Evaluation of Metal and Noise Exposures at an Aircraft Powerplant Parts Manufacturer

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Disclaimer

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

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Table of Contents

Main Report

Supporting Technical Information

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Introduction

Request

We received a request from welders at an aircraft powerplant parts manufacturing facility concerned about their exposures to chromium, hexavalent chromium, and nickel. In addition, noise levels in the welding area were potentially above noise exposure limits.

Workplace

The facility consisted of two buildings with three dedicated welding areas. We observed a total of 21 welders and 8 welding supervisors working at the time of our first visit. We observed 16 welders and 10 welding supervisors working at the time of our second visit. Welders used tungsten inert gas welding to patch and repair aircraft powerplant parts after casting. The welders occasionally used small, air-powered belt grinders to smooth surfaces on welded parts. The welders reported that the amount of work performed in the facility during our second visit was less than typically expected.

To learn more about the workplace, go to Section A in the Supporting Technical Information

Our Approach

We visited the facility twice to learn more about health concerns and to measure exposures. On our site visits, we completed the following activities:

- Reviewed facility health and safety programs and documents.
- Observed work processes, work practices, and workplace conditions.
- Measured employee exposures to both airborne metals and noise.
- Held confidential medical interviews, administered medical questionnaires, performed nasal examinations, and tested urine for nickel, chromium, and cobalt.

To learn more about our methods, go to Section B in the Supporting Technical Information

Our Key Findings

One employee was exposed to airborne nickel levels above an established occupational exposure limit

- One welder was exposed to airborne nickel levels above the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit on a day we monitored. No other employees evaluated were exposed to airborne nickel levels above occupational exposure limits.

- Four welders and one welding supervisor had urine nickel levels above the normal general population level.
- All employees who participated in personal air sampling were exposed to low levels of airborne chromium, hexavalent chromium, and cobalt. None of these results were at or above the lowest occupational exposure limit.
- One welder had a urine cobalt level that was above the normal general population range.
- Welding booths were not equipped with local exhaust ventilation (LEV). Mobile LEV units were available; however, welders reported receiving no training on their use.
- Several work practices, such as using compressed air or dry sweeping for cleaning and inconsistent hand washing before eating, drinking, or leaving work, may have contributed to these exposures.
- Welders and welding supervisors were not enrolled in the respiratory protection program.

Employees were exposed to noise levels above the NIOSH recommended exposure limit

- All five welders evaluated were exposed to noise levels above the NIOSH recommended exposure limit on at least one of the days of monitoring.
- Two welders evaluated were exposed to noise levels above the Occupational Safety and Health Administration (OSHA) action level for noise, but no welders were exposed to noise levels above the OSHA permissible exposure limit.
- One of three welding supervisors evaluated was exposed to noise levels above the NIOSH recommended exposure limit on one of the days of monitoring. However, none of the welding supervisors' noise exposures were above the OSHA action level or permissible exposure limit.

Work practices and conditions contributed to noise exposures and hearing loss risk

- Noise exposure in the welding area came primarily from the use of compressed air for cooling welds or cleaning surfaces.
- Employees who used compressed air for cleaning parts were more likely to report a history of trouble hearing clearly.
- Employees working in high-noise areas wore devices, such as earbuds or headphones for personal music players, not designated to protect hearing.
- Employees in high-noise areas wore improperly inserted ear plugs in their ears.
- Welders and welding supervisors were not included in the facility's hearing conservation program at the time our visits.

To learn more about our results, go to [Section B in the Supporting Technical Information]

Our Recommendations

The Occupational Safety and Health Act requires employers to provide a safe workplace.

Benefits of Improving Workplace Health and Safety:

- ↑ Improved worker health and well-being
- ↑ Better workplace morale
- ↑ Better employee recruiting and retention
- ↑ Improved image and reputation
- ↑ Better products, processes, and services
- ↑ Could increase overall cost savings

The recommendations below are based on the findings of our evaluation. For each recommendation, we list a series of actions you can take to address the issue at your workplace. The actions at the beginning of each list are preferable to the ones listed later. The list order is based on a well-accepted approach called the "hierarchy of controls." The hierarchy of controls 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 might be needed. Read more about the hierarchy of controls: https://www.cdc.gov/niosh/topics/hierarchy/.

We encourage the company to use a health and safety committee to discuss our recommendations and develop an action plan. Both employee representatives and management representatives should be included on the committee. Helpful guidance can be found in "Recommended Practices for Safety and Health Programs": https://www.osha.gov/shpguidelines/index.html.

Recommendation 1: Reduce employees' exposure to noise

Why? Occupational hearing loss is one of the most common work-related illnesses in the United States. Each year, about 22 million U.S. workers are exposed to hazardous noise levels at work. Noise-induced hearing loss is irreversible and progresses with noise exposure. Unlike some other types of hearing disorders, noise-induced hearing loss cannot be treated medically. Noise-exposed workers can develop substantial noise-induced hearing loss before it is clearly recognized. Even mild hearing loss can impair a person's ability to understand speech and hear many important sounds. In addition, some people with noise-induced hearing loss also develop tinnitus, a condition in which a person perceives a ringing, roaring, hissing, buzzing, chirping, or whistling sound even though no external sound is present. Currently, there is no cure for tinnitus. Noise-induced hearing loss symptoms can worsen over time and could be associated with more sick leave, job loss, and lower quality of life.

We found six employees exposed to noise levels above the NIOSH recommended exposure limit and two were exposed to noise levels above the OSHA action level. On days when more work activities are performed, noise exposures could be even higher. Among the 23 employees who completed a questionnaire, 11 reported tinnitus and/or trouble hearing clearly.

How? At your workplace, we recommend these specific actions:

Reduce welders' exposures to noise from compressed air.

- Ensure that welders receive clean parts so that they do not need to use compressed air or other cleaning methods to remove contaminants from parts prior to welding.
- Purchase and use compressed air nozzles designed to generate less noise when welders apply compressed air to cool welds.
- Provide and require employees to use vacuums equipped with high-efficiency particulate air (HEPA) filters instead of compressed air for cleaning work surfaces. When these vacuums are not available, use wet cleaning methods (e.g., wet wiping, mopping) for cleaning surfaces.

Include welders and welding supervisors in the company hearing conservation program.

- Ensure that all employees enrolled in the program receive baseline and annual audiograms, and maintain these records.
  - Evaluate audiograms using the NIOSH criteria for identifying standard threshold shifts, which are significant changes from baseline hearing thresholds. The NIOSH criteria are more protective than OSHA criteria and will identify employees with hearing loss earlier.
  - Request that the test provider not age correct when evaluating audiograms.

- Educate employees on noise exposures. Give them information on hearing hazards, such as work locations and processes that require hearing protection (based on the comprehensive noise assessments). Train them on hearing protection requirements and how to properly use and care for their hearing protection.

- Instruct employees to promptly report hearing problems possibly related to noise exposure, such as trouble hearing clearly, ringing, or buzzing in the ears, and track such reports. Encourage employees with possible work-related hearing concerns to seek medical care from qualified healthcare professionals.

