Evaluation of Lead and Isocyanate Exposure in a Maintenance Facility with Small Arms Repair and Vehicle Painting Shops

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Contents

Highlights....i

Abbreviations iii

Introduction 1

Methods 1

Results and Discussion 4

Conclusions 11

Recommendations.... 12

Appendix A 15

References.... 26

Acknowledgements.... 33

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

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

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a small arms repair and vehicle maintenance facility. A manager was concerned about airborne lead exposure and take-home lead exposures in the small arms repair shop. The manager was also concerned about employees' exposures to hazardous painting products, including isocyanates, in the vehicle painting shop.

What We Did

- We evaluated lead exposures in the small arms repair shop in May 2016.
- We collected personal air, hand, and surface wipe samples for lead.
- We collected blood to evaluate employee blood lead levels.
- We evaluated the ventilation of the single-lane firing range in the small arms repair shop.
- We evaluated hexamethylene diisocyante exposures in the vehicle spray painting shop in January 2017.
- We collected personal air samples for hexamethylene diisocyanate.
- We tested the employees' blood to look for isocyanate exposure and sensitization.
- We evaluated the ventilation system of the spray paint booth in the vehicle spray painting shop.

We evaluated exposures to lead at a small arms repair shop and hexamethylene diisocyanate at a vehicle painting shop. We found lead on employees' hands after they had washed them, and one employee had an elevated blood lead level. We found hexamethylene diisocyanate in the air in the spray paint shop, and one employee had a blood test which showed antibodies to a specific isocyanate (isophorone diisocyanate) in the paint. We recommended that the employer provide employees with a lead removal product to wash their hands and work surfaces inside the small arms repair shop, and that employees wear nitrile gloves while repairing firearms. We also recommended that the employer provide employees with eye and face protection while spray painting vehicles, and that they provide appropriately-sized protective suits.

What We Found

- We detected no lead in the personal air samples.
- We found some lead on the employees' hands after they washed them with soap and water.
- One employee had an elevated blood lead level.
- The firing line of the range had turbulent airflow, creating irregular mixing of air that can deposit lead particles on surfaces randomly and unpredictably.
- We found hexamethylene diisocyanate in personal air samples of the employees spray painting military vehicles.
- One employee had a blood test which showed antibodies to a specific isocyanate in the paint. This meant they had been exposed to that isocyanate, despite protective measures.

- The spray paint booth had missing and damaged filters and did not adequately remove paint overspray from the breathing zone of the employees.
- Personal protective equipment was stored in the spray paint preparation area.
- Personal protective equipment was not available in large enough sizes to fit all employees.

What the Employer Can Do

- Reduce air turbulence at the firing line of the firing range by maintaining air velocity between 50–75 feet per minute.
- Provide employees with a specific soap designed to remove lead from skin.
- Test employees' blood for lead every 6 months.
- Identify and use paints that do not contain isocyanates to paint military vehicles, such as polysiloxane coatings.
- Replace missing or damaged filters in the spray paint booth.
- Replace the spray paint booth with a downdraft ventilation paint booth where filtered air enters at the ceiling and is drawn through to the floor.
- Start a medical surveillance program for employees who are exposed to isocyanates.
- Refer any employee with cough, shortness of breath, or wheezing to an occupational medicine physician or other physician who is familiar with the health effects of isocyanate exposure.
- Store personal protective equipment outside of the spray paint preparation area.
- Require employees to wear nitrile gloves while repairing firearms.
- Purchase protective suits in sizes that fit all employees.

What Employees Can Do

- Use a lead removing soap to wash hands and contaminated surfaces inside the small arms repair shop.
- Wear nitrile gloves while repairing firearms.
- Wear eye and face protection while spraying with paints that contain isocyanates.
- Store respirators away from sunlight, dust, and potentially damaging chemicals, in nonporous, sturdy, airtight containers.

Abbreviations

µg	Microgram
µg/100 cm^2	Micrograms per 100 square centimeters
µg/m^3	Micrograms per cubic meter
µg/dL	Microgram per deciliter
ACGIH®	American Conference of Governmental Industrial Hygienists
BLL	Blood lead level
CFR	Code of Federal Regulations
HDI	Hexamethylene diisocyanate
IPDI	Isophorone diisocyanate
IgE	Immunoglobulin E
IgG	Immunoglobulin G
MERV	Minimum efficiency reporting value
mg/m^3	Milligrams per cubic meter
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
ppm	Parts per million
PPE	Personal protective equipment
REL	Recommended exposure limit
STEL	Short-term exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average

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Introduction

The Health Hazard Evaluation Program received a request for an evaluation from a manager of a military maintenance facility with small arms repair and vehicle maintenance shops. The requestor was concerned primarily about airborne lead exposures as well as take-home lead exposures in the small arms repair shop. The requestor was also concerned about exposures to hazardous painting products, including isocyanates, at the vehicle painting shop and exposures to crystalline silica from abrasive blasting. We visited the shops in May 2016 and January 2017. We sent summary letters with preliminary recommendations in June 2016 and February 2017.

