Followback Evaluation of Lead and Noise Exposures at an Indoor Firing Range

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Contents

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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 an indoor firing range. The employer was concerned about lead and noise exposures during firearms qualification. This followback evaluation took place after the installation of a new ventilation system.

What We Did

- We reevaluated the firing range in June 2012.
- We measured airflow in each bay of the firing range.
- We collected personal air samples for lead on instructors, shooters, and the hazardous materials technician.
- We collected area air samples for lead in the firing range, firearms cleaning area, classroom, lunchroom, and offices.
- We collected surface vacuum samples for lead. We sampled inside work and personal vehicles and from carpeted floors, rugs, and mats in the complex.
- We collected surface wipe samples for lead. We sampled in the firing range, firearms cleaning area, classroom, lunchroom, armory, offices, and in work and personal vehicles.
- We reviewed medical monitoring results of instructors and the hazardous materials technician.

We reevaluated lead exposures at an indoor firing range. Airborne exposures decreased after a new ventilation system was installed. We found lead on work surfaces and in vehicles. We measured high noise levels during firearms qualifications. Recommendations include eliminating dry sweeping, changing clothing before leaving the complex, and continuing the use of dual hearing protection.

What We Found

- Airflow along and downrange of the firing line met National Institute for Occupational Safety and Health recommendations.
- The firing range was still dry swept during cleaning.
- Instructors' and shooters' exposures to lead in the air were below occupational exposure limits.
- High levels of lead in the air were detected when cleaning behind the bullet trap.
- Low levels of lead were found in air from the firing range and firearms cleaning area.
- Surface wipe and vacuum samples detected lead throughout the complex and in work and personal vehicles.

What the Employer Can Do

- Do not dry sweep the firing range. Clean the floor with an explosion-proof vacuum cleaner that has high-efficiency particulate air filters.
- Remove carpet and rugs in the complex.
- Improve general housekeeping practices in the lunchroom, classroom, and offices.

What the Employer Can Do (continued)

- Provide instructors and the hazardous materials technician with lockers in an area that allows street clothes and shoes to be stored separately from lead-contaminated work clothes and shoes. Personal clothing should be left in a clean locker.
- Provide disposable shoe covers and coveralls.
- Require instructors and shooters to use lead removal wipes and wash their hands and faces with lead removal soap before eating, drinking, or contact with others.
- Provide instructors and shooters annual training and educational materials about the health effects of exposure to lead (including the risks of take-home exposure) and noise.

What the Employees Can Do

- Do not eat, drink, chew gum, or use tobacco in the firearms cleaning area, classroom, or firing range.
- Continue to wear dual hearing protection while in the firing range. Dual hearing protection includes ear plugs and earmuffs.
- Wash your hands and face thoroughly with lead removal soap before eating, drinking, or contact with others. Use lead removal wipes to clean your hands.
- Wear shoe covers and coveralls in the range. Leave your range shoes at the range.
- Shower at the end of the work day and put on your clean personal clothes prior to leaving the complex.
- Wash clothes worn in the firing range at the firing complex.
- Report health concerns to your employer. If needed, seek medical care.

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Abbreviations

cm^2	Square centimeter
µg/dL	Micrograms per deciliter
$µg/m^3$	Micrograms per cubic meter
ACGIH®	American Conference of Governmental Industrial Hygienists
BLL	Blood lead level
CFR	Code of Federal Regulations
dB	Decibels
dBA	Decibels, A-weighted
HEPA	High-efficiency particulate air
HHE	Health hazard evaluation
Hz	Hertz
MDC	Minimum detectable concentration
MQC	Minimum quantifiable concentration
ND	Not detected
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
REL	Recommended exposure limit
SLM	Sound level meter
TLV®	Threshold limit value
TWA	Time-weighted average

Introduction

The Health Hazard Evaluation (HHE) Program received a request from managers concerning lead and noise exposures at an indoor firing range in California. This report is a follow-up to our 2009 evaluation, in which investigators measured airborne lead exposures above occupational exposure limits (OELs) among instructors, shooters, and a hazardous materials technician and provided recommendations to reduce lead exposures at the range [NIOSH 2011]. In response, the employer redesigned the range ventilation system, removed carpeting, added step-off cleaning pads at the firing range exit, mandated full facepiece powered air purifying respirator use by the hazardous materials technician, and improved cleaning procedures. We returned in June 2012 to reassess lead and noise exposures.

Methods

Air Sampling for Lead

We collected full-shift personal air samples over 2 days on instructors and a hazardous materials technician. We also collected task-based air samples on shooters during qualifications and firearms cleaning. Task-based samples were also collected on the hazardous materials technician during high-efficiency particulate air (HEPA) vacuum use, dry sweeping, and cleaning behind the bullet trap. We collected area air samples in the hazardous materials technician's office, range office, armory, classroom, firearms cleaning area, lunchroom, and firing range. Samples were analyzed according to National Institute for Occupational Safety and Health (NIOSH) Method 7303 [NIOSH 2013].

Surface Sampling for Lead

We collected and analyzed vacuum samples for lead on porous surfaces according to NIOSH Methods 9102 and 7303 [NIOSH 2013]. We took vacuum samples in the range and range complex, and in instructors' and the hazardous materials technician's personal and work vehicles. We used a 100 square centimeter (cm^2) template when collecting vacuum samples on flat surfaces.

We collected and analyzed wipe samples for lead on nonporous surfaces according to NIOSH Method 9102 [NIOSH 2013]. We took samples from the range office, armory, classroom, lunchroom, firing range, and personal and work vehicles. We also took samples of the hazardous materials technician's respirator both inside the face mask and on the battery and motor. We used a 100 cm^2 template to collect wipe samples on flat surfaces, and estimated 100 cm^2 of sample area on irregularly shaped or uneven surfaces.

We used commercially available dust wipes (SKC Inc., Full Disclosure® Instant Wipes) to qualitatively evaluate lead contamination on skin, clothing, and shoes. After the instructors, shooters, and hazardous materials technician left the firing range, we collected wipes on their hands, pants, and boots. Wipe samples were collected from the palm of each hand, one thigh, and the bottom of one boot. We estimated an area of 100 cm^2 on these wipe samples. The visual limit of identification for the wipes was approximately 17–20 micrograms per sample.

Ventilation

We reviewed the ventilation drawings and recent test and balance report, and visually inspected the ventilation systems for the entire firing range complex. We used a TSI VelociCalc® Plus Model 8386A to measure airflow at the firing line and at the bullet trap downrange when the range was empty. We took triplicate measurements in each lane along the firing line and at the bullet trap at approximately 3 feet and 5 feet. We averaged the measurements for each location, and compared them to the NIOSH recommended values. We were unable to evaluate airflow patterns in the range with a theatrical fog machine as planned because of a smoke sensor in the exhaust ventilation system.

Noise

We collected 16 time-weighted average (TWA) personal noise exposure measurements over 2 days on six shooters, six firing range instructors, and the hazardous materials technician. We measured personal noise exposures with Larson Davis Spark™ model 706RC or 705P integrating noise dosimeters. The dosimeters measured noise using three different settings to compare with the three noise exposure limits referenced in this report; the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL), OSHA action level, and NIOSH recommended exposure limit (REL). Shooters and instructors wore noise dosimeters on day 1 of sampling. Instructors wore dosimeters on day 2 of sampling. We also measured area noise levels and took octave band measurements (noise levels in different frequencies) using two Larson Davis System 824 sound level meters (SLMs) and real-time frequency analyzers. We mounted the SLMs on tripods at a height of approximately 5 feet to represent the ear position of a standing shooter. We placed the tripods with SLMs in the middle of each group of shooters approximately 4–6 feet behind the student, where the instructors normally stood. Because of safety concerns and risk of interfering with shooters and instructors, we were not able to place SLMs closer during qualifications.

Medical Records Evaluation

We reviewed blood lead levels (BLLs) from 2008–2013 for instructors and the hazardous materials technician. BLLs were initially collected by the employer as part of OSHA mandated medical surveillance for lead, but the employer continued to offer testing to employees on a yearly basis as a service even when it was no longer required.

Results

Lead

The instructors' full-shift TWA lead exposure concentrations ranged from 0.15–3.8 micrograms per cubic meter ($\mu g/m^3$) over the sampling period (345–488 minutes). Instructors spent up to 4 hours in the range on any given day and the remainder of the time was spent in the classroom or office. Results of the air sampling for lead on individual instructors are presented in Appendix A, Table A1.

The shooters' task-based TWA lead concentrations ranged from 1.5–9.0 µg/m^3 over the sampling periods (147–200 minutes). Shooters spent approximately 1 hour in the classroom and 3 hours in the range and firearms cleaning area. The remainder of the day was spent in defensive tactics training in another section of the complex. Air sampling for lead on shooters was done while they were in the range and when cleaning their firearms. These results are presented in Appendix A, Table A2.