- Provide welders and welding supervisors with appropriate hearing protection and require that they wear it properly. Do not permit employees to use earbuds and head phones, because these devices are not considered hearing protection.

- Post clearly visible signs at entrances to areas where noise exposures are high, warning facility employees of noise exposures, hearing hazards, and hearing protection requirements.

- For further information, Oregon OSHA noise exposure information is available at https://osha.oregon.gov/OSHAPubs/factsheets/fs01.pdf, the OSHA noise standard is available at https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9735, and NIOSH noise guidance is available at http://www.nonoise.org/hearing/criteria/criteria.htm.

Perform a comprehensive noise assessment when typical levels of work are occurring.

- Install noise controls to reduce noise levels if the comprehensive noise assessment shows noise exposures above exposure limits. Consider consulting with a noise control engineer for additional guidance.

- Repeat noise assessments when work processes change or new equipment is installed. Conduct periodic noise assessments because welding activities and the type of parts being welded vary.

- Work with the facility health and safety committee to review and update written hearing protection plans for the facility based on the noise assessment results. Discuss noise monitoring plans at these meetings to determine when repeat monitoring should occur.

- Ensure that adequate supplies of appropriate personal hearing protectors, such as ear plugs and ear muffs, are always available for employees to use when performing tasks or working in areas where noise levels are high.

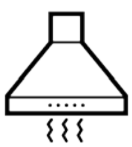
- Ensure that contractor personnel who visit the facility are notified of areas where noise exposures are high and are provided with appropriate hearing protection to use whenever they are required to enter high-noise areas.

Recommendation 2: Reduce employees' exposures to metals

Why? Overexposure to nickel and cobalt can have harmful effects. Allergic skin reactions may develop after direct skin contact with nickel or cobalt, like a rash at the site of the contact. Inhalation of nickel- or cobalt-containing dust and fumes may cause occupational asthma or lead to reduced lung function over time. Nickel is also considered a cancer-causing agent, with chronic overexposures leading to nasal sinus and lung cancer. Health effects resulting from overexposure to nickel and cobalt could result in more sick leave, job loss, and lower quality of life.

We found one welder exposed to airborne nickel levels above the NIOSH recommended exposure limit. Five welders and welding supervisors had urine nickel levels greater than the normal general population urine nickel level. One employee had a urine cobalt level greater than the normal general population urine nickel level. Work practices we observed could affect these exposures.

How? At your workplace, we recommend these specific actions:



Install LEV systems in the welding booths.

- LEV is the best way to capture welding fumes at the source.
    - Ensure the systems have a capture velocity of approximately 100–170 feet per minute with the higher values used for poor conditions, such as high cross-draft velocities and with higher hazard levels.
    - Keep the hood within 18 inches of the weld. However, positioning the hood too close or capture velocities greater than 150 feet per minute may disturb shield gas.
    - Train welders how to properly use the LEV systems.
    - Establish an operations and maintenance program for LEV systems to ensure they continue to function properly.
- In the interim, evaluate the effectiveness of existing portable LEV systems. If existing portable LEV systems are found to be ineffective in controlling employees' exposures to welding fumes, investigate alternatives, such as ventilated welding booths. Include welders in this process; those involved in the work can best set priorities and assess the feasibility of equipment choices.

Include welders in the company respiratory protection program.

- Our air sampling results revealed one welder exposed to airborne nickel levels above the NIOSH recommended exposure limit. Other welders could also be overexposed, depending on the amount of welding, number of pieces welded, and adequacy of ventilation, so they should be included in the respiratory protection program.
- Repeat exposure monitoring after engineering and administrative controls have been implemented or improved. Use the results of this monitoring to guide future changes to personal protective equipment (PPE) plans, including the need for a respiratory protection program.

Require all employees to wash their hands before eating, drinking, or smoking, and before leaving the facility.

- Educate employees about the importance of handwashing to remove metal contaminants from their hands to reduce their risk of ingesting or absorbing contaminants into the body.

Do not allow employees to consume or store food or drink in work areas.

- Separate group water stations from production (work) areas by placing them behind closed doors in nonproduction areas.
- Ensure that employees have adequate break areas—separated from production areas by closed doors—for eating, drinking, and storing food.
- Allow employees to take frequent breaks during their shift to ensure they stay well-hydrated, especially on hot days.

Provide a dedicated space for employees to change in and out of their work uniforms to reduce the risk of taking contaminants home.

Keep surfaces as free as practicable of contaminants.

- Do not dry sweep or use compressed air to clean work surfaces.
- Use a vacuum equipped with a HEPA filter or wet cleaning methods to clean contaminated surfaces.
- Provide, at a minimum, annual or periodic training to ensure compliance with approved cleaning practices.
- Review and update cleaning protocols as needed to ensure continued effectiveness.

Review and update PPE plans for all welders and welding supervisors.

- Review procedures, tasks, and tools used in all welding areas to identify what PPE is needed.
- Use the facility health and safety committee to update PPE plans for welding areas and specific job tasks.
- Communicate relevant PPE requirements to employees. Provide periodic training to ensure compliance with approved PPE plans.

Encourage employees with possible work-related health concerns to talk to their healthcare provider about their exposures to metals, such as nickel and cobalt, at work.

Recommendation 3: Address other health and safety issues we found during our evaluation

Why? A workplace can have multiple health hazards that cause worker illness or injury. Similar to the ones identified above, these hazards can potentially cause serious health symptoms and lower morale and quality of life for your employees, and increase costs to your business.

We found the following additional issues at your workplace:

- We observed several unlabeled confined spaces on-site.
- Welders who reported never wearing nitrile gloves when handling chemicals were more likely to report having dermatitis than those who reported sometimes or always wearing nitrile gloves.
- Welders who reported exposure to fluorescent liquid dye penetrant (dye penetrant) were more likely to report having respiratory symptoms that those who did not report exposure to dye penetrant.

Although these issues were not the main focus of our evaluation, they could harm your employees' health and safety and should be addressed.

How? At your workplace, we recommend these specific actions:

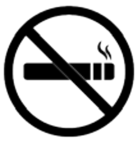
Perform a site-wide audit of confined spaces, and label these spaces appropriately.

- Further information about the Oregon OSHA confined space rule 437-002-0146 is available at https://osha.oregon.gov/OSHAPubs/2864.pdf.

Require all employees to always wear chemical-resistant nonlatex (e.g., nitrile or vinyl) gloves when handling chemicals at work.

- Ensuring that welders receive clean parts will also reduce or eliminate their exposure to chemicals that can cause skin and/or respiratory irritation, such as residual dye penetrant used to test parts for defects or acetone used for cleaning parts.

Encourage employees with possible work-related symptoms (e.g., respiratory or skin irritation) to talk to their healthcare provider about their exposures to chemicals, such as acetone and/or dye penetrant, at work.



Offer smoking cessation programs at no cost to employees. Encourage employees who smoke to participate in smoking cessation programs. Smoking cessation may decrease respiratory symptoms worsened by workplace exposures.