Description of Facility

This maintenance facility consisted of five different buildings and seven different shops, including the small arms repair shop and military vehicle painting shop. The small arms repair shop had a one-lane indoor firing range, a parts washer, three firearms repair tables, and a locked firearms vault. Three employees received firearms and repaired them. The military vehicle painting shop consisted of an abrasive blasting booth and a spray painting booth. Four employees removed old paint from and repainted military vehicles.

Methods

The objectives of this evaluation were to:

1. Determine the extent and routes of exposure to lead in the small arms repair shop and make recommendations to reduce employee exposures
2. Determine the extent and routes of exposure to isocyanates in the vehicle painting shop and make recommendations to reduce employee exposures
3. Determine the extent of exposure to respirable crystalline silica during abrasive blasting operations in the military vehicle abrasive blasting booth

Small Arms Repair Shop

We collected full-shift personal air samples for lead on the three small-arms repair employees over two work shifts. We analyzed the air samples according to National Institute for Occupational Safety and Health (NIOSH) Method 7303 [NIOSH 2017b]. However, the method was modified to include using a digestible Solucert® in the air sampling cassette to capture particles that would otherwise adhere to the inside walls of the cassette. This modification is consistent with the current NIOSH recommendation that all particles entering the sampler be included as part of the sample whether they deposit on the filter or on the inside surfaces of the sample media [NIOSH 2017a]. The Solucert insert and the sample filter were digested together during analysis.

We collected six handwipe samples from the three employees, once before they washed their hands and once after. We put on a clean pair of nitrile gloves, opened the packet containing a premoistened wipe, asked the employee to take it and wipe both hands and both sides of each hand from wrist to fingertip for 30 seconds, we then asked the employee to place the wipe onto a clean tissue. We evaluated the wipes for the presence of lead using the Full Disclosure® colorimetric wipe sampling kit, according to NIOSH Method 9105 [NIOSH 2017b]. This method has an estimated colorimetric limit of identification of 18 micrograms (µg) of lead per wipe. We then placed the wipe into a plastic container to be sent to a lab for quantification.

We collected 14 surface wipe samples using the method outlined by NIOSH Method 9100 [NIOSH 2017b]. For flat surfaces we wiped a surface area of 100 square centimeters, outlined by a 10 centimeter by 10 centimeter disposable template. For small or irregularly shaped surfaces such as doorknobs, we estimated 100 square centimeters or took a sample of the entire area or object. We qualitatively evaluated these wipes using the Full Disclosure wipe sampling kit. We also sent the wipes to the lab for quantification.

We took venous blood samples to test for lead from the three employees who worked full-time in the small arms repair shop and from nine additional employees who assisted in the shop, as needed. All 12 employees consented to testing of their blood for lead. Blood samples were analyzed at a contract laboratory. We followed universal (standard) precautions for working with blood and blood products [29 CFR 1910.1030; Siegel et al. 2007]. We individually notified participants in writing of their blood test results and what these results meant.

In addition, we asked employees who were having their blood collected for lead to allow us to collect an additional tube of venous blood and a capillary blood sample from a finger stick on each hand so that we could measure lead with a portable blood-lead testing device (LeadCare II® Test Kit) to examine its utility. Prior to sample collection, one hand was cleaned with a PDI® castile soap towelette and rinsed with water, and the other was cleaned with Hygenall® LeadOff™ cleaning and decontamination wipes and rinsed with water. The participants' venous and capillary blood samples were analyzed onsite by NIOSH researchers using the LeadCare II Test Kit. We compared these results to the results of their venous blood lead level (BLL) testing reported by our contract laboratory.

Vehicle Blasting and Painting Shop

We collected five task-based personal air samples on three employees and three task-based area air samples for hexamethylene diisocyanate (HDI) on the three vehicle maintenance and painting employees during one work shift. The air samples were collected at a flow rate of 2 liters per minute on 1-(9-anthracenylmethyl) piperazine impregnated glass fiber filters in an Institute of Medicine cassette and analyzed according to NIOSH Method 5525 [NIOSH 2017b].

We intended to collect full-shift personal air samples for respirable crystalline silica during abrasive blasting; however, the abrasive blasting operation was not at full capacity and was only done for 20 minutes. Therefore, we were not able to collect a representative full-shift sample. The company temporarily suspended abrasive blasting until safety interlock devices inside the booth were repaired.

We administered a questionnaire to all current paint and blast booth employees who were present during the evaluation. The questionnaire asked about their workplace, job duties, medical history, and current respiratory symptoms. The respiratory questions included the following validated questions on asthma symptoms from the European Community Respiratory Health Survey [Grassi et al. 2003]:

1. Have you been woken up with a feeling of tightness in your chest at any time in the last 12 months?
2. Have you had an attack of asthma in the last 12 months?
3. Are you currently taking any medicine (including inhalers or pumps, aerosols, or tablets) for breathing problems or asthma?
4. Have you had wheezing or whistling in your chest at any time in the last 12 months?
    a. Have you been at all breathless when the wheezing or whistling noise was present?
    b. Have you had this wheezing or whistling when you did not have a cold?