Full-shift and task-based air sampling results for lead on the hazardous materials technician are presented in Table 1. The hazardous materials technician's daily range cleaning activities included using a HEPA vacuum behind the firing line and dry sweeping down range. The lead concentrations for these tasks ranged from not detected (ND) (< 0.3 µg/m^3)–7.3 µg/m^3. The technician also used a HEPA vacuum behind the bullet trap approximately once a week. On June 5, 2012, the hazardous materials technician began cleaning the area behind the bullet trap but stopped so that qualifications could resume in the range. This task was usually completed in 1 day; however, in this case, the task was completed the following day. We used the same sample collection cassette for cleaning activities on June 5 (8 minutes) and June 6 (37 minutes), to meet the minimum sample volume recommended in the NIOSH sampling and analytical method. The airborne lead concentration during the task of cleaning behind the bullet trap was 330 µg/m^3. The technician's full-shift exposure to airborne lead exceeded the OSHA action level of 30 µg/m^3 on June 6, 2012. This exposure corresponded to the day that he spent 37 minutes cleaning behind the bullet trap. We did not collect any task-based samples for tasks outside the range, which included changing filters, completing paperwork, and occasionally travelling offsite.

Table 1. Concentrations of lead on personal air samples of the hazardous materials technician

Date	Location	Sample time (minutes)	Sample concentration (µg/m^3)
6/5/2012	Full-shift	440	1.6
	Task–HEPA vacuum front of range	27	ND*
	Task–dry sweep downrange	61	7.3
6/6/2012	Full-shift	480	34†
	Task–clean behind bullet trap	45	330‡

*Below the minimum detectable concentration (MDC) (0.3 µg/m^3).

†A full-shift concentration was calculated assuming no exposure for 173 minutes while offsite performing a delivery. The concentration for the sample time of 307 minutes was 53 µg/m^3.

‡This sample also includes 8 minutes spent cleaning behind the range on 6/5/2012.

Results of the area air sampling for lead are in Appendix A, Table A3. The lead concentrations ranged from ND (< 0.09 µg/m^3)–3.3 µg/m^3. Most results were low or at a concentration between the MDC and the minimum quantifiable concentration (MQC).

The range of surface sampling results is shown in Table 2. These results showed the presence of lead on work surfaces outside the range, including work and personal vehicles. Surface vacuum sample results are presented in Appendix A, Table A4 and surface wipe sample results are presented in Appendix A, Table A5.

Table 2. Summary of lead concentrations in surface vacuum and wipe samples

Sample location	Number of samples	Sample concentration (µg/100 cm^2)
Range surfaces	27	ND*–96
Personal vehicles	14	ND*–21
Work vehicles	11	0.72–120

*Below the MDC (0.4 µg/100cm^2)

We did qualitative sampling for the presence of lead on hands, shoes, and pants for 5 instructors, 5 shooters, and the hazardous materials technician. All of the samples taken on shoes and pants were above the limit of visual identification. All of the samples taken on shooters hands were above the limit of visual identification. All but one of the samples on instructor's hands was above the limit of visual identification; the one instructor who tested negative had used lead removal wipes when leaving the range. The hazardous materials technician's hands also tested negative, it was noted that he had washed his hands prior to sampling.

Ventilation

The new ventilation system was a push-pull ventilation system typically seen in indoor firing ranges. The system was computer controlled with several alarms and a pressure sensor to alert staff of system failures. Four separate ventilation systems served the range with one system serving each firing bay (eight firing lanes). Each system was designed to supply approximately 21,000 cubic feet per minute of air and exhaust approximately 24,000 cubic feet per minute of air. The ventilation systems were separate from the rest of the complex and were designed to allow air to travel from uprange to downrange, from contaminated to less contaminated areas. Supply air was delivered by perforated radial air diffusers mounted at ceiling height along the back wall

Figure 1. Location of radial air diffusers in an indoor firing range. Photo by NIOSH.

of the range. The radial diffusers were approximately 16 feet behind the firing line, except near the entry door, the range officers' desk, and the far end of the range where they were approximately 10 feet behind the firing line. Figure 1 is a picture of the radial air diffusers. Air was exhausted from the range at the bullet trap, which was about 75 feet from the firing line. Exhaust air passed through HEPA filters before delivery to the outdoor ambient environment.

A summary of the ventilation flow rate measurements is provided in Figure 2. Appendix A, Tables A6–A9 provide the supply airflow measurement data for each of the lanes. Since our previous site visit in December 2009, bay 4 had been converted from a special weapons and tactics training bay to a traditional bay with eight qualification lanes.

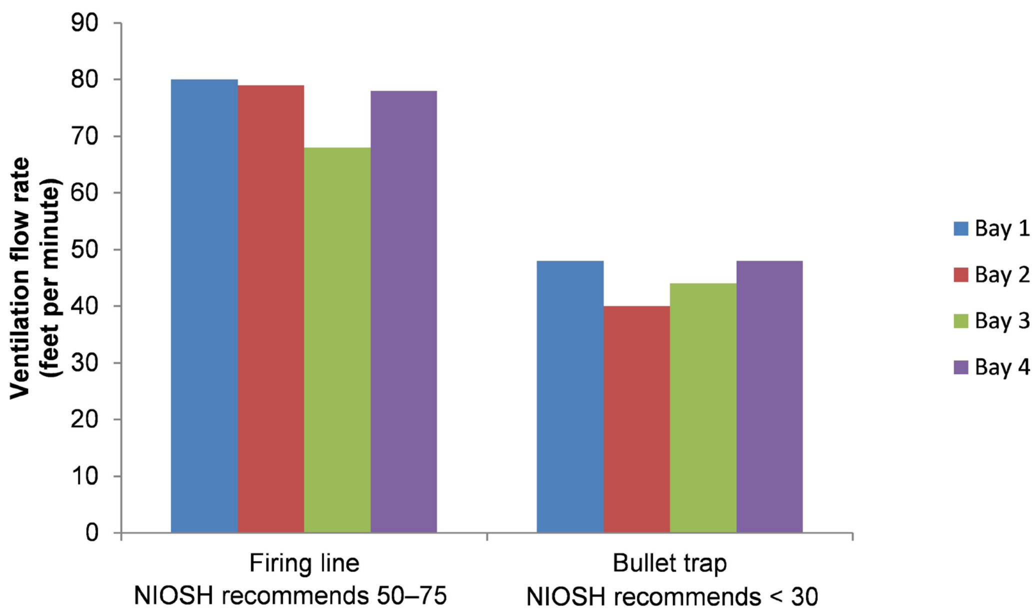

Figure 2. A graph showing a summary of the ventilation flow rates for each bay of the firing range.

Noise

Full shift personal noise monitoring results for instructors and the hazardous materials technician are provided in Appendix A, Table A10. All instructors' TWA noise exposures exceeded the NIOSH REL, OSHA action level, and OSHA PEL. Their full shift noise exposures ranged from 95–101 decibels, A-weighted (dBA), using OSHA criteria and from 106–110 dBA using NIOSH criteria. The hazardous materials technician's full shift noise exposure was below OELs. TWA noise monitoring results for shooters are provided in Appendix A, Table A11. Shooters wore noise dosimeters for 2.5–3 hours during qualification exercises and firearms cleaning. Their noise exposures during that time ranged from 103–107 dBA using OSHA criteria and from 111–115 dBA using NIOSH criteria. Because of the high noise exposures during firearms qualifications, their full-shift noise exposure would also exceed the OELs even if they had no noise exposure during the remainder of the workday. We also sampled the area in the vault with a noise dosimeter because of employee concerns of the noise produced by the electrical box. The noise level collected next to this box during a 7-hour period was 60 dBA by the NIOSH criteria. SLMs were used to measure background levels of noise in the firing range before qualifications with the ventilation system on and no other activities taking place (78.6 dBA) and during the hazardous materials technician's vacuuming activities (79.2 dBA).

One-third octave band noise frequency measurements collected when shooters were in the firing range for qualification are shown in Figure 3. Octave band measurements provide information about the frequency distribution of noise. These measurements showed that the highest sound pressure levels of 110 decibels (dB) occurred at 630 Hertz (Hz), and were greater than 100 dB across all the one-third octave bands from 12.5–31.5 Hz and between 125–4,000 Hz.