Supporting Technical Information

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HHE Report No. 2018-0001-3349

April 2019

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Section A: Workplace Information

Site Information

The facility consisted of two buildings (Buildings A and B) with three dedicated areas for welding (Areas A1, B1, and B2). The remaining space was used for grinding booths, materials testing, offices, break rooms, and product storage.

Employee Information

- The facility had 21 welders and 8 welding supervisors working at the time of our first visit in May 2018. Upon our return visit in August 2018, 16 welders and 10 welding supervisors were working at the facility. Employees were not unionized.
- The facility operated three shifts Monday through Friday. Welders and welding supervisors worked 8–10 hours per day. The length of the workweek ranged from 5–7 days depending on each employee's schedule. Overtime work was available but not mandatory.
- The median age of employees was 43 years (range: 30–65 years).
- The median job tenure was 11 years (range: 4 months–34 years).

Process Description

Metal aircraft powerplant parts were cast off-site and received initial processing at this facility. Parts came in a wide variety of shapes and sizes; from 2 to over 10 feet (ft) in diameter. Metal content of the parts varied based on metallurgical requirements. According to the manufacturers' safety data sheets (SDSs), the parts contained 0%–94% nickel, 4%–23% chromium, and 2%–15% cobalt.

Processing consisted of grinders who used air-powered belt and disc grinders to smooth casting flash or grind out imperfections. Welders then patched casting holes and cracks via tungsten inert gas welding. Between these steps, employees used radiographic testing and fluorescent penetrant inspection methods to check parts for cracks and flaws. Parts could move between these three steps several times before being cleared by quality control for shipment out of the facility.

Section B: Methods, Results, and Discussion

We focused on these objectives:

- Evaluate the routes and extent of exposures to metals (chromium, hexavalent chromium [Cr(VI)], nickel, and cobalt) and noise among welders and welding supervisors at the facility.
- Determine the prevalence of elevated urine nickel, chromium, and cobalt levels among welders and welding supervisors at the facility.
- Assess the prevalence of work-related skin, respiratory, and hearing trouble symptoms among welders and welding supervisors at the facility and identify factors that may be contributing to these health effects.

Methods: Health and Safety Program and Document Review

We reviewed the facility's written respiratory protection program, hearing conservation program, and hazard communication program. We also reviewed Industrial Hygiene Sampling Reports and exposure monitoring data from 2015–2017. In addition, we reviewed SDSs, information about welding equipment, OSHA Form 300 Log of Work-Related Injuries and Illnesses for the period of 1/1/2012–12/31/2016, and facility floor plans.

Results: Health and Safety Program and Document Review

No employees at the facility were enrolled in the company's chromium medical surveillance program. Welders and welding supervisors were not enrolled in the facility's respiratory protection program. According to the facility's written respiratory protection program dated October, 2001, "respiratory protection is required to be used . . . whenever the level of air contaminant in an employee's breathing zone exceeds a legal standard published by Oregon OSHA or other established occupational exposure limit." According to the "Optional Use of Disposable Type Respirators" section of the respiratory protection program, "employees choosing to wear a disposable particulate respirator must be provided with OSHA 1910.134 Appendix D and sign the distribution sheet verifying receipt."

The written hearing conservation program identified which manufacturing areas within Buildings A and B were included in the program on the basis of whether noise exposures were documented to exceed the OSHA action level (AL) of 85 decibels, A-weighted (dBA). The company identified work areas inside and near the welding booths to be below the AL. Therefore, welders and welding supervisors were not included in the facility's hearing conservation program.

Employees included in the hearing conservation program had baseline and annual audiometric testing completed by an external provider. In addition to training done by the company, the contracted audiologists also provided some hearing conservation training at the time of testing. The company provided employees with three different types of foam insert ear plugs for use (Moldex Spark®, Howard Leight Laser Lite®, and Howard Leight Firm Fit™). The noise reduction rating for these ear plugs ranged 30–35 decibels (dB). The company planned to purchase a hearing protector fit test system to help guide selection and ensure employees' hearing protectors fit well.

The facility's written hazard communication program provided details on SDSs, container labeling, and employee training. SDSs were kept in management offices and binders by bulletin boards in different areas of the two buildings. In addition, department supervisors were responsible for providing new or relocated employees with more specific training regarding the chemicals used in their department, including the physical and health effects of hazardous chemicals present in their work environment, and how to reduce or prevent exposures to these hazardous chemicals by means of work practices and PPE.

Review of the OSHA 300 logs for the period of 1/1/2012–12/31/16 demonstrated a variety of injuries and illnesses ranging from 1–7 injuries reported among welders and welding supervisors per year over this time. Most of the injuries and illnesses included in the logs were minor in nature, such as strains, sprains, and lacerations. One of the reported back strains was related to a welder's body being held in an awkward position for an extended period while welding. One welder reported a laceration that appears to have been caused by tripping over an air hose. Hearing loss was reported by two welders in 2014 and by one welder in 2016.

The SDS for one of the dye penetrants used to locate defects in parts stated that this substance may cause respiratory tract irritation. It also said that skin contact with this chemical can cause skin irritation such as redness, drying, or cracking of the skin. The SDS recommended wearing safety goggles, a face shield, and chemical-resistant gloves when handling this substance. The SDS also advised avoiding eating, drinking, or smoking in areas where it is handled. The SDS for acetone used to clean parts prior to welding stated that this chemical is also irritating to the skin. It advised avoiding skin contact with acetone and recommended using protective gloves and clothing to prevent exposure.

Methods: Observations of Work Processes, Practices, and Conditions

We evaluated the following in common and welding areas of the facility across all three shifts on our first visit and during the day shift on our second visit:

- Workplace conditions and work processes and practices, including PPE use among employees.
- LEV and general ventilation.

Results: Observations of Work Processes, Practices, and Conditions

The two buildings we evaluated had three different welding areas. Welding Area A1, located at the end of Building A, had four welding booths. Welding Areas B1 and B2 were at opposite ends of Building B. Area B1 had three welding booths, and Area B2 had seven welding booths. Each of these three welding areas were considered a separate department. Each welder was assigned to one area. During our second visit, eight welders were working during the day shift on the first day of observations and sampling and seven were working on the second day.

Welding booth dimensions were approximately 10×12 ft. The booths were open on top to the 20-ft ceiling and separated from each other by partitions, which were about 8-ft high. The front of each booth had plastic strip welding curtains for ultraviolet light protection. Noncommercial style heating, ventilation, and air-conditioning (HVAC) systems provided the welding booths with heating and cooling, but no fume extraction. The air intake for the welding booth HVAC systems was inside the facility, so it did not provide outside air for dilution. As a result, welding fumes were recirculated inside the facility from each of the welding areas. Some welders had modified the HVAC air supply vents to direct airflow so that it did not disrupt the shield gas during welding. We saw some portable LEV units in Building B, but none in Building A. We did not see any of them in use. All grinding booths, which were located near the welding booths, were connected to LEV systems. The remainder of the facility was ventilated by general dilution.

