Evaluation of Nonproduction Area Air and Surface Lead Levels, Employee Blood Lead Levels, and Psychosocial Factors at a Battery Manufacturing Plant

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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 a manager at a lead-acid battery company. The request concerned help in further lowering employees' blood lead levels. We visited the plant in March 2014 and January 2015.

What We Did

- We measured for lead contamination in nonproduction areas.
- We reviewed employee blood lead testing results, lead in air sample results, and related company written health and safety programs.
- We calculated employee blood lead level averages by year, by year and quarter, and by year and department. To calculate these averages, we used a single measure (the mean) for each participant within these groupings.
- We asked employees about their medical and work history, their health concerns about work, and about the lead hazard control program.
- We held two focus groups with employees to discuss their perceptions of the risk of lead exposure and the effectiveness of methods to reduce lead exposure.

What We Found

- We found airborne and surface lead in all the nonproduction areas we tested.
- The average blood lead levels of employees' means were ≥ 10 micrograms per deciliter, above the recommended limit. Blood lead level averages declined over the years for which we reviewed data.
- The employees in the focus group with the higher blood lead levels were less confident in their ability to reduce their exposure to lead when compared to the employees in the focus group with lower blood lead levels.

We evaluated air and surface lead concentrations at a battery manufacturer. Hand hygiene was generally effective in clean areas, but clean surfaces had lead on them. Many employees had blood lead levels above 10 micrograms per deciliter, and some airborne lead exposures in the past exceeded limits in all production departments. We provided recommendations to prevent exposure to workplace lead and take-home lead.

What the Employer Can Do

- Continue to improve local exhaust and general ventilation to minimize airborne exposure to lead in production areas.
- Redesign the locker rooms to have distinct clean and dirty sides.
- Encourage employees to report any health concerns that may be related to their work to their supervisors and a healthcare provider.

- Follow the guidelines for medical monitoring referenced in Appendix B of this report. Lower employee blood lead levels to < 5 micrograms per deciliter. Use a removal from work level of ≥ 20 micrograms per deciliter.
- Use the focus group results to guide further efforts to understand and address gaps in employees' perceptions of lead exposure management and the dangers of take home lead. Doing so may help challenge employees' misconceptions and improve their confidence in reducing blood lead levels.
- Identify employees who can advocate for behaviors to reduce lead exposure. Give these employee "champions" information about the benefits of minimizing lead exposure and tips for lowering lead exposure. Encourage these employee champions to share this information throughout the workplace.

What Employees Can Do

- Wash your hands before eating, drinking, and leaving work. Use a lead removal cleaner, not just soap and water.
- Take the manufacturer's recommended amount of time to walk through the air shower each time you exit the production area.
- Tell your supervisor if you have any work-related health and/or safety concerns.
- Do not give yourself any type of synthetic or natural chelation therapy. Only licensed healthcare providers should give chelation therapy because of potential adverse drug reactions.
- Tell your doctor that you work with lead. Give your doctor a copy of this report.
- Volunteer to be a low blood lead level employee champion. Teach and encourage your coworkers to do things that reduce their lead exposure.

Abbreviations

µg	Microgram
µg/dL	Micrograms per deciliter
µg/m^3	Micrograms per cubic meter
µg/wipe	Micrograms per wipe
AL	Action level
BLL	Blood lead level
CDC	Centers for Disease Control and Prevention
COS	Cast on strap
CFR	Code of Federal Regulations
EDTA	Ethylenediaminetetraacetate
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
PPE	Personal protective equipment
TWA	Time-weighted average

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Introduction

The Health Hazard Evaluation Program received a management request from a battery manufacturing company. The request concerned help in further lowering employees' blood lead levels (BLLs). A state department of health official had approached the company about participating with the National Institute for Occupational Safety and Health (NIOSH) in a multistate effort to lower employee BLLs at different battery manufacturing plants. The company had longstanding medical surveillance and exposure assessment programs, employee health and safety training, and was aware of primary exposure control challenges in their production areas. We visited the company in March 2014 and January 2015. Following each visit, we sent the company letters summarizing our activities.

Process Description

At the time of this evaluation, the plant employed about 400 employees and manufactured approximately 50,000 lead-acid batteries daily. Lead-acid battery production at this plant was similar to other plants (https://www.osha.gov/SLTC/etools/battery_manufacturing/index.html) with the exception that acid filling of batteries was done at another location. We observed these processes and describe them here just to the extent they aid understanding the results, discussion, conclusions, and recommendations later in this report. Starting with high purity blocks of lead (about 2,000 pounds each), the company cast smaller ingots that were subsequently ground into powder in ball mills and then mixed into a proprietary formulation containing lead oxide, simply called oxide by employees. This oxide was combined with sulfuric acid and water into a paste and dried onto grid plates (processes described thus far all occur in casting and pasting [including oxide, casting, and pasting jobs]) that became the cathode and anode of individual battery cells within larger batteries assembled (in assembly/COS [cast on strap], by far the largest department at the plant) later in the production process. Employees of the other departments such as warehouse (including assembly/pasting jobs), maintenance (plant wide), safety, quality, and front office (including black belt and manufacturing engineering jobs) may spend variable amounts of time in casting and pasting and in assembly/COS.

The focus of the environmental sampling portion of this evaluation was on nonproduction plant areas (see Figure 1) and whether employees were unknowingly carrying lead dust (for example, on their uniforms and exposed skin) into areas generally regarded as clean. These activities and accompanying locations were thought likely to occur: (1) leaving the production area through a door; (2) entering the main hallway connecting the locker rooms, cafeteria, and front offices; (3) washing hands and face at a sink or showering; and (4) either entering the cafeteria or exiting the building (sometimes to use the outdoor smoking shelter before returning to work). The air shower tunnel shown in Figure 1 was added by the company between our two visits.

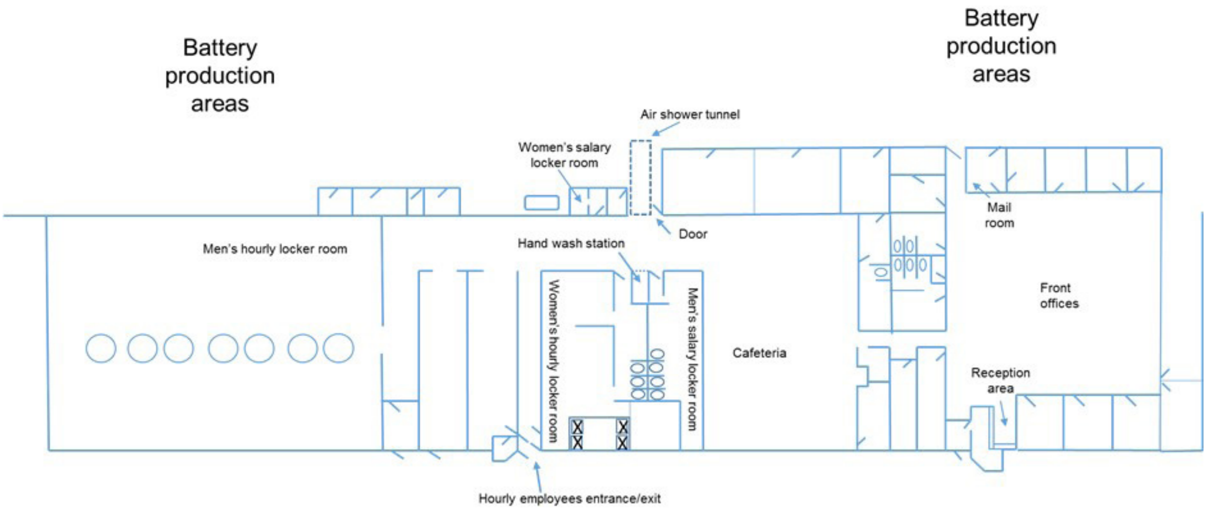

Figure 1. Diagram of plant (not to scale) nonproduction areas where we collected air and surface dust samples.