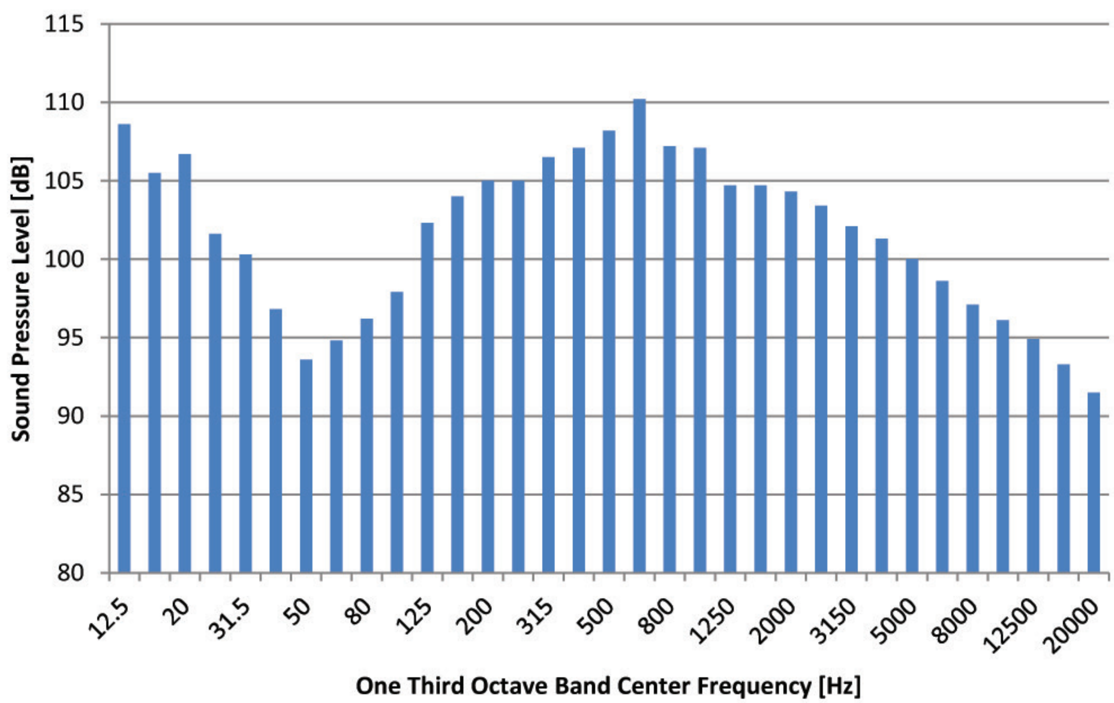

Figure 3. One-third octave band center frequency levels over a 500-second period of shooting.

Peak sound levels ranged from 149.6–154.4 dB during qualification. Shooters typically fired a series of shots in succession followed by several minutes without shooting at which time instructors provided additional guidance or training. An example of peak sound levels during 1 minute of shooting rifles is shown in Figure 4. Four peaks greater than 150 dB and several peaks greater than 140 dB occurred during this time period.

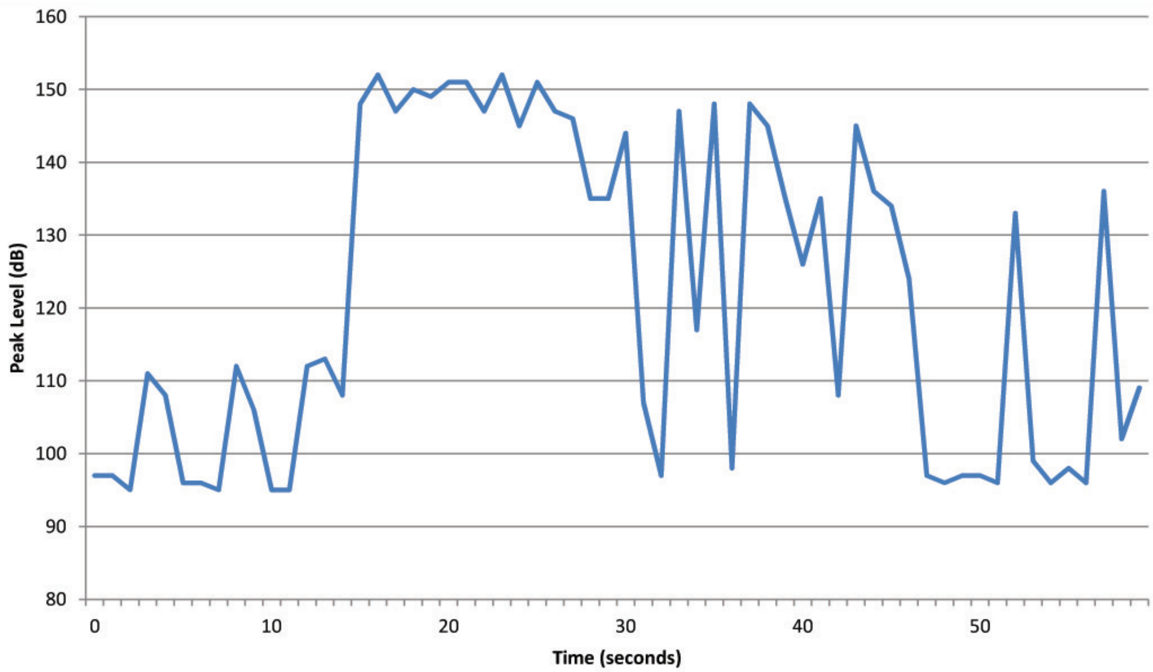

Figure 4. Peak sound levels measured on June 6, 2012, during 1 minute of shooting rifles in the indoor firing range.

Medical Records Evaluation

We reviewed 52 BLLs from 15 instructors and the hazardous materials technician between 2008–2013. Because instructors are detailed to this location for an average of 2 years, seven instructors only had BLLs prior to the installation of the new ventilation system, three had BLLs only after the installation, and five had BLLs before and after the installation. The technician had BLLs before and after the installation as well. Thirty-nine BLLs were taken before the installation of the new ventilation system. Fifteen of the 39 (38%) were below the limit of detection (< 3 micrograms per deciliter [µg/dL]). The remaining 24 ranged from 3–12 µg/dL. The 13 BLLs after the installation of the new ventilation system included 7 (54%) below the limit of detection; the remaining 6 ranged from 3–7 µg/dL.

Other Observations

The hazardous materials technician wore a Tyvek® suit with hood, gloves, and a full facepiece powered air purifying respirator during all cleaning activities that we monitored. The hazardous materials technician had received OSHA lead abatement training and had been fit tested on the respirator. We observed the hazardous materials technician's use of personal protective equipment, including donning and doffing procedures. The hood of his Tyvek suit interfered with the sealing surface of the respirator facepiece during use; he handled contaminated items without gloves; and he cleaned his respirator with a wet towel. We provided recommendations to improve these practices and noted that he had modified his procedures the following day.

Instructors and shooters did not regularly use lead removal wipes or wash their hands before eating, drinking, or smoking during breaks. Shooters and instructors also helped clean spent casings past the firing line, which potentially increases lead contamination of their shoes. Additionally, shooters may increase lead contamination of their clothing when using a prone shooting position with no protection between their clothing and the floor.

Instructors did not regularly wash their work clothing at the range. The washer and dryer were in the men's locker room; therefore, female employees did not have access.

All instructors and most shooters wore double hearing protection, a combination of insert ear plugs and earmuffs. Most instructors wore the 3M Peltor™ Optime™ 105 earmuffs with a noise reduction rating of 30 dB. Some instructors and shooters provided their own earmuffs. Formable foam insert earplugs (Howard Leight Laser Lite®) with a noise reduction rating of 32 dB were placed in locations easily accessible to instructors and shooters, such as a counter in the hallway leading to the firing range and on the tower table in the firing range.

Discussion

Lead

All instructors had full-shift airborne lead exposures less than 8% of the NIOSH REL and OSHA PEL. The average airborne lead concentration for instructors was 1.9 $\mu g/m^3$, compared to 10.3 $\mu g/m^3$ in our previous evaluation [NIOSH 2011]. We found a twentyfold reduction in average airborne lead exposures for shooters during qualifications and firearms cleaning. The average airborne lead concentration for shooters was 5.0 $\mu g/m^3$, compared to 102 $\mu g/m^3$ in the previous evaluation. We attribute these substantial reductions in instructors' and shooters' airborne lead exposures to installation of the new ventilation system because they spent approximately the same amount of time in the range performing qualifications as they did during the initial visit.

We more fully characterized the hazardous materials technician's lead exposure during this evaluation by collecting task-based and full-shift personal air samples. The higher full-shift concentration (34 $\mu g/m^3$), which was above the OSHA action level for lead, occurred on the day the technician cleaned behind the bullet trap for more than half an hour. However, these results were substantially lower than the 670 $\mu g/m^3$ full-shift concentration that we measured earlier [NIOSH 2011]. Job tasks for the hazardous materials technician were basically the same with the exception of changing filters inside the firing range. The airborne lead concentration while HEPA vacuuming behind the bullet trap was more than 6 times greater than the NIOSH REL and OSHA PEL; the exposure during this task was the primary reason the hazardous materials technician's full-shift exposure exceeded the OSHA action level for lead. It is unclear how the high lead exposure during cleaning behind the bullet trap was occurring. In a conversation with the firearms coordinator after the site visit, we learned that since the installation of the new ventilation system the hazardous materials technician no longer needed to clean behind the bullet trap. The range managers were considering permanently sealing the door to that area.