A positive response on any of these questions has a sensitivity of 75% and a specificity of 80% for asthma symptoms on the basis of a clinical examination with immunoglobulin E (IgE) testing against common allergens, spirometry, and methacholine challenge testing. Because some participants had not been in their current position for 12 months, we modified these questions by adding "or since beginning your current position if in that position less than 12 months." This modification of the questions may have affected the sensitivity and specificity of the responses. If participants responded positively to any of these questions, they were classified as having asthma symptoms. In addition, we added questions about changes in symptoms or medication use on days off work or on vacation. If participants responded that symptoms improved on days off work or on vacation, or that medication use or asthma attacks were less frequent on days off or on vacation, then their symptoms were classified as work-related.

We took blood samples from three employees who completed the questionnaire and consented to the testing. We tested their blood for immunoglobulin G (IgG) and IgE specific to HDI, HDI biuret, and isophorone diisocyanate (IPDI). Blood samples were analyzed at the Wisnewski-Redlich laboratory at Yale University. The presence of these specific antibodies demonstrates evidence of exposure or sensitization to HDI, HDI biuret, and IPDI. We followed universal (standard) precautions for working with blood and blood products [29 CFR 1910.1030; Siegel et al. 2007]. We individually notified participants in writing of their blood test results and what these results meant.

Ventilation Assessment and Worker Observations

We observed workers in the small arms repair shop, in the vehicle spray booth, mixing paints, sanding and grinding a vehicle outside of the abrasive blasting booth, and while abrasive blasting a vehicle inside the booth. We took air velocity measurements inside the firing range and visually examined the paint spray and abrasive blasting booths.

Results and Discussion

Lead Exposure in the Small Arms Repair Shop

We did not detect lead in any of the personal air samples. The minimum detectable concentration was 0.002 micrograms per cubic meter of air (µg/m³), which is well below occupational exposure limits (OELs) for airborne lead.

We found 4.3–92 µg of lead on employees' hands before they washed them at the end of the work shift. After we collected those postshift hand wipes, employees washed their hands with soap and water. We then collected a second set of hand wipes, which showed that the lead levels on employees' hands were 1.1–2.4 µg. This reduction of lead on employees' hands indicates that some lead was removed by the combination of collecting our first set of hand wipes and by employees washing their hands. However, research has shown that washing the hands with soap and water does not efficiently remove lead from skin [Filon et al. 2006]. In contrast, the use of lead removal products to clean the hands has been shown to substantially reduce lead [Esswein et al. 2011].

The small arm repair shop did daily cleaning of workstation surfaces and weekly cleaning of the floors using soap and water. Table 1 shows the quantitative and qualitative surface wipe sampling results in and around the small arms repair shop. The lead on surfaces inside the shop ranged from below the limit of detection (0.2 µg) to 53 micrograms per 100 square centimeters (µg/100 cm²). The surface with the highest relative amount of lead (53 µg/100 cm²) was the air return grill inside the small arms repair shop. Unlike most of the surfaces in the shop, this surface was not routinely cleaned. Therefore, the lead on the surface of the air return grill represents an accumulation of lead over time, presumably from airborne lead settling onto the grill. Lead levels on the regularly cleaned surfaces were relatively low with the highest surface lead (19 µg/100 cm²) on the 50 caliber rack of the vault. We collected one sample inside of one of the firearms to show employees what the color change on a lead-positive colorimetric wipe looked like.

Table 1. Surface wipe sampling results for lead in the small arms repair shop

Process/Task	Lab quantified wipes (µg/100 cm^2)	Qualitative colorimetric wipes (+/-)
Inside firearm	98*	+
Air return grill	53	+
Vault, on 50 caliber rack	19	+
Employee 1, sole of boot	17*	-
On top of worktable, by the door	5.9	-
Employee 2, sole of boot	5.8*	-
Employee 2, workstation keyboard	4.5	-
Refrigerator handle in breakroom	3.1*	-
On floor by mat where guns arrive	2.4	-
Employee 1 workstation	1.5	-
On floor of breakroom	0.5	-
Door knob out of small arms repair	0.38*	-
Bottle cap in work area	ND	-
Breakroom table	ND	-
Limit of detection	0.2	18 µg

*Estimated 100 cm^2

We tested the BLLs of 12 employees. One employee had an elevated BLL of 8.8 micrograms per deciliter (µg/dL) of blood. This employee worked full-time in the small arms repair shop, but also reported having substantial nonoccupational exposure to lead. The BLLs of the remaining employees ranged from 0.64–1.9 µg/dL. The average BLL in the United States general population, aged 20 years and older, is 1.05 µg/dL.