Each of the three welding areas had a welding supervisor who coordinated parts as they moved between welders, grinders, and quality control. Three welding supervisors worked during the day shift on both days of our second visit. Each welding supervisor had a workstation, located about 12 ft from the nearest welding booth in the area. Supervisors completed forms and other paperwork at these workstations. Welding supervisors moved around the facility as needed but spent the majority of their shift in and around the welding booths. We did not observe any welding supervisors present in a welding booth while welding was occurring.

Welders' tasks could be generalized as patching casting holes and cracks in aircraft powerplant parts. However, this is an oversimplification due to the wide variety of parts and wide variety of welding tasks for each part. One of the parts had over 20 small holes to patch. In this case, the welder spent a lot of time preparing and manipulating the part, but a short time welding each of the patches. In contrast, a different part required minimal preparation, but took 6 hours for the welder to fill a single void. Another part required welding on a section so difficult to reach that the welder could only see the weld area with a mirror. Welders reported that the amount of work performed during our second visit was less than typical.

The facility had an air compressor plant to provide power for tools (belt and disc grinders). These tools were predominantly used by grinders, but welders also had compressed air lines in their booths. We observed welders occasionally used small air-powered belt grinders on parts in their booth. However, welders mostly used compressed air to cool welds. The air compressor plant was outside, between the buildings.

We observed welders using acetone to clean parts before welding. Some parts required more cleaning than others, based on the amount of dye penetrant left on the part after testing. Nitrile gloves were available in the booths for use by welders when handling chemicals like acetone. We observed inconsistent nitrile glove used by welders. One welder also reported not wearing a glove when holding welding rods because of lost dexterity with glove use. This welder also reported sometimes holding welding rods in the mouth in order to use both hands to move or reposition a part while welding.

Welders reported they occasionally wore a filtering facepiece respirator. Some welders had a box of these respirators in their welding booth. Others reported getting a filtering facepiece respirator from a nearby grinding booth when needed. Employees had three different types of foam insert ear plugs available for use. The noise reduction rating of these ear plugs ranged 30–35 dB. We observed some welders and welding supervisors wearing ear plugs during their shift; however, we also observed other welders wearing earbuds (for music).

Welders were responsible for the cleanliness of their booths. We observed welders dry sweeping floors and equipment. Although we did not observe welders using compressed air to clean themselves or equipment, welders reported during medical interviews that they used compressed air for these purposes. We did not observe welders or welding supervisors using vacuums equipped with HEPA filters during our visit or see any vacuums present in the facility.

Most employees brought their lunch and remained on-site during breaks and lunch. The facility provided work uniforms to employees through a contract uniform service, but no dedicated space was available for employees to change out of their street clothes into their company-issued work clothes. We did not observe consistent uniform use by welders or welding supervisors.

Management had provided several water coolers for welders. During our first visit, one welder pointed out that one of these water coolers was located directly behind one of the grinders used by welders to sharpen their tungsten electrodes. A member of the company safety team immediately moved this cooler away from the grinder. During our second visit we noticed this cooler had been moved even further away from the tungsten grinding station.

We observed several unlabeled confined spaces on-site. Most of the confined spaces were tanks: some associated with the house air system, others used to store shield gas for the welders. Management had subcontracted the maintenance of both of these systems.

Methods: Exposure Assessment

Air Sampling

We measured full-shift exposures to chromium, cobalt, and nickel in the personal breathing zone of employees using NIOSH Method 7300 [NIOSH 2019]. We measured full-shift exposures to Cr(VI) in the personal breathing zone of employees using NIOSH Method 7304 [NIOSH 2019].

Noise Sampling

We measured employees' full-shift exposures to noise during two shifts using Larson Davis Spark™ model 706RC integrating noise dosimeters. The dosimeters integrated noise at a 50-hertz (Hz) sampling rate (50 measurements per second) and data-logged five-second-averaged noise levels for the duration of the measurement period. Employees wore dosimeters on their waistband, and we attached the dosimeter microphone on their outer clothing in an upright position midway between the neck and the edge of their shoulder. We covered the microphone with a windscreen to reduce artifact noise caused by the wind or by accidental bumping or rubbing. At the end of the work shift, we downloaded the noise measurement data from the dosimeters using the PCB Piezotronics Blaze™ software.

The dosimeters simultaneously collected noise data using three different settings to allow comparison of noise measurement results with three different noise exposure limits: the NIOSH recommended exposure limit (REL), the OSHA permissible exposure limit (PEL), and the OSHA AL. Noise exposure limits are meant to be the amount of noise that most employees can be exposed to without substantial risk of hearing loss.

We used Larson Davis Model 831 integrating sound level meters to measure sound levels. For our measurements we held by hand, at a height of about 5 ft above ground level and within 3–6 ft of the employees.

Results: Exposure Assessment

None of the three welders working in welding Areas A1 or B1 during our second visit agreed to participate in the industrial hygiene sampling portion of our evaluation. The air sampling results can be found in Table C1, and the noise sampling results can be found in Table C2.

Air Sampling

- Four of the five welders in welding Area B2 and three of the six welding supervisors working on day shift agreed to participate in full-shift personal air sampling during our visit. One of these welders only worked one (of the two) day shifts we evaluated, but the other three welders and the three welding supervisors participated in air sampling on each of the two days of sampling. In total, we took seven air samples on welders and six air samples on welding supervisors.
- All seven employees evaluated had detectable levels of chromium and nickel in their breathing zones on both days of monitoring. One employee was exposed to airborne nickel concentrations of 35 micrograms per cubic meter of air ($\mu g/m^3$), a level well above the NIOSH REL for nickel of 15 $\mu g/m^3$.
- Three of four welders and one of three welding supervisors evaluated had detectable levels of cobalt in their breathing zones on at least one of the days of monitoring.
- All four welders and two of three welding supervisors evaluated had detectable levels of Cr(VI) in their breathing zones on at least one of the days of monitoring.

Noise Sampling

- Five of the welders and three of the welding supervisors working on day shift agreed to participate in full-shift noise monitoring. Two of these welders only participated in noise monitoring during one of the two day shifts we evaluated, but the other three welders and the three welding supervisors participated in noise monitoring on each of the two days of the visit.
- All five welders evaluated were exposed to noise levels above the NIOSH REL on at least one of the days of monitoring. Two of the welders' noise exposures were above the OSHA AL, but none were above the OSHA PEL.
- One of three welding supervisors evaluated was exposed to noise levels above the NIOSH REL. However, none of the welding supervisors' noise exposures were above the OSHA AL or PEL.
- Sound levels varied based on work tasks and activities occurring in the area. Examples of spot sound level measurements we took during the site visit are provided below.
    - Blowing compressed air in the welding booth: 94–101 dBA
    - Using a hand-held grinder in the welding booth: 105–107 dBA
    - Hammering a metal piece in welding booth: 85–91 dBA
    - Welding in a booth: 67–82 dBA
    - Common area between welding and grinding booths: 70–82 dBA

Methods: Employee Health Assessment and Biomonitoring

Confidential Medical Interviews

During our first visit in May 2018, we invited all welders and welding supervisors across all three shifts to participate in confidential medical interviews. Interviews covered basic demographics, work practices and conditions, and work-related health effects. We summarized descriptive statistics for demographic, work, and health information.