The area airborne lead concentrations in administrative areas outside of the firing range were below the limit of detection (< 0.09 µg/m^3). Area airborne lead concentrations in the range and where firearms were cleaned or stored were detectable but low, similar to the results during our initial evaluation [NIOSH 2011].

BLLs were similar before and after the installation of the ventilation system, despite large reductions in airborne lead concentrations. This finding suggests that ingestion or dermal absorption of lead is contributing to the BLLs, although other sources (including mobilization of bone lead or sources of exposure outside the workplace) could also be a factor. We detected lead in 92% of samples from surfaces around the complex. The concentrations varied substantially but were similar to those found in our initial evaluation. We observed shooters and instructors eating and drinking in the firearms cleaning area and the classroom. Additionally, we observed instructors using smokeless tobacco and chewing gum in the firing range. These activities increase the potential for lead ingestion. The floor of the hazardous materials technician's office was carpeted, and several areas in the complex had rugs and mats. Carpets and rugs could accumulate lead and increase opportunities for contaminating shoes and clothing. The firing range contracted companies to clean offices and bathrooms, change out rugs, and wax floors; however, more frequent use of lead removal cleaner on commonly touched surfaces should reduce the amount of lead contamination. A yearly cleaning of the entire complex would help reduce the amount of lead that may have accumulated on static surfaces.

Occupational health and safety government agencies or national organizations have not established surface contamination limits for lead. However, OSHA specifies in its substance-specific standard for lead that all surfaces be maintained "as free as practicable of accumulations of lead" [29 CFR 1910.1025(h)(1)].

We found lead on the hands, pants, and shoes of most instructors, shooters, and the hazardous materials technician. This lead migrates outside of the range into the rest of the complex and into personal and work vehicles. We detected lead in all of the vehicles sampled. Lead in personal vehicles poses a potential exposure hazard to others who may ride in those vehicles. Lead in vehicles can also be tracked into the home where it can expose others. The best way to reduce the risk from take-home lead exposures is to prevent the spread of lead contamination to areas outside the range.

Ventilation

In 2009, NIOSH issued recommendations on occupational exposure to lead and noise in firing ranges [NIOSH 2009]. The new ventilation design in the range meets the NIOSH recommendations by providing a recommended minimum airflow of 50 feet per minute along the firing line and a recommended downrange minimum airflow of at least 30 feet per minute. NIOSH has also recommended an optimal airflow across firing lines in indoor firing ranges of 75 feet per minute [NIOSH 1975]. Although some of the ventilation measurements we collected at the firing line were above 75 feet per minute, all of our air sample results were less than 20% of the most conservative OELs. This finding suggests that the current ventilation design is controlling airborne lead exposures for instructors and shooters. Also, as recommended by NIOSH, the range was maintained under negative pressure relative to the adjacent firearms cleaning area. However, because of the fire suppression system we were unable to perform a smoke test in the range to determine if the air flow was distributed evenly, floor to ceiling and wall to wall.

Noise

Repeated exposure to impulse noise can result in permanent noise-induced hearing loss [Patterson and Hamernik 1992; Pekkarinen et al. 1993; Chan et al. 2001]. Impulsive noise, such as that from gunfire, has sufficient intensity to permanently damage unprotected ears in a very short period of time; damage can occur in minutes rather than the days or years typical of industrial noise exposure. The OSHA PEL and NIOSH REL state that exposure to impulse noise should not exceed 140 dB. However, peak impulse is not the sole factor in hearing damage. Other factors such as duration of the impulse and frequency of exposure also have an effect on hearing loss. Also, measuring high intensity impulsive noise, such as gunfire noise, with dosimeters may underrepresent noise exposure and hearing loss risk [Kardous et al. 2003; Kardous and Willson 2004].

Because of the high intensity noise levels in firing ranges, double hearing protection is necessary [Berger 1983]. Proper insertion of hearing protection is critically important to ensure sufficient noise attenuation. NIOSH has found that poor insertion of formable hearing protection into the ear canals reduces the ability of the hearing protectors to attenuate noise exposure [NIOSH 2005].

Octave band analysis allows for determination of the dominant noise frequencies and can be useful for identifying potential engineering controls. One of the primary sources of noise generated during firearms use is the muzzle blast during firing, which generates high noise across the mid to high frequency range. The only effective method to substantially reduce shooters' or instructors' noise exposure from gunfire is using noise suppressors attached to the end of the gun barrel.

Ototoxins

Ototoxins are chemicals that can cause hearing damage when absorbed into the body. Studies have shown that exposure to some chemicals, such as lead and some solvents, can cause hearing loss [Sliwinska-Kowalska et al. 2004; Hwang et al. 2009].

During our evaluation of medical records, we determined that audiometry and blood lead testing were done sporadically. The American Conference of Governmental Industrial Hygienists (ACGIH) states that "in settings where there may be exposures to noise and to carbon monoxide, lead, manganese, styrene, toluene, or xylene, periodic audiograms are advised and should be carefully reviewed" [ACGIH 2013]. The U.S. Army recommends annual audiometric monitoring when workers are exposed to air concentrations that are at or exceed 50% of the most stringent OEL for a variety of ototoxicants including solvents and lead [U.S. Army 2009]. The highest projected 8-hour TWA personal air concentration for lead among instructors (3.8 µg/m^3) did not exceed 50% of the NIOSH REL; however, reviewers of employees' audiometric tests should consider possible additive, potentiating, or synergistic effects between noise exposure and lead when evaluating audiograms.

Conclusions

The installation of a new ventilation system at the indoor firing range improved the airflow along the firing line and downrange. This change resulted in large reductions in average airborne lead exposure for instructors and shooters. Instructor BLLs remained virtually unchanged from the time of the first site visit but were below 10 µg/dL. We found lead on surfaces in the complex; in work and personal vehicles; and on hands, clothes, and shoes of instructors. We also observed eating and drinking in the firearms cleaning area, and employees using smokeless tobacco in the firing range. These practices and the presence of lead on surfaces may be contributing to on-going lead exposure. We found very high airborne lead levels when the hazardous materials technician cleaned behind the bullet trap. Additionally, all instructors' noise exposures exceeded OELs.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the firing range to use a labor-management health and safety committee or 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 for the specific situation at the firing range.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix B). 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.

Elimination and Substitution

Eliminating or substituting hazardous processes or materials reduces hazards and protects employees more effectively than other approaches. Prevention through design, considering elimination or substitution when designing or developing a project, reduces the need for additional controls in the future.

1. Stop dry sweeping in the range.
2. Stop cleaning behind the bullet trap. The redesign of the ventilation system makes this cleaning unnecessary.
3. Use nonlead bullets and nonlead primers as they become economically feasible.

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. Routinely test and balance the ventilation system to ensure that airflow is within the recommended ranges along the firing line (50–75 feet per minute) and downrange (35 feet per minute).
2. Sample the air for lead if changes are made to the ventilation system or administrative practices that affect lead exposures change.

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. Prohibit eating, drinking, gum chewing, or tobacco use in the range, firearms cleaning, and classroom areas. Post signs on the door to the range stating this policy.
2. Provide shooters a sheet of paper or other disposable material to place on the ground beneath them when they kneel or shoot from a prone position.
3. Stop instructors and shooters from removing spent casings past the firing line. All casings past the fining line should be removed by the hazardous materials technician during cleaning.
4. Prevent the transfer of lead from the range to other work areas and vehicles.
    a. Provide instructors and the hazardous materials technician with lockers for storing street clothes and shoes separately from lead-contaminated work clothes and shoes.
    b. Provide coveralls for instructors to wear over their work uniform when they go into the range as an extra measure to prevent lead contamination on clothing. The coveralls should be removed and left at the entrance to the range before breaks or lunch. Provide a uniform for the hazardous materials technician to wear under the Tyvek suit. At the end of the day, the uniforms and coveralls should be left at work to be laundered. Anyone handling these dirty items should follow the same controls as those who work in the range.
    c. Require instructors and the hazardous materials technician to leave shoes worn on the firing range at the complex. Additionally, all personnel should wear disposable shoe covers before entering the range and then discard them before leaving the complex.

d. Make sure all personnel entering the range thoroughly wash their hands and faces before breaks, lunch, and departing at the end of the day. We recommend the use of lead removal wipes at the range exit and lead removal soap in the restrooms.

e. Instruct the instructors and hazardous materials technician to shower at the end of the work day and put on their clean personal clothes and shoes before leaving the complex.