Methods

Our objectives were to:

- Evaluate lead in air and on surfaces in nonproduction areas that were generally regarded as "clean," such as the cafeteria, locker rooms, and front offices
- Evaluate the medical surveillance and respiratory protection programs
- Evaluate employee perceptions about their ability to keep their BLL below the company's limit

Environmental Sampling

We collected 121 wipe samples and qualitatively analyzed them in the field using SKC Inc. Full Disclosure® kits. A subset of the wipes was then analyzed for lead according to NIOSH Method 7303 [NIOSH 2018]. We collected surface wipe samples in nonproduction areas such as the tool crib, boot changing station, cafeteria, locker rooms, and front offices. We also took wipe samples from employees' hands before they entered the cafeteria and before they departed at the end of their shift, noting whether they had recently used lead removal wipes and/or soap when showering or washing their hands.

We collected 25 full-shift area air samples in locker rooms, the cafeteria, and in the front offices and had them analyzed for lead by NIOSH Method 7303 [NIOSH 2018]. We also used ventilation smoke tubes to check the airflow direction between nonproduction and production areas.

Employee Medical Interviews

During the first visit, we held voluntary, confidential medical interviews with employees from first and second shifts selected from a company roster. We selected employees until we believed we had a representative sample of the workplace population on the basis of their job title, length of employment with the company, sex, and work shift. Information collected in the interviews included job title, age, length of employment, work and medical history, symptoms experienced during work, personal protective equipment (PPE) use, hygiene practices, and health and workplace concerns associated with lead toxicity. The interviews included open-ended and yes/no questions.

Employee Focus Groups

During the second visit, we held two focus groups. We segregated the focus groups on the basis of a BLL level of 15 micrograms per deciliter (µg/dL), the limit used by the company in deciding if an employee should be in their lead compliance program. We used a roster of approximately 60 employees who had a BLL of > 15 µg/dL (tested December 29, 2014) and a roster of approximately 30 employees who had a recent history (in the past year) of a BLL < 15 µg/dL. Using these rosters, we invited every third employee to participate in a focus group. If a selected employee was unwilling to participate or not available (e.g., on leave), we selected the next employee on the roster. The focus groups were facilitated by a NIOSH behavioral scientist and lasted 1 hour each. The discussions focused on the following topics: (1) perceptions of the BLL threshold of > 15 µg/dL; (2) factors contributing to elevated BLL; (3) methods for minimizing lead exposure; (4) effectiveness of company training on the dangers of lead exposure; (5) motivation to wear PPE; and (6) take-home lead. Participant comments are summarized in the results section of this report based on recurring themes.

Document Reviews

We met with the plant nurse and safety manager and discussed medical policies and procedures, including the Occupational Safety and Health Administration (OSHA) mandated lead compliance program, which included a respiratory protection program and monitoring employee BLLs. We reviewed the OSHA Form 300 Log of Work-Related Injuries and Illnesses and OSHA Form 301 Injury and Illness Incident Report for the years 2011–2014. We reviewed results of personal air sampling for lead for the years 2012–2014. The company provided copies of employees' BLL test results from January 2011–January 2015, but in this report, we only included the years for which we have complete data (January 2011–December 2014).

Results

Environmental Sampling

Surface and Hand Wipe Samples

Table 1 summarizes results for surface wipe samples; detailed results are in Appendix A, Tables A1 and A2. Each type of nonproduction surface we tested had visually detectable amounts of lead, with 47 of the 56 wipes showing a color change indicative of the presence of lead. The notable exception was cafeteria tabletops. Neither of the wipes we collected on these eating surfaces changed color when sprayed with the lead detecting developer solution, perhaps reflective of the almost continual cleaning efforts of the janitorial staff. Janitors used Hygenall® wipes to clean cafeteria tabletops multiple times per shift, whereas cleaning efforts were not as frequent for other surfaces. Some of the clean PPE (gloves, respirators, respirator filter cartridges) tested in the storeroom had lead on it. Though the storeroom was not part of battery manufacturing processes, it was located in the production side of the building.

Table 1. Surface wipe results (# positive*/# collected) by sample location and surface type†

Sample location	Door or vertical surfaces	Floor	PPE	Chair/ bench	Tabletop	Other‡	Total
Cafeteria	0/1	2/2	NS§	2/2	0/2	NS	4/7
Front offices	1/2	1/1	NS	NS	3/6	NS	5/9
Hallway	2/2	1/1	NS	NS	1/1	NS	4/4
Locker rooms	7/7	3/3	NS	5/5	NS	NS	15/15
Production	NS	2/2	NS	1/1	3/3	1/1	7/7
Storeroom	NS	1/1	7/8	NS	1/2	4/5	12/14
Total	10/12	10/10	7/8	8/8	8/14	5/6	47/56

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

†Surface sample area was 100 square centimeters. For irregularly shaped areas where a template could not be used we estimated the sampling area.

‡This group included locations such as floors and clean PPE.

§No sample was collected.

Surface wipe samples from nonproduction areas, with the exception of two wipes collected from building exit turnstile bars, were analyzed quantitatively. In general, the highest surface concentrations measured in nonproduction areas were in the men's locker room and the nonproduction hallway at the air shower exit. The highest concentration overall was collected on the mailroom countertop in the front offices. All wipes that qualitatively tested negative for the presence of lead on the basis of color change had detectable lead (though less than the visual limit of detection of approximately 18 µg/wipe sample) on them when analyzed quantitatively in the laboratory.

Table 2 below shows results for employee hand wipes. Overall, 17 of the 65 hand wipes we collected showed colorimetric change (lead ≥ 18 µg), indicating the potential for ingestion. Most of these (13) came from employees entering the cafeteria, all of whom reported either washing their hands with lead removal soap or using Hygenall wipes (company policy required such hand hygiene before eating, drinking, smoking, or applying cosmetics) before we wiped their hands. Three of the 9 hand wipes from employees exiting the building during their shift for a smoking break were positive for lead. Only one of the 29 hand wipes we collected before the employee exited the plant after their shift was positive for lead; all these employees reported showering and using lead removal soap immediately before exiting.

Table 2. Hand wipe results (# positive*/# collected) by time and employee's department

Department	Before cafeteria entry	Before smoking	Exiting building	Total
Assembly/COS	6/12	2/6	1/14	9/32
Maintenance	2/4	0/1	0/7	2/12
Casting and pasting	3/7	0/0	0/5	3/12
Front office	2/3	1/1	0/1	3/5
Safety	0/1	0/1	0/2	0/4
Total	13/27	3/9	1/29	17/65

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

Area Air Samples

Results from area air samples for lead are summarized below in Table 3. Detailed results are in Appendix A, Table A3. Full-shift average results ranged from not detected to 8.6 micrograms per cubic meter (µg/m^3). Concentrations generally decreased the farther away the samples were collected from the main production floor exit to the nonproduction area. For example, the sample collected nearest the production employees' exit (by the hand washing sink) had a concentration of 8.6 µg/m^3, while the front office samples (the sample set collected farthest from the main production floor exit) had a mean concentration of 0.30 µg/m^3.

Table 3. Results from area air samples collected in nonproduction areas

Sample location	Number of samples	Mean (µg/m^3)	Range (µg/m^3)
Hand washing station	1	NA	8.6
Women's locker room	6	3.2	1.9–4.5
Cafeteria	6	1.2	0.2–2.9
Men's locker room	6	1.4	Not detected* to 3.4
Front office	6	0.30	Not detected* to 0.63

NA = not applicable

*The minimum detectable concentration was 0.13 µg/m^3.

