Evaluation of Ventilation and Employee Exposures to Lead 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 employer representative at an indoor firing range. The request concerned potential employee exposure to lead during routine tasks and range cleaning activities. The employer also wanted to know if the ventilation system met the National Institute for Occupational Safety and Health guidelines. We evaluated the firing range in June and October 2016.

What We Did

- We observed the work area and employee work practices, including range cleaning and use of personal protective equipment.
- We collected full-shift and task-based personal air samples on employees and area air samples for lead.
- We tested surfaces inside and outside the range for lead.
- We tested employees' hands for lead before and after range cleaning, and at the end of the workday before they left the range.
- We evaluated the range ventilation system.
- We reviewed the company's respiratory protection program, medical monitoring program, and standard operating procedures related to lead cleanup.

We evaluated employee lead exposures at an indoor public firing range. We found a clean, well maintained and organized operation. No airborne overexposures to lead were found. The ventilation system operated within performance guidelines. Small amounts of lead were found on some surfaces and on one employee's hands upon arrival for work. Increased use of a lead removal solution for surface and floor cleaning and lead removal hand wipes should reduce the possible spread of lead contamination.

What We Found

- Employees were not overexposed to airborne lead.
- The firing range and areas outside of the range appeared clean and well maintained.
- Employees used appropriate personal protective equipment during range cleaning tasks.
- In general, more lead was found on surfaces inside the range than outside the range.
- One employee had lead on their hands on arrival at work and before cleaning the range.
- The ventilation system was performing according to guidelines from the National Institute for Occupational Safety and Health.
- The company demonstrated a strong commitment to proper health and safety practices as well as maintaining written standard operating procedures and policies to protect employees and customers from lead exposure.

What the Employer Can Do

- Clean surfaces and floors that employees and customers routinely contact more frequently with a lead removal solution. To keep contamination as low as possible, cleaning efforts should focus on certain areas such as the armorer workbench, tables inside the range, customer lounge tables, and the floor outside the range exit door.
- Require employees to use lead removing wipes frequently, especially when exiting the range, after range cleaning, and after handling firearms or ammunition.
- Consider using a lead-certified laundry service or providing a dedicated onsite, washer and dryer to clean employee uniforms. This will help prevent take-home exposures.

What Employees Can Do

- Clean your hands with lead-removing wipes or lead removing soap each time you leave the range. Clean your hands with regular soap and water before eating while at work.
- Wear nitrile gloves when handling ammunition at work and outside of work, and use lead removal wipes on your hands after you remove your gloves.
- Shower before leaving work, especially after conducting weekly “deep” range cleaning tasks.

Abbreviations

µg	Micrograms
µg/dL	Microgram per deciliter
$\mu g/m^3$	Micrograms per cubic meter
cm^2	Square centimeter
ACGIH®	American Conference of Governmental Industrial Hygienists
BLL	Blood lead level
CFR	Code of Federal Regulations
HEPA	High efficiency particulate air
MERV	Minimum efficiency reporting value
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
TLV®	Threshold limit value
TWA	Time-weighted average

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Introduction

The Health Hazard Evaluation Program received a request from an employer representative at a public indoor firing range. The request concerned potential employee exposure to lead during routine range tasks and weekly range cleaning. Other concerns included the performance of the ventilation system and whether lead was migrating from the range to other areas of the building. In June 2016, we met with the employer and an employee representative to discuss the request, conducted a walk-through survey of the range to speak with employees and observe their work practices, collected full-shift personal and area air samples for lead, and reviewed the company's health and safety policy documents. In October 2016, we collected task-based and full-shift personal air samples for lead on employees during routine range tasks and weekly range cleaning activities. We also collected hand wipe samples for lead from employees before and after weekly range cleaning and also at the end of the work shift. Only one range, consisting of 10 firing lanes, was in use during both site visits. On the days we collected samples, the company indicated that the number of customers using the range was normal. We did not evaluate bullet trap cleaning because it was performed by a contractor. A summary letter outlining preliminary findings was sent to the employer and employee representatives after each site visit.