5. Clean all personal and work vehicles using HEPA vacuums on porous surfaces and wet wiping on nonporous surfaces. The American Industrial Hygiene Association maintains a list of lead abatement consultants in California: https://webportal.aiha.org/Custom/ConsultantsSearch.aspx.
6. Remove carpet in the simulation room adjacent to the range. Also remove carpeted and antifatigue mats because they may be accumulating lead.
7. Improve general housekeeping practices to remove lead from all surfaces. Use a HEPA vacuum on porous surfaces and wet wipe nonporous surfaces. Clean tables in the range after each qualification, and clean classroom tables daily. Sample surfaces that employees regularly contact using NIOSH Method 9100 [NMAM 2013] to ensure that the surfaces are "free as practicable of accumulations of lead" according to the OSHA lead standard [29 CFR 1910.1025(h)(1)].
8. Provide educational materials and prevention information about the health effects of exposure to lead and noise to all personnel on an annual basis. Include information about the risks of take-home exposure.
9. Perform medical surveillance for lead on instructors and the hazardous materials technician according to the expert guidelines outlined in Appendix B. Reviewers of audiograms should consider the effects of ototoxins, such as lead, on hearing loss.

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. Continue wearing dual hearing protection (ear plugs and earmuffs) during weapons firing. For maximum protection, select earmuffs and ear plugs that provide a high level of noise attenuation. Because of the critical importance of proper use and fit, train shooters and instructors how to properly wear hearing protection.
2. Use a chemical protective glove such as nitrile for skin protection when cleaning firearms. Instructors should provide specific guidance to shooters about proper and appropriate use of skin protection.

3. Ensure that the hazardous materials technician wears a respirator with the sealing surface positioned directly against the skin to ensure a good face-to-facepiece seal.
4. Instruct the hazardous materials technician to wear chemical protective gloves and keep those gloves on until the contaminated Tyvek suit is discarded and the respirator removed. Use lead removal wipes to clean the respirator.

Appendix A: Tables

Table A1. Concentrations of lead on personal air samples of instructors

Date	Instructor ID	Sample time (minutes)	Sample concentration (µg/m^3)
6/5/2012	1	483	1.4
	2	478	1.6
	3	488	1.2
	4	488	1.3
	5	437	0.87
6/6/2012	1	454	(0.15)*
	3	452	3.8
	4	369	3.8
	6	365	3.5
	7	345	0.93

*Concentrations below the MQC (0.44 µg/m^3) are listed in the table in parentheses to acknowledge uncertainty surrounding concentrations below the MQC.

Table A2. Concentrations of lead on personal air samples of shooters

Date	Shooter location	Sample time (minutes)	Sample concentration (µg/m^3)
6/5/2012	Lane 1	178	8.1
	Lane 2	193	7.4
	Lane 6	200	4.0
	Lane 8	184	4.0
	Lane 9	177	2.2
	Lane 12	199	9.0
	Lane 16	148	5.3
	Lane 18	147	3.8
	Lane 20	148	6.0
	Lane 30	152	3.2
	Lane 32	149	2.7
6/6/2012	Lane 2	161	1.5
	Lane 5	159	5.9
	Lane 6	159	7.5
	Lane 8	161	4.3
	Lane 9	193	7.5
	Lane 15	158	3.4

Table A3. Concentrations of lead in area air samples

Location	Sample time (minutes)	Sample concentration (μg/m³)
Firing range	562	3.3
Range officer desk	575	1.3
Hazardous materials technician office	563	(0.29)*
Armory	530	(0.18)*
Firearms cleaning table	577	(0.13)*
Classroom	578	ND†
Lunchroom	562	ND†
Administration office	530	ND†

*Concentrations between the MDC (0.09 μg/m³) and MQC (0.33 μg/m³) are listed in the table in parentheses to acknowledge uncertainty surrounding concentrations below the MQC.

†Below the MDC (0.09 μg/m³)

Table A4. Concentrations of lead in surface vacuum samples

Location	Sample concentration (μg/100cm²)
Mat between range and offices	22
Men's bathroom rug	16
Instructor #8 vehicle – floor	14
Work vehicle Insight license #221649 – floor	14
Hazardous materials technician's office carpeted floor	9.9
Instructor #6 vehicle – floor	7.9
Instructor #1 vehicle – seat	7.6
Hazardous materials technician's personal vehicle – seat	6.3
Main entry rug	6.1
Instructor #5 vehicle – seat	5.8
Work vehicle Suburban license #221856 – floor	4.9
Work vehicle Insight license #221649 – seat	4.5
Instructor #6 vehicle – seat	3.3
Defensive tactics rug	3.1
Shooter vehicle – floor	2.6
Instructor #9 vehicle – floor	2.3
Work vehicle Suburban license #221856 – seat	1.2
Work vehicle F250 – seat	0.72
Instructor #9 vehicle – seat	0.68
Instructor #1 vehicle – floor	0.34

Table A5. Concentrations of lead in surface wipe samples

Location	Sample concentration (µg/100cm²)
Hazardous materials technician's work vehicle – floor	120
Hazardous materials technician's changing area	96
Armory/vault – top of cabinet	84
Work vehicle F350 – floor	74
Hazardous materials technician's respirator mask – rubber seal and inside	40
Hazardous materials technician's respirator – battery and motor	33
Hazardous materials technician's personal vehicle – floor	21
Work vehicle F250 – floor	21
Floor outside range door	19
Gun cleaning table	16
Range officer station	13
Hazardous materials technician's work vehicle – seat	13
Range – table	11
Hazardous materials technician's office table	6.6
Classroom – near microwave	5.6
Women's restroom – floor	4.6
Work vehicle Tahoe license #221876 – armrest	4.2
Defensive tactics – classroom desk	3.3
Men's locker room – floor	2.8
Main entrance – floor	2.3
Supervisor's cubicle – floor	2.0
Instructor #5 vehicle – floor	1.7
Work vehicle Tahoe license #6EUR826 – driver door handle	1.6
Secretary's office – top of cabinet	1.3
Defensive tactics – mat	1.3
Supervisor's cubicle – desk	1.2
Lunchroom – cubicle	(0.95)*
Shooter vehicle – seat	(0.46)*
Lunchroom – table	ND†
Lunchroom – counter	ND†
Supervisory border patrol agent's desk	ND†
Instructor #8 vehicle – seat	ND†

*Concentrations between the MDC (0.4 µg/100cm²) and MQC (1.2 µg/100cm²) are listed in the table in parentheses to acknowledge uncertainty surrounding concentrations below the MQC.

†Below the MDC (0.4 µg/100cm²)

Table A6. Bay 1 ventilation flow rates (feet per minute) measured on June 7, 2012

Firing lane #	Firing line, Target 1.5m		Firing line, Target 25m		Bullet trap	
	(~3 feet*)	(~5 feet*)	(~3 feet*)	(~5 feet*)	(~3 feet*)	(~5 feet*)
1	80	64	101	61	37	52
2	51	96	58	82	45	40
3	79	60	81	60	40	46
4	96	89	70	70	50	50
5	85	100	80	85	46	52
6	77	64	76	75	53	55
7	94	105	78	108	45	50
8	85	81	74	85	46	59
Average	81	82	77	78	45	51
Total average	80				48	

*Height at which the rate of airflow was measured

Table A7. Bay 2 ventilation flow rates (feet per minute) measured on June 7, 2012

Firing lane #	Firing line, Target 1.5m		Firing line, Target 25m		Bullet trap	
	(~3 feet*)	(~5 feet*)	(~3 feet*)	(~5 feet*)	(~3 feet*)	(~5 feet*)
9	74	61	51	68	31	36
10	66	94	71	78	35	37
11	34	85	55	44	38	37
12	69	54	72	53	29	44
13	75	59	84	62	34	30
14	83	85	91	84	30	43
15	121	134	102	117	32	42
16	106	94	85	121	65	72
Average	79	83	76	78	37	43
Total average	79				40	

*Height at which the rate of airflow was measured

Table A8. Bay 3 ventilation flow rates (feet per minute) measured on June 7, 2012

Firing lane #	Firing line, Target 1.5m		Firing line, Target 25m		Bullet trap	
	(~3 feet*)	(~5 feet*)	(~3 feet*)	(~5 feet*)	(~3 feet*)	(~5 feet*)
17	60	93	76	78	47	32
18	68	80	90	95	37	50
19	43	60	74	50	54	43
20	47	27	40	36	31	37
21	40	32	49	49	32	44
22	67	88	81	80	55	37
23	87	87	94	101	44	49
24	65	96	76	74	54	48
Average	60	70	73	70	44	43
Total average	68				44	

*Height at which the rate of airflow was measured

Table A9. Bay 4 ventilation flow rates (feet per minute) measured on June 7, 2012