The gold standard for BLL measurement is collection of a venous sample, which is analyzed in a laboratory. This method can be costly and does not provide an instantaneous result. Measuring lead in the workplace from finger prick capillary blood samples using direct reading field-portable blood-lead testing instruments has been suggested as a cost and time saving alternative, but the interference from skin contamination with lead in the workplace affecting the BLL has been a concern [Taylor et al. 2001]. However, NIOSH researchers have found that hand washing with a wipe that contains a pH balanced wetting agent and chelating agent (which binds to lead) is a way to remove skin contamination and get a more accurate BLL. They have shown that the impregnated wipe allows removal of lead from the skin with greater than 99% efficacy [Esswein et al. 2011]. These type of wipes are now available commercially.

To assess the applicability of using a field portable test kit for determining BLLs among employees, NIOSH researchers compared the BLL results from the lab-analyzed venous blood samples to capillary blood sample results obtained using the field portable LeadCare II Test Kit. We present the results for the three employees with BLLs above the limit of detection using the LeadCare II Test Kit in Table 2. The nine BLLs from other employees in the shop (capillary and venous samples) analyzed on LeadCare II Test Kit were below the limit of detection of 3.3 µg/dL. The corresponding venous BLL samples analyzed by the laboratory were 0.64–1.6 µg/dL.

Table 2. Comparison of venous BLL results to capillary BLL obtained using the field portable LeadCare II test kit in μg/dL

	Capillary BLL by LeadCare II		Venous BLL by LeadCare II	Venous BLL by laboratory analysis
	Hygenall*	Castile*		
Employee 1	10.7	10.3	8.8	8.8
Employee 2	4.8	3.5	3.4	1.9
Employee 3	< 3.3	< 3.3	< 3.3	0.87

*Type of hand wipe used prior to sample collection

Our findings are consistent with previous research results showing that venous blood tested with the LeadCare II kit and venous blood tested in the laboratory had a clinically insignificant mean difference of 1.2 μg/dL [Stanton and Fritsch 2007]. Despite the results shown in the table, because of the small sample size, further research in other settings is needed to more definitively determine the utility of the LeadCare II kit.

Hexamethylene Diisocyanate Exposure in the Military Vehicle Painting Shop

Exposure to isocyanates can be irritating to the skin, mucous membranes, eyes, and respiratory tract [Lockey et al. 2015; NIOSH 1978, 2006]. The most frequent respiratory effect associated with isocyanate exposure is asthma due to sensitization [Lockey et al. 2015; Markowitz 2005]. Sensitization can occur from inhalation exposure, but also from skin exposure [Arrandale et al. 2012; Heederick et al. 2012; Lummus et al. 2011; Redlich 2010; Wisnewski 2007]. Skin exposure might even be more effective at causing sensitization than inhalation [Heederick et al. 2012; Redlich 2010]; therefore, it is important to protect the skin from exposures. Less common health effects of isocyanate exposure include contact dermatitis, rhinitis, and hypersensitivity pneumonitis [Lockey et al. 2015].

Task-based personal air samples collected in the military vehicle painting shop showed that employees were exposed to HDI monomer while spray painting vehicles inside the paint spray booth (Table 3). The typical duration may vary from 30 minutes to up to 4 hours per day, depending on the quantity or size of the equipment to be painted. None of the HDI exposures were greater than the NIOSH recommended exposure limit (REL) of 0.005 parts per million (ppm) nor the NIOSH ceiling limit of 0.02 ppm. We also analyzed the samples for HDI oligomer, which does not have an OEL. Personal air sample results for the HDI oligomer indicated airborne exposures ranged from 0.0025 to 0.097 milligrams per cubic meter (mg/m^3) inside the spray paint booth. We did not detect HDI oligomer outside of the spray painting booth.

Table 3. Task-based personal HDI monomer air sampling results in the military vehicle painting shop

Task (number of employees monitored)	Sampling time (minutes)	HDI monomer (ppm)
Mixing paint and spray painting (n = 2)	47	(0.00014 and 0.00025)
Cleaning up after spray painting (n = 2)	12	Not detected and (0.000067)
Sanding paint off of a vehicle (n = 1)	32	Not detected
NIOSH REL		0.005
NIOSH ceiling		0.02

Values in parentheses are between the minimum detectable concentration (0.000022 ppm) and the minimum quantifiable concentration (0.00106 ppm), based on an average sample volume of 67.1 liters. More uncertainty is associated with these values.

We collected area air samples on a desk near the exhaust for the spray paint booth and two inside the paint preparation room. One sample was collected while the employees were mixing the paint, and the other was collected while the employees were spray painting. None of the three area air samples had detectable concentrations of HDI monomer or HDI oligomer.