We checked the direction of airflow at the door between the air shower tunnel and the nonproduction area hallway, at the door by the hand wash station leading to the production area near the storeroom PPE crib, and the front office doors leading to the production area (Figure 1). We also checked the airflow direction between the cafeteria and the nonproduction area hallway. On both days that we checked, the airflow direction was from the production area into the nonproduction area hallway right by the air tunnel door and the hand wash station door. This illustrates an airborne contaminant pathway for lead to leave the production area and migrate to the nonproduction area hallway, which connects to the locker rooms and cafeteria. The nearby cafeteria, however, was positively pressurized relative to the main nonproduction area hallway, which is preferred. The front offices were positively pressurized to the production area on 1 day, but negatively pressurized to it the next, indicating that air pressurization could vary and on occasion allow airborne lead to enter the offices from the production area.

Document Reviews

The company required all production employees to wear steel-toe boots, a company issued uniform (pants and shirt, or coveralls, supplied clean daily and laundered by an off-site service), hearing protection devices (ear muffs or moldable disposable ear plugs), and gloves appropriate for their task. They also required production employees to wear more task-specific PPE like aprons, disposable foot coverings or coveralls, or respirators (half-mask or hooded powered air purifying respirators with P100 filters) in some cases. Employees were not permitted to leave the production area with PPE (with the exception of their uniform) used in the production area. Reusable PPE such as gloves and respirators were returned to the respirator attendant in the supply crib to be cleaned. The respirator attendant was responsible for placing a clean respirator of the appropriate size in each employee's locker. To minimize skin contamination employees were required to wash their hands and face with lead removal soap prior to eating, drinking, smoking, or applying cosmetics. The company also required production employees to shower using lead removal soap and shampoo prior to departing at the end of their shift, and to leave their uniform in dirty laundry bins in the locker room.

The company's written health and safety programs identified the conditions under which employees must wear a respirator, get their BLL measured, and participate in personal air sampling. All production employees were enrolled in the company's respiratory protection program and were required to wear their respirator for the whole shift if:

- their most recent full-shift personal air sample result was 30 µg/m^3 or higher (until two subsequent personal air sample results collected at least 30 days apart were below 30 µg/m^3), or
- they had just transferred from a nonproduction job to a production job, or
- they had a BLL of ≥ 15 µg/dL (until two subsequent samples taken not less than 30 days apart were < 15 µg/dL), or
- they were within 90 days of starting work at the company and had not yet had two consecutive personal air sample results below 30 µg/m^3 and three BLLs below 15 µg/dL, or

- they were on the monthly schedule to have BLL measured but did not do so by the 15th of that month, or
- they were pregnant and had a BLL ≥ 10 µg/dL.

Using an OSHA-approved contract laboratory for BLL analyses, employees' BLLs were measured:

- monthly for 6 months if they were a new employee, or
- monthly if they had a BLL of ≥ 15 µg/dL the previous test, or
- monthly for 1 year if they had a BLL of 8–14 µg/dL and wore a respirator in the previous 12 months, or
- monthly if they were pregnant employees, or
- bimonthly if they had a BLL of 8–14 µg/dL, but were not in mandatory respirator wear in the previous 12 months, or
- every 4 months if they had a BLL of ≤ 7 µg/dL unless in mandatory respirator wear in the previous 12 months, in which case draws were every 2 months, or
- yearly if they were front office employees.

Over the course of any 24-hour period at the plant, up to three people might work at any one particular job site (each shift was 8 hours) performing essentially identical tasks. A personal air sample exceeding 30 $\mu g/m^3$ for one of those three individuals resulted in required full-shift respirator use only for that individual, but not for the other two individuals. However, all production employees were required to wear their respirator when they cleaned up their work area at the end of each shift.

The company selected employees to participate in personal air sampling on the basis of several factors. The company's corporate industrial hygiene department managed a lead exposure monitoring database and management system that prescribed sampling on a rotating basis for all job sites and shifts. The frequency of prescribed sampling for any one job site varied depending on past results, on the basis of requirements of the OSHA lead standard (29 CFR 1910.1025), and the company's own sampling objectives. Higher past results caused more frequent sampling in the future to attempt to document lowered exposures resulting from improvements in engineering and administrative controls and work practices implemented as a result of previous air sampling results.

The OSHA lead standard has minimum expectations with regard to the frequency of personal air sampling after an initial exposure found to exceed the action level (AL) of 30 $\mu g/m^3$ or the permissible exposure limit (PEL) of 50 $\mu g/m^3$ (the NIOSH recommended exposure limit is also 50 $\mu g/m^3$ [NIOSH 2010]). It requires follow-up exposure monitoring at least every 6 months if the initial exposure was between the AL and PEL, and at least quarterly if the initial exposure exceeded the PEL. In practice, the company often conducted follow-up exposure monitoring the next 2 months after an employee exposure exceeded the AL or the PEL. If an employee registered an exposure equal to or above the AL, the supervisor conducted air lead awareness counseling with the employee. The counseling consisted of questions asked of the employee seeking to help identify the work conditions, work practices, or personal habits that could have contributed to the exposure, and to solicit suggestions from the employee about what the company could do to help reduce future airborne exposures.

The company's BLL counseling program included topics on sources of lead, lead absorption, health effects of lead, medical removal protection, frequency of blood testing, protective measures, lead exposure and the family, medical surveillance program, and chelation. The company's daily employee checklist stated personal hygiene practices and made recommendations to prevent lead absorption (e.g., take multivitamin plus minerals every day and to add 1,000 milligrams of vitamin C to their diet). Employees having a BLL equal to or above 15 µg/dL, or exposed above the OSHA AL, also received coaching from their supervisor for 4 weeks following receipt of the triggering airborne exposure or BLL result. Each week's coaching focused on a different topic (hygiene, PPE, nutrition, work habits), retraining the employee on over 30 different specific behaviors for lowering exposure to lead.

Employee Medical Interviews

We gave the plant a list of 41 employees we wanted to interview, but 7 were not on site due to medical leave, retirement, or job termination and 9 were not available. We interviewed 23 of 25 employees who were available; two refused. Employees from the assembly/COS (n = 11) and casting and pasting (n = 12) departments participated in confidential medical interviews. Of the 23 employees, 78% were male, and the average age was 51 years (range: 32–64). Of those we interviewed the average length of employment with the company was 17 years (range: 3.5–33).

We asked employees to respond "yes" or "no" to a question regarding health conditions that could be associated with lead exposure. Eleven employees reported a doctor told them they had high blood pressure. In addition, we asked employees a final open-ended question regarding what, if any, health conditions or safety concerns they believed were related to their work. Eleven employees reported having a work-related health condition, mostly musculoskeletal-related, and eight employees reported having a safety concern. Safety concerns included lead exposure from dust generated when a plastic cover was lifted from tubs or when a forklift dropped off skids of parts at their work station. Other concerns included the need for replacement of vacuum hoses used to clean up work stations, dust collecting on machines, PPE cleaning and storage procedures, floor cleaning, the plastic wall dividing lead-contaminated and lead-free areas, and poor ventilation.

Respiratory Protection

Twenty-one employees reported wearing a half-mask air-purifying respirator, and two reported wearing a powered air-purifying respirator. Of the 23 employees, 11 reported wearing a respirator all day. The other 12 employees reported only wearing a respirator during clean ups, if they noticed a smell, if dust was airborne, or if the bag houses or ventilation were not working properly. One employee reported holding their breath when picking up plates. When asked how often they changed their filter cartridges, 14 employees reported they did not know, 3 reported every month, 2 reported daily, 2 reported every 2 or 3 months, and 2 were not applicable for the respirator type they used. When asked, all employees reported receiving respirator training and a fit test every year.