Background

The newly constructed building opened in February 2016 and has two 10-lane firing ranges, each with its own ventilation system and crumb rubber bullet trap; a retail sales area and customer lounge; classrooms, locker rooms, and restrooms; an armory/repair area; and a martial arts studio. Areas outside the ranges, such as the retail sales area and customer lounge, were cleaned daily by employees using a solution of D-Lead® and water. "Sticky mats" were in place at the doorway between each range and the retail sales area. Daily cleaning inside the range by some employees included using a floor squeegee to gather spent shell casings and picking them up by hand while wearing nitrile gloves. Other daily cleaning tasks included vacuuming and mopping the floor and wet-wiping tables and other surfaces. Employees conducted a weekly "deep" cleaning and maintenance of the range from the firing line to the bullet trap using a high efficiency particulate air (HEPA) filtered vacuum, wet floor scrubber, and a lead removal solution (D-Lead). The weekly cleaning took about 1.5 to 2 hours to complete and was performed before the ranges were opened to customers. Details on the cleaning methods and the personal protective equipment worn by employees are provided in the Results section of this report.

We evaluated the following job titles:

1. Retail sales leader. This employee managed the sales counter, merchandise area, and retail showroom, and assisted customers with weapon and accessory purchases. This employee occasionally entered the firing range to let shooters test fire weapons.
2. Range safety officer. This employee monitored shooters inside the range, providing instruction on proper firing technique and weapons handling practices, inspected weapons and ammunition for compliance with range policies on type and caliber, and helped shooters clear weapon jams or other malfunctions. Other duties included

occasional range cleaning activities, such as operating a HEPA-filtered floor vacuum or wet floor scrubber.

3. Sales counter person. This employee handled transactions involving the purchase of weapons, accessories, ammunition, and range time. This employee also conducted surface cleaning activities inside the showroom and customer lounge using a lead removal solution. Other duties included range cleaning using a HEPA-filtered floor vacuum or wet floor scrubber and wiping surfaces inside and outside the range with a lead removal solution.

Methods

The objective of this evaluation was to determine if the range employees were exposed to lead above recommended levels. To achieve this objective, we (1) measured employees' personal exposures to lead in air during routine work tasks and during weekly range cleaning; (2) measured airborne lead concentrations behind the firing line and in the center of the retail sales area; (3) measured lead on surfaces inside and outside the firing range; (4) measured lead on the hands of employees upon arrival at work right before range cleaning activities, immediately after range cleaning activities, and at the end of the workday; (5) evaluated the ventilation system performance per National Institute for Occupational Safety and Health (NIOSH) guidelines; and (6) determined if work practices could increase employee lead exposure.

Full-shift and task-based personal air samples were collected for lead according to NIOSH Method 7306 [NIOSH 2017]. In June 2016, for full-shift air sampling, one sample was collected (either personal or area) for approximately 8 hours (Table 1). In October 2016, during weekly range cleaning activities, each person had two sequential air samples collected for lead. The first sample was collected for the duration of a specific weekly range cleaning task, followed by a separate second sample collected for the remainder of the shift. These two samples were used to determine an employee's lead exposure during a weekly cleaning task and then to calculate the employee's full-shift time-weighted-average (TWA) exposure to airborne lead (Table 2).

Surface wipe samples for lead were collected at locations inside and outside the range using commercially available, colorimetric dust wipes (Full Disclosure® Instant Wipes, SKC Inc.) following NIOSH Method 9102 [NIOSH 2017]. These wipes are designed to produce a color change (turn pink/red) when lead is present above 18 micrograms (µg). We used a disposable 100-square centimeter (cm^2) template to collect each surface wipe sample. For irregularly shaped areas such as a windowsill where a template could not be used, we estimated the sampling area. We used this same surface wipe sampling approach to collect a sample for laboratory measurement of lead on employees' hands. To collect a hand wipe sample we asked employees to wipe their palms, between their fingers, and the backs of their hands for 30 seconds.