Three spray paint and blast booth employees participated in our evaluation. Two employees were classified as having asthma symptoms based upon the questionnaire, but not as having work-related asthma symptoms. One employee had a blood test result (a "positive" IPDI-specific IgG test result), which showed that they had developed antibodies to the IPDI in the paint. The remaining test results for this employee and the other employees were normal. The positive blood test means the person was recently exposed to IPDI, despite protective measures. Not all people who are exposed to IPDI develop IgG antibodies so not having a positive test does not mean a person was never exposed to IPDI.

Employees who do not have a positive blood test for the antibodies IgE or IgG specific to HDI, HDI biuret, or IPDI, but have cough, shortness of breath, or wheezing need to see an occupational medicine physician or other physician who is familiar with the health effects of isocyanate exposure. They may be reacting to HDI, HDI biuret, or IPDI exposure even though their blood tests are normal. This is because the blood test to identify antibodies to isocyanates may not identify everyone who has harmful effects when exposed to isocyanates.

Ventilation Assessment

We evaluated the never-used, single lane firing range (Figure 1). The air was supplied through a wall style plenum behind the firing line. We measured an average air velocity of 288 feet per minute at the firing line, which is higher than the NIOSH recommended 75 feet per minute [NIOSH 2009]. Excessive air velocity at the firing line can create turbulence and backflow of air. We visually evaluated the air flow of the range using smoke tubes and noticed turbulence and occasional backflow at the firing line. We also looked at the range exhaust. The range exhausted in two locations, at the middle of the range and behind the bullet trap. Air was exhausted through loose-fitting filters with a minimum efficiency reporting value (MERV) of 8.

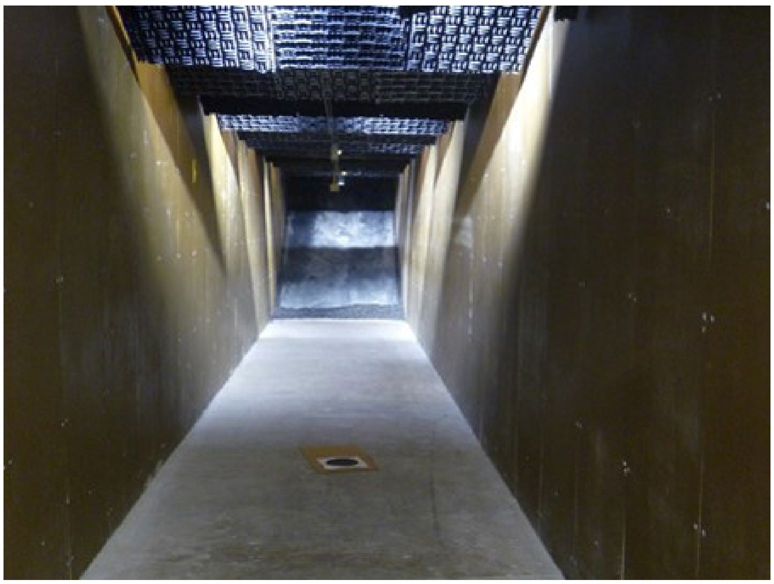

Figure 1. Single lane firing line with rubber tire bullet trap. Photo by NIOSH.

The 60-foot spray paint booth used to paint vehicles or parts was a crossdraft booth. Air passively entered through 42 air filters at the front end of the booth. These filters were changed approximately once per year. The employees worked in pairs inside the spray booth, walking around the vehicle or part they were spray painting. The air was drawn to the back of the spray booth to two exhaust stacks that exhausted to the roof. Each of the exhausts had 24 filters that were changed every 60–90 days, on the basis of visual inspection of filter loading. The booth was also equipped with a manometer to assess pressure drop across the filters, but it was not used. Some of the filters were missing (Figure 2) or damaged (Figure 3).

Figure 2. Missing exhaust air filters in the spray paint booth. Photo by NIOSH.

Figure 3. Damaged exhaust air filter in the spray paint booth. Photo by NIOSH.

Worker Observations

In the small arms repair shop, employees wore their military-issued uniforms, which were laundered at home with all of their other clothes. Employees did not wear gloves while repairing firearms.

Inside the paint spray booth, employees were required to wear half-mask respirators, equipped with an N95 and organic vapor combination cartridges. They were medically evaluated, trained, and fit-tested annually. However, employees' faces and eyes were exposed while spray painting with isocyanate-containing paints (Figure 4). When there is potential for exposure to isocyanate-containing compounds, NIOSH recommends that employees be supplied with full-face supplied-air respiratory protection, even when concentrations are below the NIOSH REL [NIOSH 1978, 1996]. Negative pressure air-purifying respirators are not recommended since diisocyanates have poor odor warning properties. Employees reported that they were unable to wear a full-face respirator, face shield or glasses because these items would quickly become covered by paint overspray and blowback. Clear plastic tear-away sheets on the visor can be used so that employees can see throughout the painting process. We observed that employees wore their respirator straps over the top of the hood of their chemical suits. The respirator straps should be worn under the hood. We observed that the chemical suits were too small for some employees. As a result, these employees were unable to put the hood of the suits over their heads, which exposed their head and skin on the back of the neck to paint overspray. In addition, the sleeves were too short, exposing the employees' wrists and forearms.