Other Personal Protective Equipment and Hygiene Practices

All employees stated they wore gloves (mostly nitrile) and safety glasses. Most employees reported usually cleaning their hands with either a lead removing soap (e.g., D-lead®) and/or "gritty" (pumice-containing) soap with water; employees also used Hygenall brand lead removing wipes. We asked how many times they washed their hands after handling materials (average of five times per shift). All employees reported washing their hands before eating, showering after their shift, and changing into clean clothes and shoes onsite after work. We asked employees about barriers to procedures for limiting their lead exposure. Some perceived managers encouraged them to get clean PPE less frequently than they wanted to. Others believed respirator cleaning by the tool crib operator could be improved, specifically the practice of returning cleaned respirators to employees with the respirator straps still wet. Other employees were dissatisfied with soap choices and a lack of hot water for hand washing.

Employee Focus Groups

BLL > 15 µg/dL Group

Six employees (four males) participated in the BLL > 15 µg/dL group. The average age was 47 years, and the average length of employment with the company was 13 years. Most of the participants were from the assembly/COS department, and some reported working in the casting and pasting department.

Is the BLL < 15 µg/dL of blood threshold achievable?

Most of the participants agreed that staying under the BLL < 15 µg/dL threshold was difficult, if not impossible to achieve. They believed this was mostly due to the work environment, which they perceived as being fully contaminated with lead. Participants agreed that proper PPE use and hygiene practices were not solely effective for reducing one's BLL.

What are contributing factors to having an elevated BLL?

Participants reported that the plant was not as clean as it had been in the past, particularly because of changes in the way they were required to clean their work areas. Employees no longer did dry floor sweeping when cleaning their work area(s). Employees were given high-efficiency particulate air filtered vacuums, which were perceived as ineffective and unreliable compared to the brooms they used in the past. Some employees did not wear respirators during cleanup, which was mandatory.

Some participants reported that the clean air supply vents were not in the correct position to blow air on them while they worked. They also expressed concerns about the overhead exhaust ventilation not working at times, and participants reported that it was difficult to get the ventilation fixed when it was not working properly, especially if facilities managers were assigned to address the problem as opposed to department maintenance.

Most participants believed the air shower, through which employees must walk to exit the production floor and enter the locker room hallway, was causing elevated BLLs. They stated they would hold their breath while walking through the air shower because they believed lead dust becomes airborne as they walk through the tunnel and the compressed air nozzles of the air shower blow dust off their uniform and the downdraft ventilation sucks the air through the floor grate and into the filter bank. Some participants reported that they avoided going through the air tunnel with others because they believed they would have been inhaling the lead blown off the person in front of them.

Most participants reported the perception that the employer discourages regular use of clean aprons and new disposable gloves to save money for the company. They also expressed concerns that changing footwear multiple times per day, as they must do when leaving or entering the production floor, increased lead exposure. Participants reported that respirators did not seem clean when they received them from the tool crib, and that they were often wet and smelled bad. They also had concerns that the respirator filter cartridges were not being changed enough, a responsibility of the tool crib attendant. Participants reported that, partly to refute these concerns, a former safety leader at the plant often told employees that the more clogged respirator filter cartridges get, the better they are at protecting the employees, which the employees believed was not true.

What is effective for reducing one's BLL?

Participants believed that the lead removal wipes were effective. They believed PPE was somewhat effective if used properly, but that it was not enough to fully protect oneself from lead exposure. Some employees reported that they believed there were individual differences in how people's bodies absorb and react to lead, which they believed may explain why some people were able to keep their BLL low with seemingly little effort.

Some participants reported that over-the-counter nutritional supplement use, particularly a chelating agent, ethylenediaminetetraacetate (EDTA), was common among employees. They believed EDTA pills were effective for reducing BLL, but were concerned about possible negative side effects or health outcomes from using them.

How well does the company train workers about lead exposure, health effects, and how to protect oneself?

Participants reported that the company showed them a training film on lead, but that the film was short (about 20 minutes) and vague. Employees were required to sign a document confirming that they viewed the film. The perception was that this process was in place to protect the company from long-term liability as opposed to protecting the employee from chronic low lead exposure.

What motivates you to wear a respirator at work?

All participants agreed that avoiding punishment from the employer was the greatest motivator for them to wear a respirator at work.

What do you think about take-home lead?

Participants agreed that take-home lead was a concern to them. Some participants discussed how they have tried to mitigate take-home lead by keeping their street clothes away from their work shoes/boots, keeping their clothes separate from family members' laundry, and double rinsing their washing machine after rinsing clothes they have worn to work.

BLL < 15 µg/dL Group

Six employees (three males) participated in the BLL < 15 µg/dL group. The average age was 45 years, and the average length of employment with the company was 6 years. All of the participants were from the assembly/COS department.

Is the BLL < 15 threshold achievable?

Participants agreed a BLL < 15 µg/dL is achievable, but that it takes focused effort by the individual, and may be more difficult for employees doing certain jobs, such as stacking.

What are contributing factors to having an elevated BLL?

Most participants believed that ineffective hand washing, not showering or just rinsing off after a shift, and poor nutrition were contributing factors to an elevated BLL. Other perceived contributing factors included not wearing a respirator during cleanup, touching work shoes with bare hands, and other "reckless" behaviors that caused clouds of lead dust to become airborne.

Participants also reported problems with the water pressure of some of the sinks and showers. The three sinks directly outside of the air shower were mentioned specifically. Female participants noted that the sinks in the women's bathroom have handles, which may cause recontamination of the hands when turning the water off with clean hands. They also reported that some of the shower heads were missing in the women's showers, which limited the number of showers that could be used. Male participants reported that there were sinks that they liked in the men's locker room that have foot pedals, so they could wash their hands and arms.

Participants believed that overall, BLLs went up when the company changed the cleanup policy from floor sweeping to using high-efficiency particulate air filtered vacuums. They believed the central vacuum lines used to clean up each work station were ineffective and would break easily.

What is effective for reducing one's BLL?

Participants had a variety of responses to this question, including:

- Shower every day, and scrub with lead removal soap.
- Use lead removal wipes and be careful not to get lead on the top of the container when removing them.
- Eat throughout the day and drink a lot of fluids.
- Take multivitamins and other nutritional supplements, but not EDTA pills.
- Do not carry a pen or other items that may get contaminated as you work.
- Use a scrub brush when washing hands.
- Wear a respirator during work station cleanup.
- Wash your own respirator before use.

- Be careful not to do anything that may cause lead dust to become airborne, such as throwing things on the ground.
- Hold your breath and run through the air shower.
- Wear nitrile gloves when handling your work shoes/clothing.
- Avoid take-home lead.
- Use lead soap and laundry detergent at home.
- Wear a new apron daily, and change nitrile gloves often.

How well does the company train workers about lead exposure, health effects, and how to protect oneself?

Most participants thought the training video contained sufficient information on how to protect oneself from lead exposure. However, some noted that new employees did not seem to be getting the message of how harmful lead exposure could be.

What motivates you to wear a respirator at work?

Participants mentioned taking care of themselves, their families, and their pets as main motivators for wearing a respirator and taking care to keep their BLL low.

What do you think about take-home lead?

Participants believed take-home lead was a concern, and that following the company's guidelines for reducing take-home lead was important. They believed that showering and careful handling and separation of street clothes from work clothes were helpful for reducing take-home lead. They believed that once home, taking shoes off at the door and keeping them away from main areas of the house and other people's shoes was important. Another recommendation was to consistently store work items in a bag, and keep it in a safe place in the house, away from children and pets. Finally, they believed that the company should hire more janitors to clean the showers and locker rooms, particularly the women's locker room, which did not have a janitor for all shifts.