We visually inspected the air handlers, supply air diffusers, ductwork, and exhaust outlets for the firing range and used qualitative and quantitative methods to evaluate the airflow. We used a Rosco Laboratories Inc. Model 1500 aerosol generating machine to generate a propylene glycol-based aerosol "smoke" to visualize airflow patterns within the range. We generated smoke behind the firing line, at each shooting position, and at the front of the bullet trap. We used ventilation smoke tubes to determine if the firing range was under negative pressure relative to the retail showroom and other adjacent areas, meaning that air flowed into the firing range from surrounding areas. We used a Shortridge Instruments, Inc. electronic micromanometer to measure the air velocity in feet per minute at the firing line for each firing lane. We took three measurements (at 1 foot, 3 feet, and 5 feet above the floor) and averaged the measurements for each of the 10 lanes.

We observed work practices and use of personal protective equipment and reviewed the company's written respiratory protection program and medical surveillance program.

Results

Air Sampling

Personal full-shift lead concentrations during routine work activities ranged from not detected (less than 0.3 micrograms per cubic meter of air [μg/m^3]) to 0.57 μg/m^3 (Table 1), and none exceeded the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL), the NIOSH recommended exposure limit (REL), or the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for lead, all of which are set at 50 μg/m^3. The highest area air lead concentration (0.95 μg/m^3) was from a sample collected inside the range on a table behind the firing line. Lead was not detected in an area air sample collected in the center of the showroom.

Table 1. Full-shift personal and area air samples for lead, June 2016

	Sampling time (minutes)	Concentration (μg/m^3)
Personal air samples		
Range safety officer	481	[0.57]
Retail sales leader	487	[0.39]*
Sales counter person	479	ND†
OSHA PEL		50
NIOSH REL		50
ACGIH TLV		50
Area air samples		
Inside range on table behind firing line	474	[0.95]‡
Center of showroom	474	ND‡

*Values in brackets mean the concentration was between the minimum detectable concentration of 0.3 μg/m^3 and the minimum quantifiable concentration of 1.0 μg/m^3. There is more uncertainty associated with these values.

†Not detected. Concentration is below the minimum detectable concentration of 0.3 μg/m^3.

‡Value is for an area air sample and should not be compared to any PEL, REL, or TLV.

Personal air sample results for lead during weekly range cleaning activities were similar to those obtained during routine work activities, and none exceeded any occupational exposure limit (OEL) for lead (Table 2). The sequence of cleaning tasks was as follows:

1. Gather spent shell casings using a floor squeegee and pick up with hands while wearing nitrile gloves.
2. Clean floor using a Nilfisk® Model S2 HEPA-filtered vacuum.
3. Clean floor using an Ecoflex® model SC750 wet scrubber.
4. Repaint ballistic baffles and perform general range maintenance.

Table 2. Task and full-shift personal air samples for lead during and after weekly range cleaning, October 2016

Employee tasks	Sampling time (minutes)	Task-specific concentration (μg/m³)	Full-shift TWA concentration (μg/m³)
Operating HEPA filtered floor vacuum	110	5.2	1.4
Sales counter activities	328	[0.15]	
Repainting ballistic baffles	97	2.8	1.1
Maintenance, receiving, inventory	215*	[0.29]	
Picking up spent shell casings	99*	[0.40]†	[0.40]
Operating wet floor scrubber	104	[0.77]	[0.33]
Range safety officer	320	[0.19]	
OSHA PEL			50
NIOSH REL			50
ACGIH TLV			50

*Indicates person worked a partial shift before leaving the building.

†Values in brackets mean the concentration was between the minimum detectable concentration of 0.3 μg/m³ and the minimum quantifiable concentration of 0.9 μg/m³ for task-specific samples. For full-shift samples, the minimum detectable concentration was 0.1 μg/m³ and the minimum quantifiable concentration was 0.3 μg/m³. There is more uncertainty associated with these values.

The highest task-based exposure (5.2 μg/m³) occurred when performing weekly range cleaning using the HEPA-filtered floor vacuum. Employees were required to wear nitrile gloves during daily cleaning inside and outside the range. For daily and weekly cleaning inside the range, employees were required to wear nitrile gloves and disposable shoe covers. N95 filtering facepiece respirators were available for voluntary use. All employees wore the respirators during weekly cleaning activities.