Written Questionnaires

We used the results of the interviews to help design the written questionnaire that we administered on our return visit in August 2018. We invited all welders and welding supervisors across all three shifts to complete a written questionnaire. Questionnaires covered basic demographics, work history and practices, training history, work-related health effects, and social history. We summarized descriptive statistics for demographic, work, and health information.

We compared characteristics of surveyed employees using 2×2 contingency tables and the Fisher's exact test for categorical variables. All statistical tests were two-sided, and statistical significance was set at $P < 0.05$. We used OpenEpi version 3.01 to perform statistical analyses.

Nasal Examinations

During the August 2018 visit, we invited all welders and welding supervisors across all three shifts to participate in nasal examinations. The nasal examinations were performed by a NIOSH physician who evaluated the inside of employees' noses for evidence of irritation, open sores, scars, or perforations that could be related to nickel or chromium exposure.

Urine Nickel, Chromium, and Cobalt Testing

During the August 2018 visit, we also invited all welders and welding supervisors across all three shifts to participate in urine testing for nickel, chromium, and cobalt. Urine testing was performed as another method to assess metal exposures among employees. Those participating provided a spot urine specimen at the end of their work shift at the end of their workweek. Urine was analyzed using a standard inductively coupled plasma mass spectrometry method by a laboratory that was contracted by NIOSH to perform the analysis. The laboratory that analyzed the urine specimens had a reporting limit, similar to a detection limit, for urine concentrations for nickel of 4.0 micrograms per liter (µg/L), for chromium of 1.0 µg/L, and for cobalt of 1.0 µg/L. Urine concentrations of nickel, chromium, and cobalt below the respective reporting limit were reported as "none detected."

Urine nickel concentrations were compared to the normal general population concentration for urine nickel of < 4 µg/L and the Finnish Institute of Occupational Health Biomonitoring Action Limit of 5.9 µg/L (0.1 micromoles per liter), an occupational exposure limit (OEL) based on an end of shift, end of workweek urine specimen [Finnish Institute of Occupational Health 2017; WHO 1996]. Elevated urine nickel concentration was defined as an employee of the facility with an end of shift, end of workweek spot urine nickel concentration of ≥ 4 µg/L.

Urine chromium concentrations were compared to the normal general population range for urine chromium of 0.22–1.8 µg/L and the American Conference of Governmental Industrial Hygienists (ACGIH®) biological exposure index (BEI®) for chromium of 25 µg/L [ACGIH 2018; ATSDR 2012].

Elevated urine chromium concentration was defined as an employee of the facility with an end of shift, end of workweek spot urine chromium concentration ≥ 25 µg/L.

Urine cobalt concentrations were compared to the normal general population range for urine cobalt of 0.04–2 µg/L and the ACGIH BEI for cobalt of 15 µg/L [ACGIH 2018; ATSDR 2004]. Elevated urine cobalt concentration was defined as an employee of the facility with an end of shift, end of workweek spot urine cobalt concentration > 2 µg/L.

Results: Employee Health Assessment and Biomonitoring

Confidential Medical Interviews

During our first visit, 28 of the 29 welders and welding supervisors working at the facility participated in confidential medical interviews. Among those interviewed, nine reported a rash or other skin problem over the past three months that they thought was related to work at the facility. Skin problems reported included rash; dry, red, ulcerated, burned, and/or itchy skin; and hives. Five employees reporting skin problems described involvement of the skin of the hands or forearms. Ten employees reported other symptoms over the past three months that they thought were related to work at the facility, including respiratory symptoms (such as cough, n = 5; sinus congestion, n = 2; and nasal ulcers, n = 1), sore throat (n = 2), eye irritation (n = 2), and hearing loss (n = 1). In addition, five interviewed employees reported worsening of their chronic asthma (n = 2), allergies (n = 2), or skin condition (n = 2) at work. In total, 13 employees reported skin or other symptoms or worsening of a chronic condition during the three months preceding the interviews that they thought was related to working at the facility. Of these 13 employees, 12 were welders and 9 worked in Area B2.

Welders we interviewed reported that they frequently received dirty parts to weld. This required them to remove dust from grinding via compressed air or acetone or remove dye penetrant from nondestructive testing with acetone prior to welding. Several welders reported inconsistent use of nitrile gloves when cleaning parts with acetone, and two attributed their skin symptoms at work to acetone exposure. Employees also reported using compressed air to clean equipment and/or work clothes. One welder reported periodic, voluntary use of a half-facepiece elastomeric respirator that was brought from home. Several welders with facial hair stated that they sometimes voluntarily used tight-fitting filtering facepiece respirators at work.

Sixteen employees expressed health and safety concerns during interviews, including dusty or dirty working conditions (n = 9), poor ventilation (n = 5), unsafe fixtures for holding parts (n = 4), and exposures from welding stainless steel parts (n = 3). Other health and safety concerns reported by employees during the interviews included overexposure to noise, exposure to dust from dry sweeping, exposure to dye penetrant used for nondestructive testing, lack of job hazard information, lack of vacuums, and poor preventive maintenance of equipment.

Written Questionnaires

During our second visit, 23 of 26 welders and welding supervisors completed a written questionnaire. Table C3 shows the tasks these employees reported that they performed. The most common tasks reported were welding and grinding. Table C4 shows the facility location where responding employees worked. Eleven employees reported working primarily in Area B2.

Table C5 shows the frequency of hygiene practices by responding employees. A few employees reported inconsistently washing their hands before eating, drinking, smoking, and/or leaving work. Ten employees reported sometimes or always eating or drinking or storing food and/or drink in their work area.

Eighteen employees reported spending time during their shift cleaning work areas, such as welding booths and shared spaces outside of welding booths. All 18 reported dry sweeping facility floors, 12 reported cleaning parts with compressed air, and six reported wiping surfaces with a dry cloth, processes that can suspend dust and other contaminants in the air. Employees noted that they were no longer allowed to clean work clothes with compressed air. Among the four employees who reported vacuuming the facility, only one reported using a vacuum equipped with a HEPA filter.

During our first visit, several employees reported receiving inadequate information about job hazards. On our second visit questionnaires, we asked employees if they had received training in five hazardous communication areas. Table C6 shows the job hazard training employees reported receiving in the past year. The median job tenure among the 10 employees who reported they had not received one more of these hazard communication trainings in the last year was 11 years (range: 1–33 years). Eight reported receiving no training in the last year about the health effects associated with exposure to workplace hazards such as welding fumes, heavy metals, or noise. Seven reported receiving no training in the last year about SDSs for hazardous materials present in the facility.

All 23 responding employees reported using eye protection at work, although 2 welders reported that they did not use eye protection throughout their entire shift. All 23 responding employees also reported using hearing protection at work, but 9 welders and welding supervisors reported that they did not use hearing protection throughout their entire shift. Although 17 employees reported using chemicals or solvents at work, only 2 reported ever wearing goggles.