Company Air Sample Results

Evaluating company airborne lead exposures was not our focus during this evaluation. We did however, need to establish whether airborne overexposures occurred in production areas, so that we would have a better frame of reference with which to consider historic BLLs. The company's data set from 2012–2014 had more than 1,300 full-shift personal air sample results in it. These samples showed that all production departments had some employees exposed above the OSHA AL and PEL. The casting and pasting department had the highest exposures recorded, with strip casters and scrap coordinators working there having exposures above 100 $\mu g/m^3$ (437 $\mu g/m^3$ was the highest). Nonproduction departments (safety, quality, front office) had no exposures above the AL.

Company Blood Lead Levels

All 23 employees we interviewed were aware of their most recent individual BLL test results. None of them reported they had been given a medication such as a dietary supplement to lower their BLL. However, some employees reported taking calcium pills, natural chelating agents, vitamin C, or ascorbic acid (recommended in company provided training), and drinking distilled water and/or cranberry juice on their own because they thought would help lower their BLLs and/or it was recommended by the employer (vitamins and diet). When we asked employees how they kept their BLL low, all reported they did so by hand washing, showering, laundering clothes, and wearing PPE at the worksite. In our BLL analyses for the years 2011–2014, we used the Centers for Disease Control and Prevention (CDC)/NIOSH case definition for an elevated BLL, which at that time of our first visit was ≥ 10 µg/dL. Descriptive statistics of the BLL data collected from the plant included the following:

Table 4. Employee BLLs

Year*	No. of employees†	% of employees having at least one BLL ≥ 10 µg/dL	Average BLLs (µg/dL)
2011	478	82%	12
2012	482	82%	11
2013	465	83%	11
2014	433	77%	10

*BLLs for these years ranged from < 1–40 µg/dL.

†Number of employees who contributed at least one BLL each year.

We calculated BLL averages by year, by year and quarter, and by year and department. To calculate these averages, we used a single measure (the mean) for each participant within these groupings. This was done because participants with higher BLLs tended to have more blood lead tests and would have been overrepresented in the averages for the periods and departments. Figure 2 shows the average BLLs of the individual means were ≥ 10 µg/dL, for all quarters and years evaluated.

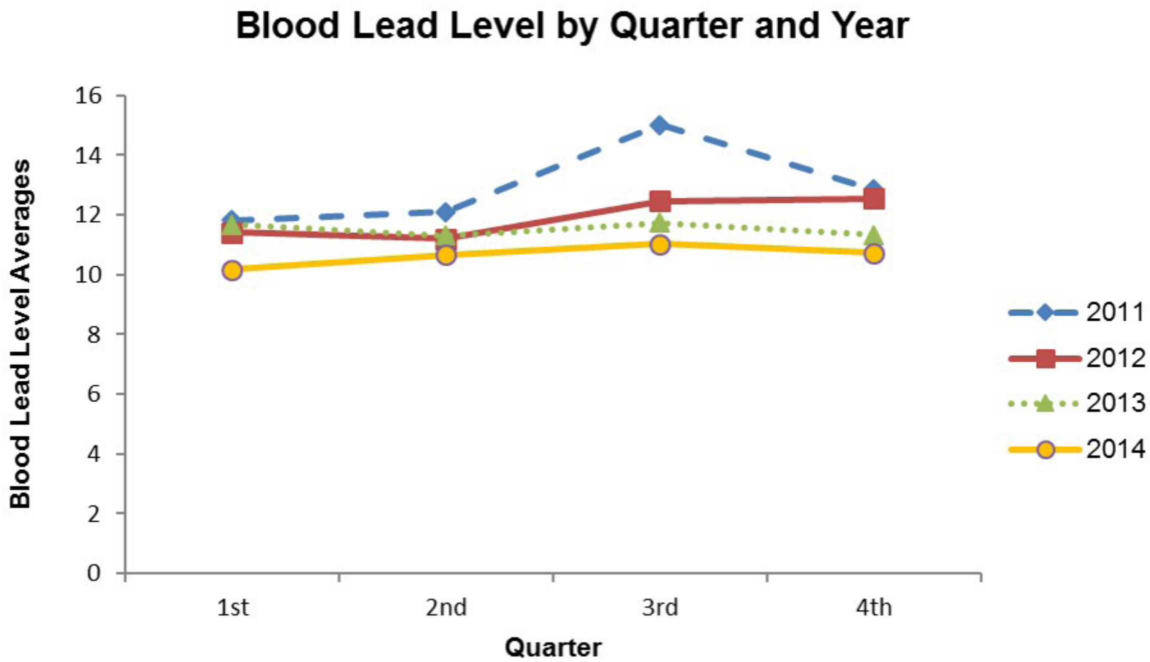

Figure 2. Average employee BLLs of the individual means for January 2011–December 2014 by quarter and year. Average BLLs of the individual means were ≥ 10 µg/dL for all quarters and years with possible spikes during the third quarter (July/August/September) for all years, though overall BLL averages declined over the years.

Figure 3 shows the maintenance department (plant wide) had the highest average BLLs of the individual means each year.

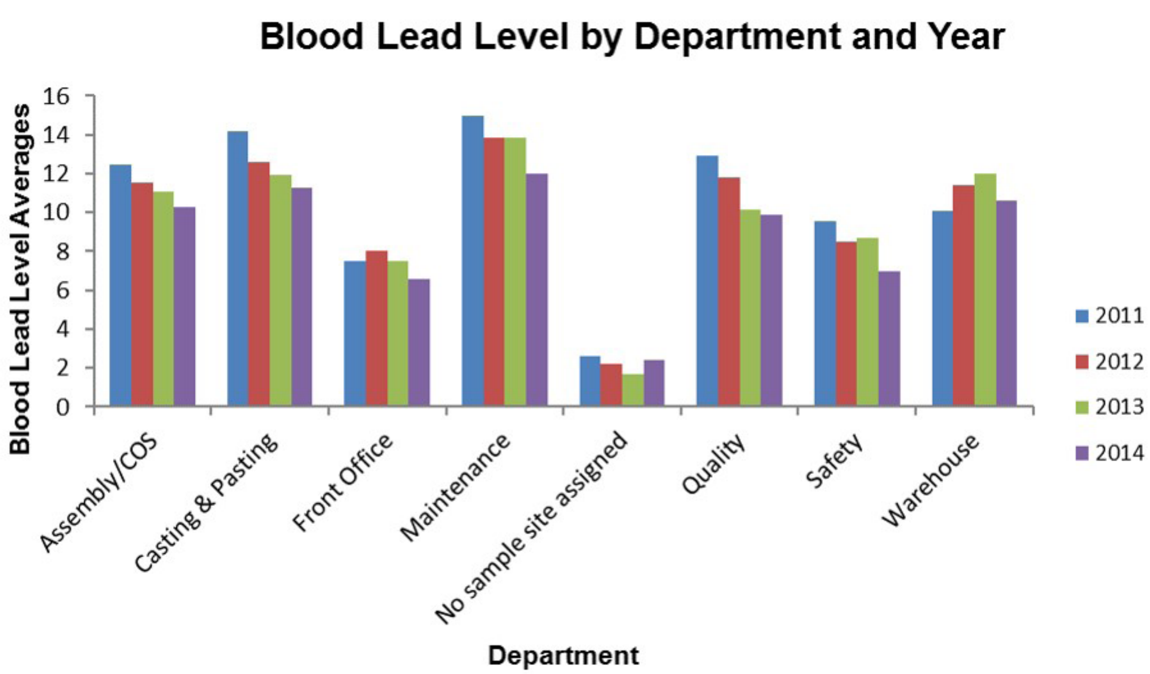

Figure 3. Average employee BLLs of the individual means for January 2011–December 2014 by department and year. Some employees were represented in more than one department. The maintenance department (plant wide) had the highest average BLL of the individual means for all years.