Surface Sampling

Table 3 presents the results for lead on employees' hands before and immediately after weekly range cleaning, and at the end of the workday. One employee's handwipe sample collected upon arrival for work and prior to beginning range cleaning activities showed a color change indicating the presence of lead. Another employee's handwipe sample collected after range cleaning also produced a color change indicating the presence of lead, and two out of three handwipe samples collected at the end of this employee's work shift showed a color change. The amount of lead measured on these samples ranged from 3.6 µg per wipe to 65 µg per wipe. The highest amount of lead on any handwipe was measured on one employee upon arrival at work.

Table 3. Colorimetric and quantitative handwipe sample results for lead, October 2016

Tasks	Before range cleaning		After range cleaning		At end of work shift†	
	Color*	µg/wipe	Color	µg/wipe	Color	µg/wipe
Operating wet floor scrubber and serving as range safety officer	Yes	65‡	No	5.3	Yes	32
Operating HEPA floor vacuum and working at sales counter activities	No	7.5	Yes	26	No	3.6
Painting baffles and conducting building maintenance	No	4.1	No	7.7	Yes	28

*Limit of detection is estimated to be 18 µg/wipe sample to produce a color change.

†Employees cleaned their hands with lead removal wipes (D-Lead) following the collection of the handwipe sample after range cleaning but before starting the remainder of their work shift.

‡Total mass of lead on the handwipe after the employee wiped both hands for 30 seconds.

Of the 10 surface wipe samples collected inside and outside the firing range, only three produced a color change indicating the presence of lead (Table 4). These samples were also analyzed for lead with results ranging from 0.25 µg/100 cm^2 at the sales counter to 85 µg/100 cm^2 on a windowsill inside the range. All of these levels are much lower than surface contamination measured at other indoor firing ranges investigated by NIOSH [1999, 2013, 2014].

Table 4. Colorimetric and quantitative surface wipe samples for lead, June 2016

Locations	Detected*	Amount (µg/100 cm^2)
Inside range		
Windowsill	Yes	85
Floor, 6 feet behind firing line	Yes	29
Ammunition loading table	No	2.8
Outside range		
Armorer workbench	Yes	24
Floor outside range exit door	No	7.5
Range safety officer desktop	No	7.3
Table top in customer lounge	No	0.95
Desktop in martial arts studio	No	0.67
Table top in employee break room	No	0.56
Sales counter near cash register	No	0.25

*Limit of detection is estimated to be 18 µg/wipe sample to produce a color change.

Ventilation Assessment

A recirculating air handler provided climate control to the showroom, classrooms, martial arts studio, and other non-range areas. A separate air handler provided conditioned air to the range and exhausted air from the range to the outdoors. On the basis of ventilation smoke tube testing we determined that the range was under a slight negative air pressure relative to adjacent areas, meaning that air flowed from these surrounding areas and into the range, a ventilation design that is desired.

The range ventilation system delivered up to 40,000 cubic feet per minute of air to the range, recirculating approximately 80% of the indoor air. The ventilation system had a minimum efficiency reporting value (MERV) 8 prefilter, a MERV 15 secondary filter, and a MERV 17 HEPA final filter. The maintenance employee monitored the condition of the air filters daily via a computerized sensor system that measured the air pressure drop across each filter. Air filters were changed when the pressure drop reached a predetermined point, usually every 3 months for the prefilter and secondary filter. The MERV 17 final filter was designed to last about a year before changing. Personal protective clothing that staff, usually two employees, were required to wear during an air filter change-out included a full body Tyvek® suit with hood, N95 filtering facepiece respirator, nitrile gloves, and disposable shoe covers. All employees involved in deep range cleaning tasks and filter change-out kept an extra set of footwear onsite that was stored in their locker and used solely during these activities. We did not evaluate employee exposure during a filter change-out during either site visit because the filters were not ready to be changed.

