Units	
			B-Duration (msec)	Allowable number of exposures	LeqA8hr w/ HPD (dB)	Allowable number of exposures	ARU w/ HPD	Allowable number of exposures
Dillon M134D/Range 2	168.0–171.4	15–45	8–15	276–1,498	63.0–69.9	32–158	11.3–36.9	5–17
Dillon M134D (with barricade)/Range 2	157.8–160.7	28–52	16–20	17,131–40,000	53.8–59.4	363–1,318	1.4–5.4	37–144
M240/Range 1 (Instructor 1)	158.7–163.9	6–16	82–94	412–2,542	58.8–65.4	89–417	2.2–10.3	19–91
M240/Range 1 (Instructor 2)	147.0–150.7	6–16	92–110	40,000	52.4–56.9	645–1,819	0.4–1.3	154–571
M249/Range 1 (Instructor 1)	157.0–159.0	7–13	50–60	2,772–17,619	53.0–58.6	436–1,585	0.4–1.8	113–526
M249/Range 1 (Instructor 2)	147.0–149.2	7–13	66–75	40,000	50.7–56.3	741–2,692	0.3–1.0	208–625
M4/Range 1 (Instructor 1)	158.6–164.2	1–3	56–100	1,509–23,727	53.1–59.0	398–1,549	0.5–2.1	95–417
M4/Range 1 (Instructor 2)	147.3–149.0	1–3	64–115	40,000	41.9–48.5	4,467–20,417	0.1–0.2	1,111–2,857
M240/Range 3 (Instructor 1)	163.6–164.4	14–15	26–44	554–1,467	62.5–64.1	123–178	5.1–6.2	32–39
M240/Range 3 (Instructor 2)	148.2–149.8	14–15	35–70	40,000	51.0–52.0	1,995–2,512	0.3–0.4	500–645
M249/Range 3 (Instructor 1)	156.8–159.0	8–13	22–46	12,693–26,556	53.0–58.6	436–1,585	0.4–1. 8	113–526
M249/Range 3 (Instructor 2)	147.2–149.0	8–13	34–65	40,000	50.7–56.3	741–2,692	0.3–1.0	208–625

Table B2. Peak sound pressure levels, damage risk, and allowable number of exposures at the indoor range

Weapon/Location	Peak level (dB SPL)	Number of impulse exposures per trigger pull or impulsive event	U.S. DOD criterion MIL–STD–1474D		Equal energy criterion LeqA8hr		AHAAH Auditory Risk Units	
			B-Duration (msec)	Allowable number of exposures	LeqA8hr w/ HPD (dB)	Allowable number of exposures	ARU w/ HPD	Allowable number of exposures
M4 rifle – 50 yards, Instructor 1	150.4–150.5	8–18	> 200	40,000	47.5–51.8	2,089–5,623	0.4–1.2	167–455
M4 rifle – 50 yards, Instructor 2	150.4–151.6	8–18	> 200	40,000	48.2–52.7	1,698–4,677	0.5–1.3	149–385
M4 rifle – 50 yards, Instructor 3	147.9–150.9	8–18	> 200	40,000	47.7–51.6	2,188–5,370	0.4–1.1	182–465
9 mm pistol – 50 yards, Instructor 1	144.6–146.2	10–18	> 200	40,000	43.2–45.6	8,710–15,135	0.2–0.4	541–1,000
9 mm pistol – 50 yards, Instructor 2	142.9–144.8	10–18	> 200	40,000	43.0–45.7	8,511–15,849	0.2–0.3	588–1,111
9 mm pistol – 50 yards, Instructor 3	141.3–143.4	10–18	> 200	40,000	42.9–46.8	6,607–16,218	0.2–0.4	476–1,176
M4 rifle – 25 yards, Instructor 1	149.4–149.5	28	> 200	40,000	53.8	1,318	1.7–1.8	111–116
M4 rifle – 25 yards, Instructor 2	150.2–151.6	28	> 200	40,000	53.2–55.0	1,000–1,514	1.5–2.2	91–131
M4 rifle – 25 yards, Instructor 3	150.8–152.0	28	> 200	40,000	54.2–54.6	1,096–1,202	1.9–2.1	95–106
M4 – 5 yards, Instructor 1	144.3	2	> 200	40,000	45.2	9,550	0.3	800
M4 – 5 yards, Instructor 2	160.1	2	> 200	40,000	49.8	3,311	0.8	256
9 mm Pistol – 5 yards, Instructor 1	159.7	6	> 200	9,613	54.6	1,096	2.2	91
9 mm Pistol – 5 yards, Instructor 2	160.5	6	> 200	6,651	54.2	1,202	1.9	104