The maximum BLL measured was 40 µg/dL in 2011, 37 µg/dL in 2012, 39 µg/dL in 2013, and 26 µg/dL in 2014. Table 5 shows the distributions of employees' maximum BLLs within each department and year. All departments from January 2011–December 2014 had maximum BLLs of ≥ 10 µg/dL. Of 23 interviewed employees, 13 had maximum BLLs ≥ 10 µg/dL from January 1, 2014–March 12, 2014 (3 months before and at the time of our first visit).

The company was only legally required to follow OSHA's medical removal criteria (average BLL is ≥ 50 µg/dL); however, if the company had followed the updated guidelines for medical removal as referenced in the Kosnett et al. [2007] criteria, more employees would have been medically removed from exposure. Assembly/COS department had the highest number of employees who would have met those criteria to be medically removed from exposure in 2011. The criteria to be met included a repeat BLL measured in 4 weeks that remained ≥ 20 µg/dL or if any BLL was ≥ 30 µg/dL. The maintenance department (plant wide) had the highest number of employees that would have met those criteria in 2014 (Table 5).

Of note, we defined 4 weeks as 28–36 days. The half-life of lead in human adult blood has been estimated to be 28 days [Griffin et al. 1975] to 36–40 days in adult males [Rabinowitz et al. 1976]. Furthermore, BLLs may have decreased after a repeat measure ≥ 20 µg/dL, indicating that the employee may have been removed, for any reason, from a short-term exposure or because of individual variability. Individual variability may have included changes of exposure, mobilization of lead, administration of tests, and/or lab variability. In addition, some employees may not have had a repeat BLL measure and in that case they were not included in this particular analysis.

Table 5. Employees' **maximum*** BLLs by department and year, January 2011–December 2014

Department	Year	N	< 10 µg/dL No. (%)	10–19 µg/dL No. (%)	≥ 20 µg/dL No. (%)	Medical removal† No.
Assembly/ COS	2011	305	44 (14)	181 (59)	80 (26)	21
	2012	299	42 (14)	230 (77)	27 (9)	1
	2013	284	40 (14)	227 (80)	17 (6)	1
	2014	253	44 (17)	204 (81)	5 (2)	1
Casting and pasting	2011	80	13 (16)	30 (38)	37 (46)	12
	2012	84	12 (14)	53 (63)	19 (23)	6
	2013	81	11 (14)	59 (73)	11 (14)	3
	2014	76	13 (17)	56 (74)	7 (9)	0
Maintenance	2011	30	0 (0)	23 (77)	7 (23)	7
	2012	36	3 (8)	22 (61)	11 (31)	5
	2013	32	0 (0)	23 (72)	9 (28)	4
	2014	37	6 (16)	21 (57)	10 (27)	6
Warehouse/ forklift	2011	28	9 (32)	17 (61)	2 (7)	0
	2012	28	3 (11)	22 (79)	3 (11)	1
	2013	28	2 (7)	26 (93)	0 (0)	0
	2014	25	3 (12)	22 (88)	0 (0)	0
Safety	2011	11	3 (27)	7 (64)	1 (9)	1
	2012	11	4 (36)	7 (64)	0 (0)	0
	2013	11	5 (45)	5 (45)	1 (9)	0
	2014	13	7 (54)	6 (46)	0 (0)	0
Front office	2011	29	17 (59)	12 (41)	0 (0)	0
	2012	28	17 (61)	10 (36)	1 (4)	1
	2013	29	17 (59)	10 (34)	2 (7)	0
	2014	29	19 (66)	9 (31)	1 (3)	0
Quality	2011	6	1 (17)	4 (67)	1 (17)	0
	2012	5	1 (20)	4 (80)	0 (0)	0
	2013	6	1 (17)	5 (83)	0 (0)	0
	2014	6	2 (33)	4 (67)	0 (0)	0
No sample site‡	2011	61	58 (95)	3 (5)	0 (0)	0
	2012	39	39 (100)	0 (0)	0 (0)	0
	2013	17	17 (100)	0 (0)	0 (0)	0
	2014	36	36 (100)	0 (0)	0 (0)	0

*Calculated using maximum BLL for each employee within each department and year.

†Of those with a repeat BLL measured in 4 weeks that remained ≥ 20 µg/dL or if any BLL was ≥ 30 µg/dL on the basis of Kosnett et al. 2007 medical removal criteria.

‡A sample site was not assigned to these employees at the time of the BLL collection.

Logs of Injuries and Illnesses

Thirteen entries were reported on the OSHA Logs for 2011–2014. Lacerations were the most commonly reported event, accounting for about 46% of all injuries. No incidents of lead poisoning or standard threshold shifts were recorded.

Other Observations

Several procedural changes implemented to reduce the potential for take-home lead occurred between our two visits to the plant. During our first visit, employees donned and doffed their uniform and boots in the locker room where they also stored their street clothes. When they left the production floor, they had access to vacuum hoses and electric boot dusters right by the main production area exit. Employees were not required to use these tools, and most employees we observed did not use them before exiting the production area. By the time of our second visit, the company required employees to doff their work boots and don rubber clogs while still in the production area (Figure 4), and then exit to the locker room area through an Escha Tech Inc. downdraft air tunnel (Figure 5). This air tunnel had pressurized directional airflow nozzles designed to lift contaminants off occupants and move them downward though floor grilles before recirculating the air to the tunnel through high-efficiency particulate air filters. The manufacturer recommended that people spend a minimum of 15 seconds passing through the tunnel to allow enough lead removal from their clothes, skin, and hair, but we observed many employees walking through much faster.

Figure 4. Changing station for boots and clogs. Photo by NIOSH.

Figure 5. Air shower tunnel viewed from production area into nonproduction area hallway. Photo by NIOSH.

Several other observations related to respirator use may affect employee lead exposure. A production employee in the ball mill area (a section of the casting and pasting department) wearing a half-mask elastomeric tight-fitting facepiece respirator with P100 filters had facial hair that prevented a good seal between the respirator and the user's face. Several respirator users replied to our questions that they were unsure how often they were supposed to exchange their used filter cartridges for new ones. The bag holding respirators in the storeroom respirator washing machine seemed stuffed full to or perhaps beyond capacity, which may inhibit the machine's ability to rinse away lead-containing washing solution.

Discussion

A health hazard existed from lead in this workplace. The company's evidence of historic personal air sampling data, which documented overexposures in all production departments, bears this out and establishes the need for improving ongoing exposure control measures. Using respiratory protection remains a necessary step to mitigate overexposures until permanent engineering controls are implemented. Respirators used at this plant were sufficiently protective against the documented concentrations of airborne lead. However, the company practice of not requiring respirator use for all people staffing a job site where one personal air sample was above 30 $\mu g/m^3$ may result in the other employees staffing that job site also to be exposed above 30 $\mu g/m^3$.

The area air and surface samples we collected were positive for lead in areas and from surfaces previously thought of as clean. The area air samples we collected and the air pressurization problems we found between production and nonproduction areas indicated airborne lead exposure. The likelihood for take-home lead on hands seemed small, based on the results of our hand wipes. Some employees had detectable amounts of lead on their hands as they came into the cafeteria. We found lead on surfaces in clean nonproduction areas of the plant, but not on the tabletops in the cafeteria. The presence of lead on cleaned respirators indicates the potential for cross-contamination if hand hygiene practices are not effective.

The area air and surface wipe samples we collected in the locker rooms indicated the potential for continued exposure. The addition of the air tunnel and changing into clog footwear (and preventing dirty boots from leaving the production area) prior to entering nonproduction areas should help reduce take-home lead and exposures in nonproduction areas. However, using a single locker room to doff dirty work uniforms and dress in street clothes could result in cross-contamination lead exposures. Having a unidirectional flow of employees from a uniform doffing area, through the showers, to a clean area where they can don street clothes is better suited to preventing additional exposure in the locker rooms and subsequent take-home lead.