Firing lane #	Firing line, Target 1.5m		Firing line, Target 25m		Bullet trap	
	(~3 feet*)	(~5 feet*)	(~3 feet*)	(~5 feet*)	(~3 feet*)	(~5 feet*)
25	80	114	102	97	65	42
26	79	69	66	89	41	50
27	92	73	98	89	38	38
28	95	76	71	83	39	50
29	53	68	49	55	42	43
30	44	88	54	59	46	53
31	84	83	77	111	58	60
32	79	91	61	69	46	55
Average	76	83	72	82	47	49
Total average	78				48	

*Height at which the rate of airflow was measured

Table A10. Full-shift noise dosimetry results for instructors and the hazardous materials technician

Date	Job title	Duration (hours:minutes)	OSHA AL		OSHA PEL		NIOSH REL	
			TWA 8-hr* (dBA)	Dose (%)	TWA 8-hr* (dBA)	Dose (%)	TWA 8-hr* (dBA)	Dose (%)
Day 1	Instructor	8:07	101	485	101	474	110	30,189
Day 1	Instructor	8:06	101	435	100	421	109	25,793
Day 1	Instructor	8:08	100	412	100	403	109	26,294
Day 1	Instructor	7:15	100	410	100	398	109	22,417
Day 2	Instructor	7:32	100	405	100	396	109	24,283
Day 2	Instructor	7:01	99	331	98	323	108	21,181
Day 2	Instructor	7:35	99	335	99	324	108	19,671
Day 2	Instructor	6:12	99	334	99	327	108	17,806
Day 2	Instructor	6:07	95	205	95	199	106	11,848
Day 2	Technician	5:07	65	3.1	53	0.6	74	7.5
Occupational noise exposure limits			85	50	90	100	85	100

*Projected 8-hour TWA assuming that noise exposures beyond the measured duration were below 80 dBA.

Table A11. Personal noise dosimetry results for shooters during time in the firing range

Job title	Lane	Duration (hours:minutes)	OSHA AL TWA (dBA)	OSHA PEL TWA (dBA)	NIOSH REL TWA (dBA)
Shooter	29	2:37	107	107	115
Shooter	27	2:29	107	107	114
Shooter	5	2:45	106	106	114
Shooter	22	2:30	106	106	114
Shooter	14	2:48	103	103	111
Shooter	10	2:40	104	103	112

Appendix B: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limit or ceiling values. Unless otherwise noted, the short-term exposure limit is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the NIOSH Pocket Guide to Chemical Hazards [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Other OELs commonly used and cited in the United States include the threshold limit values (TLVs), which are recommended by ACGIH, a professional organization, and the workplace environmental exposure levels), which are recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and workplace environmental exposure levels are developed by committee members of these associations from a review of the published, peer-reviewed literature. These OELs are not consensus standards. TLVs are considered voluntary exposure guidelines

for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2013]. Workplace environmental exposure levels have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2013].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/Gefahrstoffdatenbanken/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 1,500 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Below we provide the OELs and surface contamination limits for the compounds we measured, as well as a discussion of the potential health effects from exposure to these compounds.

Lead

Inorganic lead is a naturally occurring, soft metal that has been mined and used in industry since ancient times. It comes in many forms (e.g., lead acetate, lead chloride, lead chromate, lead nitrate, lead oxide, lead phosphate, and lead sulfate). Lead is considered toxic to all organ systems and serves no useful purpose in the body.

Occupational exposure to inorganic lead occurs via inhalation of lead-containing dust and fume and ingestion of lead particles from contact with lead-contaminated surfaces. When careful attention to hygiene, particularly hand washing is not practiced, smoking cigarettes or eating may create another route of exposure among workers who handle lead and then transfer it to their mouth through hand contamination. In addition to the inhalation and ingestion routes of exposure, lead can be absorbed through the skin [Stauber et al. 1994; Sun et al. 2002; Filon et al. 2006]. Workplace settings with exposure to lead and lead compounds include smelting and refining, scrap metal recovery, automobile radiator repair, construction and demolition (including abrasive blasting), and firing ranges. Occupational exposures also occur among workers who apply or remove lead-based paint and among welders who burn or torch-cut metal structures.

Blood Lead Levels

In most cases, an individual's BLL is a good indication of recent exposure to lead because the half-life of lead (the time interval it takes for the quantity in the body to be reduced by half its initial value) is 1–2 months [Lauwerys and Hoet 2001; Moline and Landrigan 2005; CDC 2013a]. Most lead in the body is stored in the bones, with a half-life of years to decades. Measuring bone lead, however, is primarily done only for research. Elevated zinc protoporphyrin levels have also been used as an indicator of chronic lead intoxication; however, other factors, such as iron deficiency, can cause an elevated zinc protoporphyrin level, so monitoring the BLL over time is more specific for evaluating chronic occupational lead exposure.

BLLs in adults in the United States have declined consistently over time. In the last 10 years alone, the geometric mean BLL went from 1.75 µg/dL to 1.23 µg/dL [CDC 2013b]. The NIOSH Adult Blood Lead Epidemiology and Surveillance System uses a surveillance case definition for an elevated BLL in adults of 10 µg/dL of blood or higher [CDC 2012a].

Occupational Exposure Limits

In the United States, employers in general industry are required by law to follow the OSHA lead standard (29 CFR 1910.1025). This standard was established in 1978 and has not yet been updated to reflect the current scientific knowledge regarding the health effects of lead exposure.

Under this standard, the PEL for airborne exposure to lead is 50 µg/m^3 of air for an 8-hour TWA. The standard requires lowering the PEL for shifts that exceed 8 hours, medical monitoring for employees exposed to airborne lead at or above the action level of 30 µg/m^3 (8-hour TWA), medical removal of employees whose average BLL is 50 µg/dL or greater, and economic protection for medically removed workers. Medically removed workers cannot return to jobs involving lead exposure until their BLL is below 40 µg/dL.

In the United States, other guidelines for lead exposure, which are not legally enforceable, are often followed. Similar to the OSHA lead standard, these guidelines were set years ago and have not yet been updated to reflect current scientific knowledge. NIOSH has an REL for lead of 50 µg/m^3 averaged over an 8-hour work shift [NIOSH 2010]. ACGIH has a TLV for lead of 50 µg/m^3 (8-hour TWA), with worker BLLs to be controlled to, or below, 30 µg/dL. The ACGIH designates lead as an animal carcinogen [ACGIH 2013].

Health Effects

The PEL, REL, and TLV were intended to prevent overt symptoms of lead poisoning, but were not set at levels that would protect workers from lead's contributions to conditions such as hypertension, renal dysfunction, and reproductive and cognitive effects [Schwartz and Hu 2007; Schwartz and Stewart 2007; Brown-Williams et al. 2009; Institute of Medicine 2012]. Generally, acute lead poisoning with symptoms has been documented in persons having BLLs above 70 µg/dL. These BLLs are rare today in the United States, largely as a result of workplace controls put in place to comply with current OELs. When present, acute lead poisoning can cause myriad adverse health effects including abdominal pain, hemolytic anemia, and neuropathy. It has, in very rare cases, progressed to encephalopathy and coma [Moline and Landrigan 2005].

People with chronic lead poisoning, which is more likely at current exposure levels, may not have symptoms or they may have nonspecific symptoms that may not be recognized as being associated with lead exposure. These symptoms include headache, joint and muscle aches, weakness, fatigue, irritability, depression, constipation, anorexia, and abdominal discomfort [Moline and Landrigan 2005].

The National Toxicology Program recently released a monograph on the health effects of low-level lead exposure [NTP 2012]. For adults, the NTP concluded the following about the evidence regarding health effects of lead (Table B1).

Table B1. Evidence regarding health effects of lead in adults

Health area	NTP conclusion	Principal health effects	Blood lead evidence
Neurological	Sufficient	Increased incidence of essential tremor	Yes, < 10 µg/dL
	Limited	Psychiatric effects, decreased hearing, decreased cognitive function, increased incidence of amyotrophic lateral sclerosis	Yes, < 10 µg/dL
	Limited	Increased incidence of essential tremor	Yes, < 5 µg/dL
Immune	Inadequate		Unclear
Cardiovascular	Sufficient	Increased blood pressure and increased risk of hypertension	Yes, < 10 µg/dL
	Limited	Increased cardiovascular-related mortality and electrocardiography abnormalities	Yes, < 10 µg/dL
Renal	Sufficient	Decreased glomerular filtration rate	Yes, < 5 µg/dL
Reproductive	Sufficient	Women: reduced fetal growth	Yes, < 5 µg/dL
	Sufficient	Men: adverse changes in sperm parameters and increased time to pregnancy	Yes, ≥ 15–20 µg/dL
	Limited	Women: increase in spontaneous abortion and preterm birth	Yes, < 10 µg/dL
	Limited	Men: decreased fertility	Yes, ≥ 10 µg/dL
	Limited	Men: spontaneous abortion	Yes, ≥ 31 µg/dL
	Inadequate	Women and Men: stillbirth, endocrine effects, birth defects	Unclear

Various organizations have assessed the relationship between lead exposure and cancer. According to the Agency for Toxic Substances and Disease Registry [ATSDR 2007] and the National Toxicology Program [NTP 2011], inorganic lead compounds are reasonably anticipated to cause cancer in humans. The International Agency for Research on Cancer classifies inorganic lead as probably carcinogenic to humans [WHO 2006]. According to the American Cancer Society [ACS 2011], some studies show a relationship between lead exposure and lung cancer, but these results might be affected by exposure to cigarette smoking and arsenic; some studies show a relationship between lead and stomach cancer, and these findings are less likely to be affected by the other exposures. The results of studies looking at other cancers, including brain, kidney, bladder, colon, and rectum, are mixed.