Table B3. Peak sound pressure levels, damage risk, and allowable number of exposures at the shoothouse

Weapon/Location	Peak level (dB SPL)	Number of impulse exposures per trigger pull or impulsive event	U.S. DOD criterion MIL–STD–1474D		Equal energy criterion LeqA8hr		AHAAH Auditory Risk Units	
			B–Duration (msec)	Allowable number of exposures	LeqA8hr w/ HPD (dB)	Allowable number of exposures	ARU w/ HPD	Allowable number of exposures
M4 rifle, Doorway	159.8–162.7	1–12	100–120	11,524–28,553	54.2–56.9	646–1,202	1.8–3.6	55–111
M4 rifle, Walkway	153.3–156	1–12	148–150	40,000	50.0–52.7	1,698–3,162	0.6–1.4	146–323
M4 rifle, Hallway	159.4	2	125	40,000	51.5	2,239	1.2	174
Shotgun 870, Doorway	166.9–171.8	1	30–62	2,724–9,920	55.1–55.2	955–977	1.6–2.1	95–127
Shotgun 870, Walkway	150.5–154.7	1	172–185	40,000	42.0–45.9	8,128–19,953	0.1–0.4	540–1,818
Flash Bang (reduced load), Doorway	163.8	1	125	16,297	50.2	3,020	0.5	392
Flash Bang (reduced load), Walkway	151.1	1	180	40,000	42.5	17,783	0.1	1,667
Flash Bang (reduced load), Midroom	157.7–162.9	1	154–200	13,213	50.7–53.5	692–2,692	1.4–4.3	47–145
Flash Bang (full load), Doorway	171.8	1	100	551	53.5	1,413	0.4	571
Flash Bang (full load), Walkway	157.8	1	170	40,000	43.0	15,849	0.1	1667
Flash Bang (full load), Midroom	168.4	1	96	2,782	57.0	631	3.3	60
Sledgehammer	137.9–140.4	1	84–125	40,000	66.8	50,000	< 0.01	20,000
M249, Virtual training facility	127.7	1	180	40,000	51.4	50,000	1.9	6,667

References

ANSI [1996]. Determination of occupational noise exposure and estimation of noise–induced hearing impairment, American National Standards Institute. American National Standard ANSI S3.44–1996. Acoustical Society of America, Melville, New York.

CFR. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

CHABA [1968]. Proposed damage risk criterion for impulse noise (Gunfire). Committee on Hearing, Bioacoustics, and Biomechanics. National Research Council, Washington, D.C.

CHABA [1992]. Hazardous exposure to impulse noise. Committee on Hearing, Bioacoustics, and Biomechanics. National Research Council, Washington, D.C.

Dancer A, Plessiet D, Vaillant T [1995]. Damage risk criteria for weapons noises. CD nl 241/CT/DTB/1995. Etablissement Technique de Bourges, Bourges, France.

DTAT [1983]. Recommendations on evaluating the possible harmful effects of noise on hearing. AT–83/27/28. Direction Technique des Armements Terrestres. Etablissement Technique de Bourges, Bourges, France.

Dunn DE, Davis RR, Merry CJ, Franks JR [1991]. Hearing loss in the chinchilla from impact and continuous noise exposure. J Acoust Soc Am *90*(4):1979–1985.

ECD [1986]. Protection of workers from risks related to exposure to noise at work. European Council Directive 86/188/EEC. Brussels, Belgium.

Fedele PD, Binseel MS, Kalb JT, Price GR [2013]. Using the auditory hazard assessment algorithm for humans (AHAAH) with hearing protection software, release MIL–STD–1474E. ARL-TR–6748, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD.

Garinther GR, Hodge DC [1971]. Small rocket noise: hazards to hearing. Advanced LAW Program, Report No. HEL–TM–7–71. Army Material Command, Human Engineering Lab. Aberdeen Proving Ground, Maryland.

ISO [1990]. Acoustics—determination of occupational noise exposure and estimation of noise–induced hearing impairment. International Standards Organization, International Standard ISO 1999:2013. International Organization for Standardization, Geneva, Switzerland.

Luz G, Hodge R [1971]. The recovery from impulse noise-induced TTS in monkeys and men: a descriptive model. J Acoust Soc Am *49*(6):1770–1777.

Mrena R, Savolainen S, Kuokkanen JT, Ylikoski J [2002]. Characteristics of tinnitus induced by acute acoustic trauma: a long–term follow–up. Audiol Neurootol *7*(2):122–130.

Murphy WJ, Flamme GA, Meinke DK, Sondergaard J, Finan DS, Lankford JE, Khan A, Stewart M [2012]. Measurement of impulse peak insertion loss for four hearing protection devices in field conditions. Int J Aud *51*:S31–S42.