Figure 4. Employees spray painting a military vehicle part inside the spray paint booth. Photo by NIOSH.

Employees were required to wear a positive-pressure supplied airline respirator with an abrasive blasting hood, earmuffs, and cut resistant palmar coated gloves when blasting vehicles inside the booth. A Hankison® breathing air purifier system provided breathing air to the supplied air respirators. The air intake was located on the roof approximately 10 feet from the dust collector. A contractor inspected the system annually as recommended by the manufacturer. They could choose to wear their military-issued uniforms or coveralls while abrasive blasting.

We observed that personal protective equipment (PPE) was stored inside the paint mixing room and that some respirators were stored incorrectly (Figure 5).

Figure 5. Respirator sitting on top of an overpack barrel. Photo by NIOSH.

Conclusions

Employees in the small arms shop were exposed to lead from surfaces. This can result in elevated BLLs from skin absorption and transfer from the hands to the mouth. Lead can also be transported out of the workplace on the hands. Lead is harmful to the body at very low levels. Employees in the military vehicle painting shop were exposed to HDI in the air they breathed and one employee developed a positive blood antibody test to IPDI, confirming recent exposure. We also observed multiple opportunities for dermal exposure to paints that contained isocyanates. Isocyanates cause of variety of skin and respiratory disorders, the most common of which is asthma, from both skin contact and breathing it in.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the small arms repair and vehicle maintenance and painting shops to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the small arms repair and vehicle maintenance and painting shops.

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

Elimination and Substitution

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

1. Find alternatives for isocyanate paints for the military vehicles.

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. Adjust the velocity to 50–75 feet per minute to reduce turbulence at the firing line. Re-evaluate the air distribution before using the range.
2. Equip the filters for the firing range exhaust with side and face gaskets to prevent air from bypassing the filter. Use filters that have a MERV of at least 18.
3. Relocate the exhaust air filtration system so that it is as close as possible to the firing range to minimize the distance that lead dust needs to travel before reaching the filter.
4. Replace missing or damaged filters in the spray paint booth.
5. Replace current spray paint booth with a downdraft ventilation paint booth where filtered air enters at the ceiling of the booth and is drawn down through the floor of the booth. More information is available in the NIOSH hazard controls guidance (Publication No. 96-106), Control of Paint Overspray in Autobody Repair Shops at https://www.cdc.gov/niosh/docs/hazardcontrol/pdfs/hc2.pdf.

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. Continue to clean the workstations in the repair shop and shelves in the vault routinely. In addition, clean the return air grill. We recommend using a soap designed to remove lead.
2. Collect BLLs for all employees in the small arms repair shop every 6 months, and increase medical monitoring if sampling results indicate an increase in BLLs as listed in Appendix A. Conduct training about exposure to lead, both at work and outside of work, and the health effects of lead exposure. Our medical surveillance recommendations for lead-exposed employees are listed in Appendix A.
3. Refer any employee with cough, shortness of breath, wheezing, or skin problems who may be exposed to the isocyanate paints to be evaluated by an occupational medicine physician or other physician who is familiar with the health effects of isocyanate exposure.
4. Remove any employee with isocyanate-induced health effects from work environments where isocyanate exposure occurs. The only effective intervention for employees with isocyanate-induced asthma is cessation of all isocyanate exposure. Place the employee in a job without MDI exposure while maintaining earnings, seniority, and other rights and benefits. Explain to employees what workplace policies, workers' compensation, pay, and benefits are available to them.
5. Start a medical surveillance program for employees who are exposed to HDI and crystalline silica. Work with an occupational medicine physician to design and implement this program. These physicians can be located through a variety of sources, including the Association of Occupational and Environmental Clinics at http://www.aoec.org/ and the American College of Occupational and Environmental Medicine at http://www.acoem.org/. One program near the facility is the Comprehensive Occupational Medicine for Business and Industry.
6. Evaluate employee exposure to respirable crystalline silica when the abrasive blasting operation is restarted. Our recommendations for medical surveillance of silica-exposed employees are listed in Appendix A.
7. Use the following general recommendations to provide medical monitoring for asthma:
    a. Provide preplacement, annual, and exit general medical examinations with the following:
        i. Special emphasis on the respiratory system
        ii. Medical history including an extensive work history, history of pre-existing respiratory conditions such as asthma, and a smoking history
        iii. Spirometry–Information for employers and employees can be found on the spirometry information sheet at

http://www.osha.gov/Publications/osha3415.html and spirometry worker information sheet at http://www.osha.gov/Publications/osha3418.html.

b. Inform employees with a history of respiratory conditions of the potential for increased health risks associated with exposure to isocyanates.