A bank of radial-style, perforated diffusers covered a plenum at the junction between the ceiling and wall. The diffusers ran the entire length of the back wall behind the firing line and provided supply air to the shooting lanes. The distance from the radial diffusers to the firing line was about 16 feet, and the height from the floor to the bottom of the radial diffuser was about 7 feet. This push-pull ventilation design is intended to control airborne contaminants by uniformly moving clean air across the firing line and towards the crumb rubber bullet trap and overhead slot exhaust inlets located 25 yards downrange. This ventilation approach is discussed in the NIOSH guideline for firing ranges [NIOSH 2009]. We confirmed this airflow pattern using ventilation smoke.

We averaged the air velocities measured at 1 foot, 3 feet, and 5 feet off the floor of the firing line in each of the 10 shooting lanes. The average air velocities per lane ranged from 56 feet per minute to 88 feet per minute. The overall average for all 10 lanes was 70 feet per minute, within the NIOSH recommended guideline of 50 to 75 feet per minute for firing ranges [NIOSH 2009].

Workplace Observations and Program Review

The company has a health and safety committee consisting of two employer representatives and two employee representatives. All employees are provided a company-issued uniform that consisted of a short sleeve polo shirt with a pin-on name tag and long khaki pants. Employees provided their own footwear. The respiratory protection program and the medical surveillance program contained all the necessary elements established by the Occupational Safety and Health Administration.

Discussion

Employee exposures to airborne lead during routine work activities and weekly range cleaning were well below any OEL. These low airborne exposures can be attributed to the design and maintenance of the firing range ventilation system and maintaining the range under a negative air pressure compared to adjacent areas. Overall, the employer demonstrated a strong commitment to health and safety by creating and following detailed policies, programs, and standard operating procedures that appear to be effective in minimizing lead migration and contamination outside of the range.

Surface sampling inside and outside the range identified some locations with higher lead levels than others, likely due to specific work tasks or customers' actions. For example, the highest amount of lead found on any surface outside the range was on the armorer's workbench, a location where firearms were cleaned and repaired. Another route of lead transfer and subsequent surface contamination could involve customers transferring lead to surfaces inside and outside the range. For example, if a customer has lead on their hands from handling ammunition or a lead-contaminated firearm, and then exits the range without cleaning their hands and sits and touches a table in the lounge, a transfer of lead from the customer's hands could occur. Another example could be customers tracking lead from the range to the retail sales area on the soles of their shoes despite the use of sticky mats, a control that does not remove 100% of lead present on footwear (Table 4). All of these scenarios could result in a buildup of lead contamination over time.

Packages of D-Lead hand cleaning wipes were available for employee and customer use inside and outside the ranges, but we were not aware of a company policy regarding their use. A one-gallon dispenser of D-Lead hand soap was present at the sink inside the range supply area, and employees were required to wash their hands before exiting the range. Our finding of some lead on the hands of all employees at the end of the work shift suggests they were not thoroughly cleaning their hands during or at the end of the workday. The presence of lead on one employee's hands upon arrival for work may be due to activities occurring outside of work. Another employee had a detectable amount of lead on their hands after conducting weekly range cleaning activities despite wearing nitrile gloves. There were no visible tears in the gloves upon inspection at the end of range cleaning, so the origin of the contamination is unknown. Because the gloves only extend to the wrist, it is possible that the exposed skin just above the wrist could have contacted a contaminated surface and been captured by the handwipe sampler. Regardless of the reason for the contamination, the finding of lead on employees' hands illustrates the importance of hand hygiene at various times during the day and before leaving the workplace. As a precaution, hands and skin above the wrist should be thoroughly cleaned with lead removal wipes even when gloves are worn.

We reviewed the company's written documents related to their policies and programs on occupational lead exposure and found them to be well written and easy to understand. We were informed that the company had a health and safety committee that included managers and employees and met quarterly. Finally, we reviewed, the medical monitoring and surveillance program for employees that was based on OSHA guidelines for medical monitoring of employees exposed to lead. For example, the company enrolled all employees in a blood lead monitoring program administered by a local occupational health provider and established pre-employment blood lead levels (BLLs) as a baseline with additional blood lead samples collected every 6 months.