Murphy WJ [2014]. Comparing personal attenuation ratings for hearing protector fit-test systems. CAOHC Update *25*(3).

NIOSH [1998]. Criteria for a recommended standard—occupational noise exposure (revised criteria 1998). Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-126.

NIOSH [2003]. Health hazard evaluation report: Fort Collins Police Services, Fort Collins, CO. By Tubbs R, Murphy W. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HHE Report No. 2002-0131-2898.

NIOSH [2012]. In–depth survey report: a case for using A–weighted equivalent energy as a damage risk criterion. By Murphy WJ, Kardous CA. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, EPHB–350-11a, 1-32, 2012.

NIOSH [2013a]. Engineering report: development and validation testing of an impulse noise meter. By Kardous CA. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, EPHB–349-11a, 1-31, 2013.

NIOSH [2013b]. In–depth survey report: comparison of two acoustic test fixtures for measurement of impulse peak insertion loss. By Khan A, Fackler CJ, Murphy WJ. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, EPHB–350-13a, 1-40, 2013.

OSHA [1992]. Occupational noise exposure 29 CFR 1910.95. U.S. Government Printing Office, Office of the Federal Register. Occupational Safety and Health Administration, Washington, D.C.

Price GR, Kalb JT [1991]. Insights into hazard from intense impulses from a mathematical model of the ear. J Acoust Soc Am *90*(1):219–227.

Price GR [2007]. Validation of the auditory hazard assessment algorithm for the human with impulse noise data. J Acoust Soc Am *122*(5):2786–2802.

Salmivalli A [1967]. Acoustic trauma in regular army personnel—clinical audiologic study. Acta Otolaryngol *222*(Suppl):1–85.

Starck J, Toppila E, Pyykko I [2003]. Impulse noise and risk criteria. Noise Health *5*(20):63–73.

U.S. DOD [1997]. MIL-STD-1474D Design criteria standard noise limits. U.S. Department of Defense, Washington, D.C.

Ward WD, Fleer RE, Glorig A [1961]. Characteristics of hearing losses produced by gunfire and steady noise. J Aud Res *1*:325–356.

Ylikoski ME [1994]. Prolonged exposure to gunfire noise among professional soldiers. Scand J Work Environ Health *20*(2):87–92.

Keywords: North American Industry Classification System 928110 (National Security), noise, impulse noise, impulsive noise, peak noise, damage risk criteria, firearms, weapons, guns, gunfire, hearing loss

The Health Hazard Evaluation Program investigates possible health hazards in the workplace under the authority of the Occupational Safety and Health Act of 1970 (29 U.S.C. § 669(a)(6)). The Health Hazard Evaluation Program also provides, upon request, technical assistance to federal, state, and local agencies to investigate occupational health hazards and to prevent occupational disease or injury. Regulations guiding the Program can be found in Title 42, Code of Federal Regulations, Part 85; Requests for Health Hazard Evaluations (42 CFR Part 85).

Disclaimer

The recommendations in this report are made on the basis of the findings at the workplace evaluated and may not be applicable to other workplaces.

Mention of any company or product in this report does not constitute endorsement by NIOSH.

Citations to Web sites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. NIOSH is not responsible for the content of these Web sites. All Web addresses referenced in this document were accessible as of the publication date.

Acknowledgments

Desktop Publisher: Shawna Watts
Editor: Ellen Galloway
Logistics: Donnie Booher

Availability of Report

Copies of this report have been sent to the employer, employees, and union at the facility. The state and local health department and the Occupational Safety and Health Administration Regional Office have also received a copy. This report is not copyrighted and may be freely reproduced.

This report is available at http://www.cdc.gov/niosh/hhe/reports/pdfs/2013-0124-3208.pdf.

Recommended citation for this report:
NIOSH [2014]. Health hazard evaluation report: measurement of exposure to impulsive noise at indoor and outdoor firing ranges during tactical training exercises. By Brueck SE, Kardous CA, Oza A, Murphy WJ. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HHE Report No. 2013-0124-3208.

Delivering on the Nation's promise:
Safety and health at work for all people through research and prevention

To receive NIOSH documents or more information about occupational safety and health topics, please contact NIOSH:

Telephone: 1–800–CDC–INFO (1–800–232–4636)

TTY: 1–888–232–6348

CDC INFO: www.cdc.gov/info

or visit the NIOSH Web site at www.cdc.gov/niosh

For a monthly update on news at NIOSH, subscribe to NIOSH eNews by visiting www.cdc.gov/niosh/eNews.

SAFER • HEALTHIER • PEOPLE™