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. Use a full-facepiece, supplied-air respirator in a pressure-demand or other positive-pressure mode when spray painting.
2. Ensure employees eyes and face are protected while spray painting.
3. Provide employees with appropriately sized chemical protective suits to wear while spray painting.
4. Require employees to wear nitrile gloves while repairing firearms.
5. Require respirators to be stored away from sunlight, dust, and potentially damaging chemicals in nonporous, sturdy, airtight containers, such as a plastic bag. Also, make sure the respirators are cleaned prior to storage.
6. Store PPE outside of the paint mixing area.
7. Require employees to vacuum or remove contaminated work clothing before eating, drinking, or smoking and to launder contaminated clothing onsite before going home when the abrasive blasting operation is restarted.

Appendix A: Occupational Exposure Limits and Health Effects

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

Most OELs are expressed as a 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 (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 Occupational Safety and Health Administration (OSHA) permissible exposure limits (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, 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 (ACGIH) threshold limit values (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) 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 [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 µg/dL of whole blood 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].

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 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 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, 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 CDPH, ACOEM, and CSTE.

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.

Isocyanates

Diisocyanates and polyisocyanates (isocyanates) are a group of highly reactive, low-molecular-weight aromatic and aliphatic compounds [Lockey et al. 2015]. The most common isocyanates include the aliphatic compounds HDI and IPDI, and the aromatic compounds toluene diisocyanate and MDI. Isocyanates are widely used in the production of polyurethane materials such as foams, adhesives, resins, elastomers, binders, and coatings.

Exposure to isocyanates can be irritating to the skin, mucous membranes, eyes, and respiratory tract [Lockey et al. 2015; NIOSH 1978, 2006]. The most frequent respiratory effect associated with isocyanate exposure is asthma due to sensitization [Lockey et al. 2015; Markowitz 2005]. Sensitization can occur from inhalation and from skin exposure [Arrandale et al. 2012; Heederick et al. 2012; Lummus et al. 2011; Redlich 2010; Wisnewski 2007]. Skin exposure might even be more effective at causing sensitization than inhalation [Heederick et al. 2012; Redlich 2010]. Less common health effects of isocyanate exposure include contact dermatitis, rhinitis, and hypersensitivity pneumonitis [Lockey et al. 2015].

Isocyanates are the most common cause of occupational asthma in many industrialized countries [Tarlo and Lemiere 2014]. The level of exposure influences sensitization rates, with lower levels of exposure leading to lower asthma rates [Heederick et al. 2012]. An employee with isocyanate-induced asthma exhibits the traditional symptoms of acute airway obstruction such as coughing, wheezing, shortness of breath, tightness in the chest, and nocturnal awakening [NIOSH 1978, 1986]. Isocyanate-induced asthma occurs with variable latency following the initial exposure, although characteristically the asthma develops within 2 years of exposure [Markowitz 2005]. The asthmatic reaction may occur minutes after exposure (immediate phase), several hours after exposure (late phase), or both (dual phase) [Lummus et al. 2011]. After sensitization, any exposure, even to levels below OELs or below the level of detection, can produce an asthmatic response that may be life threatening [NIOSH 1978, 1996, 2006; Redlich 2010]. The only effective intervention for employees with isocyanate-induced asthma is cessation of all isocyanate exposure. This intervention can be accomplished by removing the employee from the work environment where isocyanate exposure occurs.

Isocyanate asthma is clinically indistinguishable from common allergic asthma [Wisnewski 2007; Wisnewski and Jones 2010]. Common allergic asthma is mediated by allergen-specific IgE and isocyanate-specific IgE is found in up to 50% of people with isocyanate asthma [Wisnewski 2007]. While isocyanate specific-IgE is not always found in people with isocyanate asthma, its detection is strongly predictive of asthma [Budnick et al. 2013; Wisnewski 2007]. IgE, which is a marker of sensitization, has a very short half-life of about 2 days so that it may disappear after short periods away from work [Wisnewski 2007]. IgG, which is a marker of exposure, has a half-life of about 30 days [Wisnewski 2007]. Isocyanate-albumin conjugate specific IgG is rarely observed in people without exposure to isocyanates [Wisnewski 2007], but is prevalent among exposed workers [Wisnewski et al. 2012].

OSHA has not established PEL for HDI monomer. NIOSH has established a REL of 0.005 ppm (0.035 mg/m^3) that is a time weighted average for up to 10 hours and a ceiling limit of 0.020 ppm (0.140 mg/m^3). ACGIH has a TLV of 0.005 ppm (0.034 mg/m^3) as an 8-hour TWA. None of the three organizations (OSHA, NIOSH, ACGIH) has established an OEL for HDI oligomer.

Respirable Crystalline Silica

Silica, or silicon dioxide, occurs in a crystalline or noncrystalline (amorphous) form. In crystalline silica, the silicon dioxide molecules are oriented in a fixed pattern versus the random arrangement of the amorphous form. The more common crystalline forms in workplace environments are quartz and cristobalite, and to a lesser extent, tridymite. Occupational exposures to respirable crystalline silica have been associated with silicosis, lung cancer, pulmonary tuberculosis, and airway diseases. Several serious nonrespiratory diseases are associated with occupational exposure to crystalline silica. These include immunologic disorders and autoimmune diseases (including systemic sclerosis, rheumatoid arthritis, and systemic lupus erythematosis) and renal diseases.