The company provided N95 filtering facepiece respirators for voluntary use and adhered to the OSHA guidelines outlined in the Code of Federal Regulations (CFR) (29 CFR 1910.134, Appendix D). The company also conducted employee training on the hazards of lead each year in accordance with the OSHA hazard communication standard (29 CFR 1910.1200).

Overall, the company policies and operation appear to be well thought out and demonstrate a best practices approach on how to operate a firing range. However, despite employee exposures being well below OELs, the possibility of take-home and household member exposure to lead is always a possibility. To reduce the chances of take-home lead exposure, additional protective measures such as showering before leaving work and laundering uniforms through a lead-certified laundry service or onsite are strategies that may be worth implementing. For more information and a detailed discussion of the health effects of lead, recommended medical monitoring, and the dangers of take-home lead to household members, see Appendix A.

Conclusions

No employees were overexposed to airborne lead. However, we did find lead on surfaces and employees' hands. This indicates that unrecognized sources of lead (including from customers and their ammunition or firearms) may be present. Such a finding, especially in a newly constructed building, justifies the need for increased surface cleaning to keep contamination as low as possible and also to use D-Lead handwipes frequently. The ventilation system performance met NIOSH guidelines. The company adhered to the OSHA lead standard and the type and availability of personal protective equipment was appropriate for the work performed by employees.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage this firing range to use the labor-management health and safety committee 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 this firing range.

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 the case of this firing range, the main exposure control used a mechanical ventilation system to effectively keep airborne lead concentrations well below the PEL, therefore the recommendations that follow focus on dermal routes of exposure.

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. Create a written program that describes the use of lead removal wipes.
2. Increase the number of signs identifying locations of lead removal wipes. These signs should also remind customers and employees to use the wipes, especially when exiting the range.
3. Clean surfaces and floors that employees and customers routinely contact more frequently with a lead removal solution (e.g., armorer workbench, tables inside range, customer lounge tables, floor outside range exit door) to keep contamination as low as possible.
4. Educate employees about the importance of cleaning their hands and wrists with lead removal wipes frequently throughout the day (especially after handling firearms and ammunition, touching surfaces inside the range, before eating or drinking, after removing gloves), and before leaving the building at the end of the work shift.
5. Educate employees about the importance of wearing nitrile gloves when handling lead outside of work (e.g., reloading ammunition) and cleaning hands with lead removal wipes when done.
6. Encourage employees to shower before leaving work.
7. As a precaution against take-home lead exposure, consider using a lead-certified laundry service or provide an onsite, dedicated washer and dryer to clean employee uniforms.

Appendix A: Occupational Exposure Limits and Health Effects of Lead

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 STEL or ceiling values. Unless otherwise noted, the STEL 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.
- Another set of OELs commonly used and cited in the United States is the ACGIH TLVs. The TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They 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 2017].

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/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 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.

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. Exposure may also occur through transfer of lead to the mouth from contaminated hands or cigarettes when careful attention to hygiene, particularly hand washing, is not practiced. In addition to the inhalation and ingestion routes of exposure, lead can be absorbed through the skin, particularly through damaged skin [Filon et al. 2006; Stauber et al. 1994; Sun et al. 2002].

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 [Centers for disease Control and Prevention 2013a; Lauwerys and Hoet 2001; Moline and Landrigan 2005]. 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. The geometric mean BLL went from 1.75 micrograms per deciliter of whole blood (µg/dL) in 1999–2000 to 1.09 µg/dL in 2011–2012 [Centers for Disease Control and Prevention 2015b]. The NIOSH Adult Blood Lead Epidemiology and Surveillance System uses a surveillance case definition for an elevated BLL in adults of 5 µg/dL of blood or higher [Centers for Disease Control and Prevention 2015a]. Very high BLLs are defined as BLLs ≥ 40 µg/dL. From 2002–2011, occupational exposures accounted for 91% of adults with very high BLLs (where exposure source was known) [Centers for Disease Control and Prevention 2013b]. This underscores the need to increase efforts to prevent lead exposures in the workplace.