We asked employees about symptoms and health effects that could be related to exposures at the facility. Table C7 shows selected data related to symptoms and health effects experienced at work by responding employees. Among the six employees with tinnitus symptoms, three reported daily or weekly occurrence. Six of eight employees with trouble hearing clearly or fully reported that the hearing trouble began after starting work at the facility. Among those reporting trouble hearing clearly or fully, the median job tenure at the facility was 20 years compared to a median job tenure of 10 years among those who denied trouble hearing clearly or fully. Reporting use of compressed air for cleaning was significantly associated with reporting trouble hearing clearly or fully, with hearing trouble reported by 7 of the 12 employees who reported using compressed air for cleaning compared to 1 of the 11 who did not ($P = 0.02$). Three employees reported having both tinnitus symptoms and trouble hearing clearly or fully. Although all responding employees reported using hearing protection at work, the activities for which hearing protection was used varied. Some employees reported always wearing hearing protection at work while others reported only wearing hearing protection for specific activities such as grinding.

Six employees reported a history of dermatitis at work during the past three months. Five of these employees reported dermatitis of the upper extremities, with involvement of the arms, forearms, wrists, and/or hands. All employees who reported a history of dermatitis at work during the past three months reported participating in cleaning activities and exposure to chemicals or solvents, especially acetone and dye penetrant. Among the 17 employees who reported handling chemicals, reporting never wearing nitrile gloves when handling these chemicals was significantly associated with reporting a history of dermatitis at work when compared to those who reported sometimes or always wearing nitrile gloves when handling chemicals. Four of five employees who reported never wearing nitrile gloves when handling chemicals reported a history of dermatitis at work during the past three months compared to 2 of 12 who reported sometimes or always wearing nitrile gloves when handling chemicals ($P = 0.03$). Four employees reported improvement of the dermatitis when they were away from work. One employee reported that a healthcare provider felt the dermatitis was related to work at the facility.

We also asked about respiratory symptoms experienced at work over the past three months (Table C7). Nine employees reported at least one respiratory symptom at work during the past three months. Seven of these employees were welders. Symptoms and health effects reported by at least one employee included nasal irritation, wheezing, shortness of breath, chest tightness, nose bleeds, chronic cough, sinus congestion, and sinus infections. Nasal irritation was the most common respiratory symptom reported. Listing exposure to dye penetrant when asked about work-related chemical exposures was significantly associated with reporting at least one respiratory symptom at work. Respiratory symptoms were reported by 5 of the 6 employees who listed exposure to dye penetrant when asked about work-related chemical exposures compared to 4 of 17 who did not list exposure to dye penetrant ($P = 0.02$). Two employees reported worsening of chronic allergy conditions at work.

Nasal Examinations

We looked inside 22 employees' noses for evidence of irritation, open sores, scars, or perforations (open holes through the nasal septum, the cartilage that divides the two nostrils). All employees evaluated had intact nasal septa without evidence of perforation or open sores. However, eight employees had evidence of irritation of the membranes inside the nose.

Among those eight employees with nasal membrane irritation, six were welders, five were assigned to Area B2, and six reported participating in grinding at work. Six reported dry sweeping floors and five reported cleaning parts with compressed air—activities that suspend contaminants in the air. Three of the four employees who reported a history of cigarette smoking and/or e-cigarette use had evidence of nasal membrane irritation.

Urine Nickel, Chromium, and Manganese Testing

Among the 26 welders and welding supervisors working during our second visit, 18 participated in end of shift, end of workweek urine testing for nickel, chromium, and cobalt. Urine nickel results ranged from none detected to 14 µg/L. The result for one welder, 14 µg/L, was above the Finnish Institute of Occupational Health Biomonitoring Action Limit for nickel and slightly soluble nickel salts of 5.9 µg/L [Finnish Institute of Occupational Health 2017]. Four welders and one welding supervisor had results (range: 4.6–14 µg/L) that were above the normal general population urine nickel level of < 4 µg/L [WHO 1996]. One welder with an elevated urine nickel level was exposed to airborne nickel levels above the NIOSH REL. The other three welders and the welding supervisor with elevated urine nickel concentrations did not participate in personal air sampling during our August 2018 visit.

All four welders with elevated urine nickel levels reported regularly dry sweeping floors and using compressed air for cleaning parts. Others reported work practices included eating, drinking, or storing food or drinks in work areas and inconsistent handwashing before leaving work or before eating or drinking while at work. One welder with elevated urine nickel levels reported a history of dermatitis at work in the three months prior to our second visit that improved away from work. Three of the welders with elevated urine nickel levels had evidence of nasal membrane irritation on nasal examination.

Urine cobalt results ranged from none detected to 3.3 µg/L. All of the results were below the ACGIH BEI of 15 µg/L [ACGIH 2018]. The result for one welder, 3.3 µg/L, was above the normal general population urine cobalt range of 0.04–2 µg/L [ATSDR 2004]. This welder reported sometimes eating, drinking, or storing food or drink in work areas and regularly dry sweeping floors and cleaning parts with compressed air.

Urine chromium results ranged from none detected to 1 µg/L. All of the results were below the ACGIH BEI of 25 µg/L and within the normal general population urine chromium range of 0.22–1.8 µg/L [ACGIH 2019; ATSDR 2012].

Discussion

All five welders and one of the welding supervisors who participated in noise sampling were exposed to noise above the NIOSH REL for noise. Two welders were also exposed to noise above the OSHA AL. Our observations suggested that the use of compressed air in welding booths was one of the largest contributors to noise exposures among welders and welding supervisors at the facility. During the second site visit, we observed that welders sometimes used compressed air to cool parts after welding. Our sound level measurements showed that levels reached 101 dBA when the welders performed this task. At this level, a welder's full-shift noise exposures would exceed the NIOSH REL after only 12 minutes of cumulative exposure.

During our first visit, welders reported the occasional use of air-powered grinders; an activity they felt was extremely noisy. Sound level measurements during the second visit showed that noise levels were 105–107 dBA during use of these grinders. Although use is limited, welders' full-shift exposures to noise would be above the NIOSH REL after 3 minutes of cumulative exposure. None of the welders wore hearing protection while welding, but many wore audio headphones or earbuds, which did not provide hearing protection.

Welders told us during interviews that they frequently received dirty parts for welding. We observed welders using acetone to clean dye penetrant from parts before welding. Although we did not observe welders using compressed air for cleaning parts during our site visit, interview and questionnaire responses suggested that they often used compressed air to clean dirty parts prior to welding. Reporting use of compressed air for cleaning was significantly associated with welders reporting trouble hearing clearly.

Questionnaire responses and review of OSHA 300 logs also suggested that employees may have developed noise-induced hearing loss while working at the facility. Among questionnaire respondents, 11 reported tinnitus symptoms and/or trouble hearing clearly. Review of OSHA 300 logs demonstrated that three welders reported hearing loss over the period of 1/1/2012–12/31/2016. Because welders and welding supervisors were not enrolled in the facility's hearing conservation program at the time of our evaluation, no audiometry testing records were available to assist us with confirming the presence or absence of hearing loss.