Of the interviewed employees, over half had maximum BLLs ≥ 10 µg/dL (3 months before and at the time of our visit). Although, the interviewed employees were unlikely to exhibit symptoms associated with lead exposure at the levels reported, there is evidence that chronic lead exposure may have some impact on health, such as hypertension (high blood pressure), adverse effects on renal function, cognitive dysfunction, and reproductive outcomes [CDPH 2009]. More information on acute and chronic health effects of lead is in Appendix B.

During this evaluation, both employees and managers asked us about whether the role of prophylactic use (preventive use) of chelation therapy would be of value. Prophylactic chelation therapy of lead-exposed employees to prevent elevated BLLs or to routinely lower BLLs, is prohibited by OSHA [29 CFR 1926.62]. Using over the counter synthetic or natural chelating products as preventive measures are not advised or safe. NIOSH and other CDC Centers currently do not make any interventional dietary recommendations for lead-exposed workers.

The focus groups revealed markedly different perceptions by the participants of one's ability to minimize lead exposure. The individuals who were grouped with those with BLL less than 15 µg/dL expressed greater confidence in their ability to control their lead exposure, offered more suggestions for how to reduce lead exposure, and were motivated to reduce lead exposure for their own health and that of their families. In comparison, the individuals grouped with those who had BLL of greater than 15 µg/dL expressed a defeatist attitude about their own ability to control lead exposure, offered few suggestions for controlling the exposure (including use of potentially dangerous chelation supplements), and were mainly motivated to try to reduce lead exposure as a means of avoiding what they perceived as punishment (i.e., mandatory respirator use) rather than protecting their own health and the health of others.

Although the focus groups represented a small proportion of the total workforce (about 3%) and the results are not generalizable to the entire workforce, the results are useful in identifying a potential need for improvement, particularly in terms of changing some employees' beliefs about their ability to reduce their own lead exposure. One method for improving people's confidence in reaching a goal is to have employee "champions" who have met the goal share their successes with their coworkers through personal testimonies of what behaviors are effective in reducing lead exposure, and to intervene, coach, and show support for their coworkers. Employees will be more likely to engage in behaviors to reduce their lead exposure if (1) they believe such behaviors are effective, (2) they have the resources and ability to engage in the behaviors, and (3) they perceive social pressure to engage in the behavior [Ajzen 1991; Armitage and Conner 2001].

In response to the question, "What are contributing factors to having an elevated BLL?" individuals grouped with those who had BLL of greater than 15 µg/dL expressed concerns that the respirator filter cartridges were not being changed enough, a responsibility of the tool crib attendant. Furthermore, partly to refute these concerns, a former safety leader at the plant apparently told employees that the more clogged respirator filter cartridges get, the better they are at protecting the employees. We note here such a statement about respirator filter cartridges is only partly true, and may be misleading with regard to the protection provided by the respirator. Presuming the respirator is properly worn by a trained user, the protection provided to the user would not increase beyond the point where the filter becomes so clogged that the contaminated air of the workplace more easily passes through leaks in the mask or facepiece seal rather than through the filter. The point at which this occurs is unknowable by the user. As a result, respirator users should not be encouraged to continue using respirator filter cartridges in hopes that greater filter cartridge clogging yields better protection.

Conclusions

The average BLLs of employees' means were ≥ 10 µg/dL, though the company overall BLL averages declined over the years for which we reviewed data. Surface and hand wipe results and area air sample results showed continued exposure potential in supposedly clean areas, though potential for take-home lead seemed small on the basis of all the clean hand wipes collected as people exited at the end of their shift. Opportunities to minimize lead dust exposure remained in optimizing locker room layout, better maintaining positive air pressurization in clean nonproduction areas, and potentially requiring respirator use for all employees at a job site where an exposure above the OSHA AL (the level at which the company requires respiratory protection) has occurred. When prioritizing resources to enable reducing BLLs, the company air sample data and our own wipe sample data suggested that minimizing direct production related exposures remained crucial to overall BLL reduction efforts. More reliable means of exposure control ultimately will yield better results than relying so much on emphasizing individual workers' practices such as dietary practices, though we do recognize the critical importance of workers being intentional about protecting themselves and others from exposure by consistently following safe work practices.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the battery manufacturing company 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 this plant.

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 PPE may be needed.

Engineering Controls

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

1. Improve containment and exhaust ventilation at all work stations where airborne overexposures occur.
2. Redesign the locker rooms so that employees have a unidirectional flow from where they doff their uniforms, proceed into the showers, and emerge on the other side to don clean clothing. Prevent staff from re-entering the "dirty side" of the locker rooms unless they again exit and shower.
3. Install foot pedal controls on sinks and water fountains in locker rooms that do not already have them.
4. Install a constant, visual indicator of relative air pressurization between nonproduction areas and production areas. This way if general ventilation fails to keep clean areas under positive pressurization relative to production areas, building maintenance can take immediate corrective action.

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. Recognize that the OSHA lead standard [29 CFR Part 1910.1025] and the NIOSH recommended exposure limit do not protect employees from all adverse health effects from lead exposure. We encourage taking the additional measures identified in this report and to pursue lowering employees' BLLs < 5 µg/dL on the basis of the current CDC/NIOSH surveillance case definition.
2. Follow the guidelines in Appendix B in addition to complying with the OSHA medical surveillance requirements for preplacement.
    - Recommendations for medical surveillance using BLL, including guidance on removal from lead exposure, are presented in Table B2 in Appendix B. Medical removal could be accomplished by having the employee work in an area that does

not involve the potential for production-related lead exposure, where the lead exposure would be expected to be markedly reduced. The employee should retain full pay and benefits rather than filing for workers' compensation.

3. Ensure that employees exiting the production area through the air shower spend the manufacturer recommended amount of time walking through.

4. Ensure that all employees on all shifts whose job site yields an airborne overexposure wear a respirator at that job site until either engineering controls can reduce exposures below the exposure limit, or a post-exposure investigation identifies and eliminates the factors causing the overexposure. Evaluate whether employees at adjacent job sites might be similarly exposed and also in need of respiratory protection.

5. Encourage employees to report potential work-related health and safety concerns to their supervisors. Employees with persistent symptoms should promptly seek medical attention from a healthcare provider who is knowledgeable in occupational medicine.

6. Discourage self-administered chelation therapy. Post information signage in employee break rooms, lunch rooms, restrooms, and public spaces that inform employees that using over-the-counter synthetic or natural chelating products are not safe, no scientific evidence supports chelation, and that OSHA prohibits the use of chelation agents.

7. Use the focus group results to guide further efforts to understand and address gaps in employees' perceptions of lead exposure management and the dangers of take-home lead. Doing so may help the employer address employee misconceptions and improve their confidence in achieving and maintaining a low BLL.

8. Identify employees who can advocate for behaviors to reduce other's BLLs. Provide these employee champions with information regarding the benefits of minimizing lead exposure and tips for reducing exposure, and encourage these employee champions to share this information throughout the workplace. This has been shown to be effective in increasing influenza vaccination rates among healthcare personnel [Slaunwhite et al. 2009].

9. Encourage employees to engage in behaviors to reduce their lead exposure by including messages on signage in highly visible areas, in emails, and company newsletters. Messages should be encouraging and highlight motivators such as protecting their own health and that of family members. Examples of messages include, "To protect your health and your family, take a shower with deleading soap at the end of your shift," and "Protect yourself and your family by reducing take-home lead. Keep your work clothes and shoes separate from other laundry!"

10. Offer employees the NIOSH publication "Protect Your Family: Reduce Contamination at Home," which provides general information on preventing employees from unknowingly taking hazardous substances home on their clothes, bodies, or other items. The document can be found at http://www.cdc.gov/niosh/docs/97-125/.