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 a 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, 20 µg/dL. ACGIH designates lead as an animal carcinogen [ACGIH 2001]. In 2013, the California Department of Public Health recommended that Cal/OSHA lower the PEL for lead to 0.5 to 2.1 µg/m^3 (8-hour TWA) to keep BLLs below the range of 5 to 10 µg/dL [Billingsley 2013].

Neither NIOSH nor OSHA has established surface contamination limits for lead in the workplace. The U.S. Environmental Protection Agency and the U.S. Department of Housing and Urban Development limit lead on surfaces in public buildings and child-occupied housing to less than 40 micrograms of lead per square foot [EPA 1998; HUD 2012]. OSHA requires 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)]. An employer with workplace exposures to lead must implement regular and effective cleaning of surfaces in areas such as change areas, storage facilities, and lunchroom/eating areas to ensure they are as free as practicable from lead contamination.

Health Effects

The PEL, REL, and TLV may prevent overt symptoms of lead poisoning, but do not protect workers from lead's contributions to conditions such as hypertension, renal dysfunction, reproductive, and cognitive effects [Brown-Williams et al. 2009; Holland and Cawthorn 2016; Institute of Medicine 2012; Schwartz and Hu 2007; Schwartz and Stewart 2007]. 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. Lead poisoning 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 occupational 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 National Toxicology Program concluded the following about the evidence regarding health effects of lead (Table A1).

Table A1. 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 [IARC 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 convened by the Association of Occupational and Environmental Clinics published guidelines for the management of adult lead exposure [Kosnett et al. 2007]. The panel recommended BLL testing for all lead-exposed employees, regardless of the airborne lead concentration. 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 were endorsed by the Council of State and Territorial Epidemiologists and the California Department of Public Health in 2009 and the American College of Occupational and Environmental Medicine in 2010 [ACOEM 2010; CDPH 2009; CSTE 2009]. The Council of State and Territorial Epidemiologists published updated guidelines in 2013 to reflect the new definition of an elevated BLL in adults of 5 µg/dL [CSTE 2013]. The California Department of Public Health recommended keeping BLLs below 5 to 10 µg/dL in 2013 [Billingsley 2013] and updated their medical management guidelines in 2014 [CDPH 2014]. In 2015, NIOSH designated 5 µg/dL of whole blood, in a venous blood sample, as the reference BLL for adults. An elevated BLL is defined as a BLL ≥ 5 µg/dL. In 2016, the American College of Occupational and Environmental Medicine released a position statement titled "Workplace Lead Exposure," which reinforces the guidelines and recommendations above [Holland and Cawthorn 2016]. Table A2 incorporates recommendations from the expert panel guidelines and those from the California Department of Public Health, the American College of Occupational and Environmental Medicine, and the Council of State and Territorial Epidemiologists.

Table A2. 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 < 5 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 5–9 µg/dL	• Discuss health risks • Minimize exposure • Consider removal for pregnancy and certain medical conditions • BLL monthly for first 3 months placement or every 2 months for the first 6 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	• Discuss health risks • Decrease exposure • Remove from exposure for pregnancy • Consider removal for certain medical conditions or BLL ≥ 10 µg/dL for extended period • 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 20–29 µg/dL	• Remove from exposure for pregnancy • Remove from exposure if repeat BLL measured in 4 weeks remains ≥ 20 µg/dL • Annual lead medical exam recommended • Monthly BLL testing • Consider return to work after 2 BLLs < 15 µg/dL a month apart, then monitor as above
BLL 30–49 µg/dL	• Remove from exposure • Prompt medical evaluation • Monthly BLL testing • Consider return to work after 2 BLLs < 15 µg/dL a month apart, then monitor as above
BLL 50–79 µg/dL	• Remove from exposure • Prompt medical evaluation • Consider chelation with significant symptoms
BLL ≥ 80 µg/dL	• Remove from exposure • Urgent medical evaluation • Chelation may be indicated

Adapted from Kosnett et al. 2007, CSTE 2013, and CDPH 2014.

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 [Centers for Disease Control and Prevention 2009, 2012].

The Centers for Disease Control and Prevention 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 [Centers for Disease Control and Prevention 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.

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