Tinnitus has been associated with work-related noise exposures [Steinmetz et al. 2009] and objectively measured hearing loss, with hearing loss detected in 85%–96% of those with tinnitus [Martines et al. 2010; Savastano 2008]. Study results evaluating the association between subjectively reported hearing loss and the presence of objective hearing loss on audiometry are mixed. A recent study from Brazil found that subjective measures of hearing loss correlated with audiometry findings [Costa-Guarisco et al. 2017]. However, another analysis of a nationally representative sample in the United States found that demographic factors such as age, race, and education level may impact the accuracy of subjective measures of hearing loss [Kamil et al. 2015].

Our small sample size and the lack of available audiograms prevented us from evaluating for statistical associations between hearing-related symptoms reported on questionnaires and objective findings on audiometry. However, the results of our evaluation and evidence from the scientific literature demonstrate the importance of including welders and welding supervisors in a hearing conservation program. Limiting or eliminating the use of compressed air and utilizing noise dampening nozzles for air hoses will help to reduce noise exposures to welders and welding supervisors from this major noise source. Ensuring that welders receive clean parts should prevent them from needing to use compressed air to remove contaminants from parts prior to welding.

Although we generally found relatively low air exposures to metals during our sampling, one welder's airborne nickel exposure level was 35 $\mu g/m^3$—more than twice the NIOSH REL for nickel of 15 $\mu g/m^3$. This welder was one of five welders and welding supervisors participating in urine metal testing that had end of shift, end of workweek urine nickel levels above the normal general population urine nickel level. These findings suggest that overexposure to airborne nickel at work likely contributed to this welder's elevated urine nickel concentration. In addition, another welder had a urine nickel concentration that was elevated above the Finnish Institute of Occupational Health Biomonitoring Action Limit for nickel and slightly soluble nickel salts [Finnish Institute of Occupational Health 2017]. Although this welder did not participate in personal air monitoring during our visit, the level of urine nickel we detected and the lack of other reported sources of nickel exposure outside of work strongly suggest that occupational exposures contributed to the elevated urine nickel concentration we detected.

Evidence suggests that increased urinary nickel levels may be associated with work and personal hygiene practices [ATSDR 2005; Sunderman et al. 1986]. Our small sample size did not allow us to make statistical associations between elevated urine nickel concentrations and specific factors. However, work practices reported on questionnaires such as using compressed air and dry sweeping to clean surfaces, practices that suspend contaminants in the air, may have contributed to inhalational exposure to nickel. Personal practices identified on questionnaires and workplace observations such as eating, drinking, or storing food or drinks in work areas, holding a welding rod in the mouth, and inconsistent handwashing before eating or drinking at work may also have contributed to occupational nickel exposures. The scientific literature suggests that urinary nickel excretion among nickel-exposed workers increases over the course of a work shift and throughout the workweek [ATSDR 2005]. Studies also indicate that elevated urine nickel levels may persist even after nickel exposures are reduced or eliminated [Boysen et al. 1984; Sunderman et al. 1986]. It is possible that the urine nickel concentrations we found represent declining levels from exposures that occurred prior to our visit. If so, our results could significantly underestimate typical nickel exposures at the facility.

One welder's urine cobalt level was elevated above the normal general population urine cobalt range. Cobalt enters the body primarily through inhalation but ingestion and dermal absorption are other routes of exposure [ATSDR 2004; Christensen and Poulsen 1994; Scansetti et al. 1994]. Although this welder's airborne cobalt level of 7.1 $\mu g/m^3$ was well below current OELs, it was the highest cobalt air concentration we measured during our visit. Dry sweeping floors and cleaning parts with compressed air may have also contributed to inhalational cobalt exposures. Eating, drinking, and/or storing food and drink in work areas may have contributed to exposures through ingestion. As with other metals, cobalt can accumulate in the body of those who are chronically overexposed [ATSDR 2004; Scansetti et al. 1994]. Therefore, exposures prior to our visit may also have contributed to the elevated urine cobalt level we detected.

The results for previous air sampling performed at the facility in 2017 indicated that a welder's airborne Cr(VI) level was elevated above the NIOSH REL. Although our air sampling did not identify any overexposures to chromium or Cr(VI), we detected chromium and Cr(VI) in every personal air sample we collected. One welder had a urine chromium level of 1 µg/L, but none of the other welders and welding supervisors participating in urine metal testing had detectable levels of chromium in their urine. No one had a urine chromium level that approached or exceeded the ACGIH BEI for chromium of 25 µg/L, an OEL based on an end of shift, end of workweek urine specimen [ACGIH 2019].

Nickel exposure can cause allergic skin reactions and respiratory problems, such as asthma and reduced lung function [ATSDR 2005]. It may also irritate nasal mucous membranes. Chronic overexposure to insoluble nickel compounds is associated with the development of cancers of the nasal sinus and lung [ATSDR 2005; IARC 2012]. Cr(VI) can also cause skin and nasal irritation and result in nasal septal scarring or perforations and lung cancer in individuals who are chronically overexposed [Gibb et al. 2000; NIOSH 2013]. Cobalt exposure can also cause skin irritation and respiratory conditions such as asthma [ATSDR 2004]. Although 8 of 22 welders and welding supervisors who participated in nasal examinations had evidence of nasal membrane irritation, this finding is nonspecific with factors such as dust exposure or environmental allergens causing similar findings [Shusterman 2003]. We did not find evidence on nasal examinations of more severe complications of Cr(VI) exposure, such as nasal septal scarring or perforations. Our small sample size prevented us from being able to evaluate for associations between levels of urine nickel, chromium, and/or cobalt and specific skin or respiratory health effects.

Eliminating work activities like dry sweeping and the use of compressed air for cleaning could reduce employees' exposures to metal dusts and the respiratory hazard they pose. Instead, facility management should ensure that welders receive clean parts and use vacuums equipped with HEPA filters for cleaning surfaces when necessary. When HEPA-filtered vacuums are not available, wet cleaning methods (e.g., wet wiping, mopping) can be used in areas where these housekeeping methods do not cause a potential electrical or other safety hazard. Until engineering controls reduce exposures to below exposure limits, welders should be enrolled in the respiratory protection program.

In addition to prohibiting work practices that can increase airborne metal particulates, installing and using LEV systems during welding could reduce employees' exposures to metal fumes. The company had previously purchased some of these systems, but welders reported receiving no training on their use. Welders also reported that these systems interfered with the shield gases during welding. In general, LEV systems for welding should use movable hoods that can be easily positioned within 18 inches of the weld and can maintain capture velocity ranging from 100 to 170 feet per minute [ACGIH 2016].