Silicosis is a fibrotic disease of the lung caused by the deposition of fine crystalline silica particles in the lungs. It is the disease most often associated with exposure to respirable crystalline silica. This lung disease is caused by the inhalation and deposition of crystalline silica particles that are 10 micrometers or less in diameter. Particles 10 micrometers and below are considered respirable particles and classified as having the potential to reach the lower portions of the human lung (alveolar region). Although particle sizes 10 micrometers and below are considered respirable, some of these particles can be deposited before they reach the alveolar region [Hinds 2012]. Symptoms of silicosis usually develop insidiously, with cough, shortness of breath, chest pain, weakness, wheezing, and nonspecific chest illnesses. Silicosis usually occurs after years of exposure (chronic), but may appear in a shorter period of time (acute) if exposure concentrations are very high. Acute silicosis is typically associated with a history of high exposures from tasks that produce small particles of airborne dust with a high silica content [NIOSH 2002]. Chronic silicosis can develop or progress even if exposure to silica ends [NIOSH 2002].

The International Agency for Research on Cancer [2012] and NIOSH [2002] have classified inhaled crystalline silica in the form of quartz or cristobalite as carcinogenic to humans in reference to lung cancer. While individuals with silicosis clearly are at risk of lung cancer, exposure to silica in the absence of silicosis also increases the risk for lung cancer [Liu et al. 2013].

Several forms of nonmalignant respiratory disease are associated with exposure to silica [NIOSH 2002]. These include chronic obstructive pulmonary disease (emphysema and chronic bronchitis) and asthma. Silica exposure is also related to other abnormalities noted on pulmonary function tests.

Exposure to silica increases the risk of developing tuberculosis even in the absence of silicosis [NIOSH 2002]. This increase is due to impaired macrophage function from silica. This risk for individuals with silicosis is even higher. The odds of an individual with silicosis dying with tuberculosis are 19 to 40 times higher than for individuals without silicosis [Calvert et al. 2003].

Exposure to crystalline silica is also associated with development of several autoimmune diseases [Cooper et al. 2002; Lee at al. 2014]. The strongest evidence exists for an association with systemic sclerosis, rheumatoid arthritis, systemic lupus erythematosis, and antineutrophil cytoplasmic autoantibody related vasculitis [Cooper et al. 2002; Lee et al. 2014].

Silica exposure is related to an increased risk of end-stage kidney disease [Ghahramani 2010; NIOSH 2002]. Kidney disease is associated with the effect of silica deposited in the kidneys and with an autoimmune process with activated macrophages. A wide range of kidney pathology is associated with silica exposure.

When proper practices are not followed or controls are not maintained, respirable crystalline silica exposures can exceed the OSHA PEL, NIOSH REL, or the ACGIH TLV. For general industry, the OSHA PEL for respirable dust containing 1% or more of quartz is calculated by dividing 10 mg/m^3 by the percent quartz in the sample, plus two [OSHA 2017]. OSHA instituted an updated silica PEL on June 23, 2016. The updated silica PEL (50 $\mu g/m^3$ as an 8-hour TWA), is the same as the NIOSH REL (which is applied as a TWA up to 10 hours), and is scheduled to be enforced for general industry and the maritime industry beginning 2 years after the effective date (June 23, 2018). The NIOSH REL is intended to reduce the risk of developing silicosis, lung cancer, and other adverse health effects [NIOSH 2010]. The ACGIH TLV for quartz is 25 $\mu g/m^3$, as an 8-hour TWA [ACGIH 2017].

We recommend medical surveillance for any employee who is exposed above the action level of 25 $\mu g/m^3$ for 30 or more days per year. Our recommendations are identical to the medical surveillance requirements mandated by OSHA. This includes an initial examination within

30 days of initial assignment to the job. This examination must include the following:

- Medical and work history with emphasis on past, present, and anticipated exposure to respirable crystalline silica, dust, and other agents affecting the respiratory system; any history of respiratory system dysfunction, including signs and symptoms of respiratory disease (e.g., shortness of breath, cough, wheezing); history of tuberculosis; and smoking status and history
- Physical examination with special emphasis on the respiratory system
- Chest x-ray interpreted and classified according to the International Labour Office International Classification of Radiographs of Pneumoconioses by a NIOSH-certified B Reader
- Pulmonary function test to include forced vital capacity and forced expiratory volume in one second administered by a spirometry technician with a current certificate from a NIOSH-approved spirometry course
- Testing for latent tuberculosis infection
- Other tests deemed appropriate by the physician or licensed healthcare provider.

Periodic examinations including the same elements must be offered at least once every 3 years or more often if recommended by the physician or licensed healthcare provider.

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