Personal Protective Equipment

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

1. Consult employees to ensure that they are using the respirators properly. For example, tight-fitting respirators must not be worn if facial hair interferes with the respirator's seal on their face. Communicate and share with employees about how often the filter cartridges should be changed in a filter cartridge change-out schedule, then enforce the change-out schedule.
2. Determine the maximum number of respirators that may be washed in the storeroom washing machine while still yielding negative surface wipe lead results on those respirators. Experimenting with an additional lead removing soap and/or rinse cycle may be necessary. Encourage employees to wipe out their respirator prior to donning it.

Recommendation for Employees:

1. Volunteer to be a low BLL champion, and educate and encourage your coworkers to engage in behaviors to reduce their lead exposure.
2. Tell your supervisor if you have any work-related health and/or safety concerns.
3. Do not take lead chelating agents unless directed to do so by your doctor.
4. Be diligent in the locker room to avoid contaminating clean clothing and skin with potentially lead contaminated uniforms nearby. If safely possible, avoid sitting on locker room benches and chairs prior to disrobing used uniforms.
5. Tell your doctor that you work with lead and give them a copy of this report.

Appendix A: Tables

Table A1. Surface wipe sampling results for nonproduction areas

General location	Specific location	Qualitative result	Micrograms of lead/100 cm^2
Hallway	Floor at exit of air shower	++	550
	Tabletop near exit of air shower	+	29
	Building exit turnstile bar	++	Not applicable
	Building entrance turnstile bar	++	Not applicable
Men's locker room	Floor in front of a locker	++	540
	Bench seat in front of lockers	++	350
	Bench seat in front of lockers	++	330
	Floor in front of dirty uniforms bin	++	330
	Outside of locker door	++	85
	Outside of locker door	+	30
	Floor of shower	+	25
	Inside of locker door	+	24
	Inside of locker door	+	8.3
Women's locker rooms	Chair	++	94
	Chair	++	50
	Chair	++	20
	Outside of locker door	++	19
	Inside of locker door	++	11
	Inside of locker door	+	8.2
Cafeteria	Floor in front of microwave	++	260
	Chair seat	++	140
	Chair seat	++	84
	Floor in front of microwave right after mopped	+	23
	Tabletop	-	1.4
	Vending machine	-	0.8
	Tabletop	-	0.63
Front offices	Mailroom countertop	++	600
	Floor in front of restrooms	++	110
	Large conference room tabletop	++	45
	Small conference room tabletop	+	26
	Door on mini-fridge	+	9.5
	Office desktop	-	4.2
	Cubicle desktop	-	3.2
	Office desktop	-	3.2
	Cabinet next to restrooms	-	2.1

Qualitative result: ++ (full to brilliant color change), + (faint but distinct color change), - (no visible color change)

Table A2. Surface wipe sample results for production areas

General location	Specific location	Qualitative result	Micrograms of lead/100 cm^2
Main production floor	Floor in front of clog bins	++	2,900
	Bottom of a clog bin	++	2,000
	Floor of air shower	++	280
	Tabletop between respirator lockers	++	120
	Bench seat in front of clog bins	++	93
	Office desktop	++	Not analyzed
	Office cabinet top	++	Not analyzed
Stores	Floor by washing machine	++	Not analyzed
	Washing machine cylinder	+	Not analyzed
	Respirator dryer	++	Not analyzed
	Inside glove washer	++	Not analyzed
	Bag of respirators inside washing machine	-	Not analyzed
	Bagged set of respirator filters	+	Not analyzed
	"Clean" respirator after washing in bag	+	Not analyzed
	"Clean" respirator after washing without bag	+	Not analyzed
	Respirator	+	Not analyzed
	Respirator	+	Not analyzed
	Powered air purifying respirator after cleaning	++	Not analyzed
	Glove after washing	++	Not analyzed
	Tabletop	-	Not analyzed
	Main window countertop	+	Not analyzed

Qualitative result: ++ (full to brilliant color change), + (faint but distinct color change), - (no visible color change)

Table A3. Complete list of area air sample results for nonproduction areas

Date	Sample location	Sample duration (minutes)	Lead concentration (µg/m³)
Day 1	Women's locker room, south end by entrance	514	4.5
	Men's locker room, 1st uniform drop area, west end	517	3.4*
	Cafeteria, on ice machine	525	2.9
	Women's locker room, north end by showers	513	2.8
	Office area, book shelf	447	[0.34]*
	Cafeteria, center long table	526	[0.20]
	Office area, by pillar	529	Not detected†
	Men's locker room far end, east end, 2nd uniform drop area	517	Not detected†
Day 2	Women's locker room south end	514	3.4
	Cafeteria on ice machine	523	2
	Women's locker room north end	515	1.9
	Men's locker room west end	520	1.8
	Cafeteria center table	525	0.72
	Men's locker room east end	350	[0.68]
	Office area by receptionist	528	[0.29]*
	Office area by mail room	527	[0.19]
Day 3	Handwashing station	481	8.6
	Women's locker room near door	480	4.2
	Women's locker room shower area	480	2.6
	Men's locker room entrance	483	2.4
	Cafeteria by ice machine	391	2.2
	Office area near receptionist	483	0.63
	Cafeteria table	483	0.76*
	Men's locker room, far end	479	[0.34]
	Office area, back cabinet	484	[0.15]

[ ] = Result fell between the minimum detectable concentration (ranging from 0.13 to 0.19 µg/m³, on the basis of sample volume for each sample) and the minimum quantifiable concentration (ranging from 0.56 to 0.8 µg/m³ on the basis of sample volume for each sample), and has more uncertainty associated with it.

*Sampling pump postcalibration flow rate more than 5% different from precalibration value, so table result is semiquantitative.

†The minimum detectable concentration was 0.13 milligrams per cubic meter.

Appendix B: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended Occupational Exposure Limits (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 time-weighted average (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 recommended exposure limits 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 recommended exposure limits 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, PPE, 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 American Conference of Governmental Industrial Hygienists threshold limit values. The threshold limit values are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. Threshold limit values 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) PPE (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 [CDC 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 µg/dL of whole blood in 1999–2000 to 1.09 µg/dL in 2011–2012 [CDC 2015a]. OSHA recommends a level of 40 µg/dL for workers to maintain at or below over their lifetime [29 CFR Part 1910.1025]. From 2009 until November 2015, CDC/NIOSH Adult Blood Lead Epidemiology Surveillance System used a surveillance case definition for an elevated BLL of $\geq$ 10 µg/dL in adults. In December 2015, $\geq$ 5 µg/dL was defined as an elevated BLL in adults [CDC 2015b]. Very high BLLs are defined as BLLs $\geq$ 40 µg/dL. From 2002–2011, occupational exposures accounted for 91% of adults with very high BLLs (where exposure source was known) [CDC 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 AL 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 recommended exposure limit for lead of 50 µg/m^3 averaged over an 8-hour work shift [NIOSH 2010]. The American Conference of Governmental Industrial Hygienists has a threshold limit value for lead of 50 µg/m^3 (8-hour TWA), with worker BLLs to be controlled to, or below, 20 µg/dL. The American Conference of Governmental Industrial Hygienists designates lead as an animal carcinogen [ACGIH 2017]. 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, recommended exposure limit, and threshold limit value may prevent overt symptoms of lead poisoning, but do not protect workers from lead's contributions to conditions such as hypertension, renal dysfunction, and 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 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 [IARC 2006]. According to the American Cancer Society [American Cancer Society 2014], 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, “Workplace Lead Exposure,” which reinforces the guidelines and recommendations above [Holland and Cawthorn 2016]. Table B2 incorporates recommendations from the expert panel guidelines and those from CDPH, ACOEM, and CSTE.

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 < 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, 2015, 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 [CDC 2009, 2012].

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.

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