Medical Management

To prevent acute and chronic health effects, a panel of experts published guidelines for the management of adult lead exposure [Kosnett et al. 2007]. The complete guidelines are available at http://www.cdph.ca.gov/programs/olppp/Documents/medmanagement.pdf. The panel recommended BLL testing for all lead-exposed employees, regardless of the airborne lead concentration. The panel's recommendations are outlined in Table B2. These recommendations do not apply to pregnant women, who should avoid BLLs > 5 µg/dL. Removal from lead exposure should be considered if control measures over an extended period do not decrease BLLs to < 10 µg/dL or an employee has a medical condition that would increase the risk of adverse health effects from lead exposure. These guidelines are endorsed by the California Department of Public Health [CDPH 2009], the Council of State and Territorial Epidemiologists [CSTE 2009], and the American College of Occupational and Environmental Medicine [ACOEM 2010]; and have been adapted for use by the U.S. Department of Defense [DOD 2007].

Table B2. Health-based medical surveillance recommendations for lead-exposed employees

Category of exposure	Recommendations
All lead exposed workers	• Baseline or preplacement medical history and physical examination, baseline BLL, and serum creatinine
BLL < 10 µg/dL	• BLL monthly for first 3 months placement, or upon change in task to higher exposure, then BLL every 6 months; if BLL increases ≥ 5 µg/dL, evaluate exposure and protective measures, and increase monitoring if indicated
BLL 10–19 µg/dL	• As above for BLL < 10 µg/dL, plus: BLL every 3 months; evaluate exposure, engineering controls, and work practices; consider removal • Revert to BLL every 6 months after 3 BLLs < 10 µg/dL
BLL ≥ 20 µg/dL	• Remove from exposure if repeat BLL measured in 4 weeks remains ≥ 20 µg/dL, or if first BLL is ≥ 30 µg/dL • Monthly BLL testing • Consider return to work after 2 BLLs < 15 µg/dL a month apart, then monitor as above

Adapted from Kosnett et al. 2007

Take-home Contamination

Occupational exposures to lead can result in exposures to household members, including children, from take-home contamination. Take-home contamination occurs when lead dust is transferred from the workplace on employees' skin, clothing, shoes, and other personal items to their vehicle and home [CDC 2009, 2012b].

The CDC considers a BLL in children of 5 µg/dL or higher as a reference level above which public health actions should be initiated, and states that no safe BLL in children has been identified [CDC 2013a].

The U.S. Congress passed the Workers' Family Protection Act in 1992 (29 U.S.C. 671a). The Act required NIOSH to study take-home contamination from workplace chemicals and substances, including lead. NIOSH found that take-home exposure is a widespread problem [NIOSH 1995]. Workplace measures effective in preventing take-home exposures were (1) reducing exposure in the workplace, (2) changing clothes before going home and leaving soiled clothing at work for laundering, (3) storing street clothes in areas separate from work clothes, (4) showering before leaving work, and (5) prohibiting removal of toxic substances or contaminated items from the workplace. NIOSH noted that preventing take-home exposure is critical because decontaminating homes and vehicles is not always effective. Normal house cleaning and laundry methods are inadequate, and decontamination can expose the people doing the cleaning and laundry.

Noise

Noise-induced hearing loss is an irreversible condition that progresses with noise exposure. It is caused by damage to the nerve cells of the inner ear and cannot be treated medically [Berger et al. 2003]. More than 22 million U.S. workers are estimated to be exposed to workplace noise levels above 85 dBA [Tak et al. 2009] and are at risk of noise-induced hearing loss [NIOSH 1998].

Although hearing ability commonly declines with age, exposure to excessive noise can increase the rate of hearing loss. In most cases, noise-induced hearing loss develops slowly from repeated exposure to noise over time, but the progression of hearing loss is typically the greatest during the first several years of noise exposure. Noise-induced hearing loss can also result from a single noise exposure or short duration noise exposures, depending on the intensity of the noise and the individual's susceptibility [Berger et al. 2003]. Noise exposed workers can develop substantial hearing loss before it is clearly recognized. Even mild hearing losses can impair a person's ability to understand speech and hear many important sounds. Some people with noise-induced hearing loss also develop "tinnitus." Tinnitus is a condition in which a person perceives hearing sound in one or both ears, but no external sound is present. Persons with tinnitus often describe hearing ringing, hissing, buzzing, whistling, clicking, or chirping like crickets. Currently, no cure for tinnitus exists.

The preferred unit for reporting of noise measurements is the dBA. A-weighting is used because it approximates the "equal loudness perception characteristics of human hearing for pure tones relative to a reference of 40 dB at a frequency of 1,000 Hz" and is considered to provide a better estimation of hearing loss risk than using unweighted or other weighting measurements [Earshen 2003].

Employees exposed to noise should have baseline and yearly hearing tests to evaluate their hearing thresholds and determine whether their hearing has changed over time. Hearing testing should be done in a quiet location. In workplace hearing conservation programs, hearing thresholds must be measured at 500, 1000, 2000, 3000, 4000, and 6000 Hz. Additionally, NIOSH recommends that 8,000 Hz should also be tested [NIOSH 1998]. The OSHA hearing conservation standard requires analysis of changes from baseline hearing thresholds to determine if the changes are substantial enough to meet OSHA criteria for a standard threshold shift. OSHA defines a standard threshold shift as a change in hearing threshold relative to the baseline hearing test of an average of 10 dB or more at 2000, 3000, and 4000 Hz in either ear [29 CFR 1910.95]. If a standard threshold shift occurs, the company must determine if the hearing loss also meets the requirements to be recorded on the OSHA 300 Log of Injury and Illness [29 CFR 1904.1]. In contrast to OSHA, NIOSH defines a significant threshold shift as an increase in the hearing threshold level of 15 dB or more, relative to the baseline audiogram, at any test frequency in either ear measured twice in succession [NIOSH 1998].

NIOSH has an REL for noise of 85 dBA, as an 8-hour TWA. For calculating exposure limits, NIOSH uses a 3-dB time/intensity trading relationship, or exchange rate. Exposure to impulsive noise should never exceed 140 dBA. For extended work shifts NIOSH adjusts the REL. When noise exposures exceed the REL, NIOSH recommends the use of hearing protection and implementation of a hearing loss prevention program [NIOSH 1998].

The OSHA noise standard specifies a PEL of 90 dBA and an action level of 85 dBA, both as 8-hour TWAs. OSHA uses a less conservative 5-dB exchange rate for calculating the PEL and action level. Exposure to impulsive or impact noise must not exceed 140 dB peak noise level. OSHA does not adjust the PEL for extended work shifts. However, the action level is adjusted. OSHA requires implementation of a hearing conservation program when noise exposures exceed the action level [29 CFR 1910.95].

References

ACGIH [2013]. 2013 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

ACOEM [2010]. ACOEM provides input to OSHA on key issues facing agency in 2010. Letter to David Michaels. Elk Grove Village, IL: American College of Occupational and Environmental Medicine. [http://www.acoem.org/Page2Column.aspx?PageID=7392&id=6676]. Date accessed: October 2013.

ACS [2011]. Lead. Atlanta GA: American Cancer Society. [http://www.cancer.org/cancer/cancercauses/othercarcinogens/athome/lead]. Date accessed: October 2013.

AIHA [2013]. AIHA 2013 Emergency response planning guidelines (ERPG) & workplace environmental exposure levels (WEEL) handbook. Fairfax, VA: American Industrial Hygiene Association.

ATSDR [2007]. Toxicological profile for lead. Atlanta, GA: U.S. Department of Health and Human Services.

Berger EH [1983]. Laboratory attenuation of earmuffs and earplugs both singly and in combination. Am Ind Hyg Assoc J *44*(5):321–329.

Berger EH, Royster LH, Royster JD, Driscoll DP, Layne M, eds. [2003]. The noise manual. 5th rev. ed. Fairfax, VA: American Industrial Hygiene Association.

Brown-Williams H, Lichterman J, Kosnett M [2009]. Indecent exposure: lead puts workers and families at risk. Health Research in Action, University of California, Berkeley. Perspectives *4*(1):1–9.

CDPH [2009]. Medical guidelines for the lead–exposed worker. Sacramento, CA: California Department of Public Health, Occupational Lead Poisoning Prevention Program. [http://www.cdph.ca.gov/programs/olppp/Documents/medgdln.pdf]. Date accessed: October 2013.

CDC (Centers for Disease Control and Prevention) [2009]. Childhood lead poisoning associated with lead dust contamination of family vehicles and child safety seats --- Maine, 2008. MMWR *58*(32):890–893.

CDC (Centers for Disease Control and Prevention) [2012a]. Adult blood lead epidemiology and surveillance (ABLES). [http://www.cdc.gov/niosh/topics/ABLES/description.html]. Date accessed: October 2013.

CDC (Centers for Disease Control and Prevention) [2012b]. Take-home lead exposure among children with relatives employed at a battery recycling facility – Puerto Rico, 2011. MMWR *61*(47):967–970.

CDC (Centers for Disease Control and Prevention) [2013a]. Blood lead levels in children aged 1–5 years — United States, 1999–2010. MMWR *62*(13):245–248.

CDC (Centers for Disease Control and Prevention) [2013b]. Fourth national report on human exposure to environmental chemicals updated tables, March, 2013. [http://www.cdc.gov/exposurereport/pdf/FourthReport_UpdatedTables_Mar2013.pdf]. Date accessed: October 2013.

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

Chan PC, Ho KH, Kan KK, Stuhmiller JH, Mayorga MA [2001]. Evaluation of impulse noise criteria using human volunteer data. J Acoust Soc Amer 110(4):1967–1975.

CSTE [2009]. Public health reporting and national notification for elevated blood lead levels. CSTE position statement 09-OH-02. Atlanta, GA: Council of State and Territorial Epidemiologists [http://c.ymcdn.com/sites/www.cste.org/resource/resmgr/PS/09-OH-02.pdf]. Date accessed: October 2013.

DOD [2007]. Occupational examinations and surveillance manual. Washington, DC: Under Secretary of Defense for Acquisitions, Technology and Logistics. [http://www.dtic.mil/whs/directives/corres/pdf/605505mp.pdf]. Date accessed: October 2013.

Earshen J [2003]. Sound measurement: instrumentation and noise descriptors. In: Berger EH, Royster LH, Royster JD, Driscoll DP, Layne M, eds. The noise manual. 5th rev. ed. Fairfax, VA: American Industrial Hygiene Association, p. 54.

Filon FL, Boeniger M, Maina G, Adami G, Spinelli P, Damian A [2006]. Skin absorption of inorganic lead (PbO) and the effect of skin cleansers. J Occup Environ Med *48*(7):692–699.

Hwang YH, Chiang HY, Yen-Jean MC, Wang JD [2009]. The association between low levels of lead in blood and occupational noise-induced hearing loss in steel workers. Sci Total Environ *408*(1):43–49.

Institute of Medicine [2012]. Potential health risks from recurrent lead exposure of DOD firing range personnel. Washington, D.C.: National Academies Press.

Kardous CA, Willson RD, Hayden CS, Szlapa P, Murphy WJ, Reeves ER [2003]. Noise exposure assessment and abatement strategies at an indoor firing range. App Occup Environ Hyg *18*(8):629–636.

Kardous CA, Willson RD [2004]. Limitations of using dosimeters in impulse noise environments. J Occup Environ Hyg *1*(7):456–462.

Kosnett MJ, Wedeen RP, Rothenberg SJ, Hipkins KL, Materna BL, Schwartz BS, Hu H, Woolf A [2007]. Recommendations for medical management of adult blood lead exposure. Environ Health Perspect *115*(3):463–471.

Lauwerys RR, Hoet P [2001]. Industrial chemical exposure: guidelines for biological monitoring. 3rd ed. Boca Raton, FL: CRC Press, LLC, pp. 21–180.

Moline JM, Landrigan PJ [2005]. Lead. In: Rosenstock L, Cullen MR, Brodkin CA, Redlich CA, eds. Textbook of clinical occupational and environmental medicine. 2nd ed. Philadelphia, PA: Elsevier Saunders, pp. 967–979.

NIOSH [1975]. Lead exposure and design considerations for indoor firing ranges. By Anania TL and Seta JA. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 76-130.

NIOSH [1995]. Report to Congress on the workers' home contamination study conducted under the Workers' Family Protection Act 29 U.S.C. 671a. 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. 95-123. [http://www.cdc.gov/niosh/docs/95-123/]. Date accessed: October 2013.

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 [2005]. Hazard evaluation and technical assistance report: Immigration and Naturalization Service, National Firearms Unit, Altoona, PA. By Harney J, King B, Tubbs R, Crouch K, Hayden C, Kardous C, Khan A, Mickelsen L, Willson R. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA Report No. 2000-0191-2960.

NIOSH [2009]. NIOSH alert: preventing occupational exposures to lead and noise at indoor firing ranges. 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. 2009-136.

NIOSH [2010]. NIOSH pocket guide to chemical hazards. 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. 2010-168c. [http://www.cdc.gov/niosh/npg/]. Date accessed: October 2013.

NIOSH [2011]. Health hazard evaluation report: evaluation of lead exposure at an indoor firing range – California. By Ramsey JG, Niemeier RT. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA Report No. 2008-0275-3146.

NIOSH [2013]. NIOSH manual of analytical methods (NMAM®) 4th ed. Schlecht PC, O'Connor PF, eds. 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 94-113 (August 1994); 1st Supplement Publication 96-135, 2nd Supplement Publication 98-119; 3rd Supplement 2003-154. [http://www.cdc.gov/niosh/docs/2003-154/]. Date accessed: October 2013.

NTP [2011]. Report on carcinogens, Twelfth Edition. Research Triangle Park, NC: U.S. Department of Health and Human Services, National Institutes of Health, National Institute of Environmental Health Sciences, National Toxicology Program. [http://ntp.niehs.nih.gov/ntp/roc/twelfth/profiles/Lead.pdf]. Date accessed: October 2013.

NTP [2012]. Monograph on the health effects of low-level lead. Research Triangle Park, NC: U.S. Department of Health and Human Services, National Institutes of Health, National Institute of Environmental Health Sciences, National Toxicology Program.

Patterson J, Hamernik R [1992]. An experimental basis for the estimation of auditory system following exposures to impulse noise. In: Noise-induced hearing loss. Dancer A, Henderson D, Salvi R, Hamernik R, eds. Philadelphia, PA: BC Decker, pp. 336–348.

Pekkarinen J, Iki M, Starck J, Pyykko I [1993]. Hearing loss risk from exposure to shooting impulses in workers exposed to occupational noise. Br J Aud *27*(3):175–182.

Schwartz BS, Hu H [2007]. Adult lead exposure: time for change. Environ Health Perspect *115*(3):451–454.

Schwartz BS, Stewart WF [2007]. Lead and cognitive function in adults: a question and answers approach to a review of the evidence for cause, treatment, and prevention. Int Rev Psychiatry *19*(6):671–692.

Sliwinska-Kowalska M, Zamyslowska-Szmytke E, Szymczak W, Kotylo P, Fiszer M, Wesolowski W, Pawlaczyk-Luszczynska M, Bak M, Gajda-Szadkowska A [2004]. Effects of coexposure to noise and mixture of organic solvents on hearing in dockyard workers. J Occup Environ Med *46*(1):30–38.

Stauber JL, Florence TM, Gulson B, Dale L [1994]. Percutaneous absorption of inorganic lead compounds. Sci Total Environ *145*(1–2):55–70.

Sun CC, Wong TT, Hwang YH, Chao KY, Jee SH, Wang JD [2002]. Percutaneous absorption of inorganic lead compounds. Am Ind Hyg Assoc J *63*(5):641–646.

Tak S, Davis RR, Calvert GM [2009]. Exposure to hazardous workplace noise and use of hearing protection devices among US workers--NHANES, 1999–2004. Am J Ind Med *52*(5):358–371.

U.S. Army [2009]. Just the facts…occupational ototoxins (ear poisons) and hearing loss. Hearing Conservation and Industrial Hygiene and Medical Safety Management. [http://www.nmcphc.med.navy.mil/downloads/occmed/toolbox/occupationalototoxinfactsheet-chppm.pdf]. Date accessed: October 2013.

WHO [2006]. IARC monographs on the evaluation of carcinogenic risks to humans volume 87. Inorganic and organic lead compounds. Summary of data reported and evaluation. World Health Organization, Geneva, Switzerland. [http://monographs.iarc.fr/ENG/Monographs/vol87/volume87.pdf]. Date accessed: October 2013.

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