Before purchasing an LEV system, involve welders in the process of identifying, testing, and selecting a system they feel would work for them. After engineering controls have been installed, worker exposures should be reevaluated to determine if controls are effectively reducing exposures of concern (e.g., chromium, Cr(VI), nickel, and cobalt) below relevant OELs. Worker exposures should also be reevaluated after any process changes in the facility to determine exposure levels under new conditions. Any LEV system must be designed to meet fire, safety, or environmental codes that apply to this facility and operations. Maintenance should be performed regularly to remove material that accumulates in LEV systems. Personal exposure monitoring should be conducted to characterize worker exposures during the maintenance activities. Personnel performing these maintenance tasks should be provided with appropriate controls or PPE to protect them from exposures.

We found a significant association between welders and welding supervisors who reported never wearing nitrile gloves when handling chemicals and those who reported dermatitis on questionnaires. The most common chemical exposures reported included acetone and dye penetrant, a product used at the facility to check parts for cracks and defects. During interviews, welders reported that acetone was commonly used to clean dirty parts prior to welding. We also observed welders using acetone to clean parts before welding during our visits. The SDSs for acetone and the dye penetrant both state that these chemicals can cause skin irritation. We also found a significant association between welders and welding supervisors who reported respiratory symptoms and those who reported exposure to the dye penetrant. Respiratory tract irritation is a known health effect of the dye penetrant according to the SDS for this chemical. These associations further demonstrate the need to ensure that welders receive clean parts. Receiving clean parts would eliminate both the need to use acetone for cleaning and their exposure to the dye penetrant. As a result, exposures to these known skin and respiratory irritants will be reduced or eliminated. All employees should be required to wear nonlatex, chemical-resistant gloves when handling chemicals to further protect their skin from irritation caused by chemical exposure.

Limitations

Our evaluation is subject to several limitations. First, industrial hygiene sampling can only document exposures on the days of sampling in the locations sampled. These results may not be representative of conditions during other days. Second, poor participation in the industrial hygiene sampling resulted in a small population, limiting the statistical power and generalizability of our results. Third, reports of a lower than usual workload during our visit may have resulted in lower than usual exposure levels on the days of sampling. The low workload also prevented us from fully accounting for the wide variety of parts handled and welding tasks performed at the facility. Consequently, our industrial hygiene sampling and urine testing results may underestimate exposures at the facility. Fourth, we were unable to account for seasonal effect on general ventilation at the facility. Finally, because the interviews and questionnaires asked employees about the past, these results are subject to recall bias.

Conclusions

Although these workers faced some overexposures, the use of various controls could significantly reduce these exposures. The results of our document review, noise sampling, and questionnaires suggest that welders and welding supervisors are overexposed to noise. Engineering and administrative controls are needed to prevent or reduce noise exposures at the facility. Based on the air sampling and biological monitoring results, some welders may be overexposed to nickel and cobalt. Implementation of engineering and administrative controls can reduce these exposures.

Section C: Tables

Table C1. Range of personal air sampling results, in micrograms per cubic meter of air (µg/m³)

Position	Nickel	Cobalt	Chromium	Cr(VI)
Welders (n = 4)	3.5–35	0.085–7.1	1.3–12	0.0084–0.046
Welding supervisors (n = 3)	0.75–2.5	0.03–0.32	0.25–1.0	0.0038–0.011
NIOSH REL	15	50	500	2
ACGIH TLV	1,500	20	500	10*; 50†
OSHA PEL	1,000	100	1,000	5
Minimum detectable concentration (MDC)	0.11‡	0.085‡	0.11‡	0.0021§
Minimum quantifiable concentration (MQC)	0.47¶	0.29¶	0.43¶	0.0081**

TLV = Threshold limit value

*TLV for water-insoluble Cr(VI) compounds

†TLV for water-soluble Cr(VI) compounds

‡MDC was calculated by dividing the analytical methods limit of detection (LOD) by an air sample volume of 944 m^3.

§MDC was calculated by dividing the analytical methods LOD by an air sample volume of 937 m^3.

¶MQC was calculated by dividing the analytical methods limit of quantitation (LOQ) by an air sample volume of 944 m^3.

**MQC was calculated by dividing the analytical methods LOQ by an air sample volume of 937 m^3.

Table C2. Range of full shift time-weighted average noise exposures in decibel, A-weighted (dBA)

Position	Number of measurements	Results based on OSHA AL method	Results based on OSHA PEL method	Results based on NIOSH REL method
Welder	8	72.6–88.6	62.2–88.2	78.7–95.0
Welding Supervisors	7	70.3–81.9	50.0–77.7	76.0–86.9
Noise exposure limits (8-hour work shift)		85.0	90.0	85.0

Table C3. Description of job tasks reported by employees on the questionnaire

Task	Number of employees (n = 23)
Welding	15
Grinding	11
Training	6
Cutting	5
Supervise other employees	5
Quality control	4
X-ray parts	3

Table C4. Primary work location reported by employees on the questionnaire

Location	Number of employees (n = 23)
Area B2	11
Area B1	7
Area A1	4
Multiple areas throughout the facility	1

Table C5. Frequency of hygiene practices reported by employees on the questionnaire (n = 23)

Practice	Frequency		
	Always	Sometimes	Never
Wash hands before eating/drinking/smoking	18	5	0
Wash hands before leaving work	16	5	2
Eat/drink or store food/drink in work area	2	8	13

Table C6. Description of training activities reported by employees on the questionnaire

Training	Number of employees (n = 23)
Workplace hazards	20
Use of PPE	20
Ways to prevent or reduce exposures to workplace hazards	18
Safety data sheets for hazardous materials present in the facility	16
Health effects associated with exposure to workplace hazards	15

Table C7. Symptoms and health effects occurring at work reported by employees on the questionnaire

Symptom or health effect	Number of employees (n = 23)
Trouble hearing clearly or fully	8
Nasal irritation	7
Tinnitus (ringing, roaring, or buzzing in the ears)	6
Dermatitis	6
Wheezing	3
Shortness of breath	2
Chest tightness	2
Nose bleeds	2
Chronic cough	1
Sinus congestion	1
Sinus infections	1

Section D: Occupational Exposure Limits

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 preexisting 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 limits (STELs) 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.

- OSHA, an agency of the U.S. Department of Labor, publishes PELs [29 CFR 1910 for general industry; 29 CFR 1926 for construction industry; and 29 CFR 1917 for maritime industry] called PELs. These legal 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 2007]. 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.
- Other OELs commonly used and cited in the United States are the ACGIH TLVs®. The TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2019].

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.

Chromium and Hexavalent Chromium

Chromium (Cr) metal is a hard, blue-white to steel-gray colored, lustrous, brittle element [NIOSH 2007]. In the environment, it exists primarily in two valence states: trivalent Cr or Cr(III) and hexavalent Cr or Cr(VI) [EPA 2000]. Materials containing Cr(VI) include various paint and primer pigments, graphic art supplies, fungicides, corrosion inhibitors, and wood preservatives. Some of the industries where the largest numbers of workers are exposed to high concentrations of Cr(VI) compounds include electroplating, welding, and painting. An estimated 558,000 U.S. workers are exposed to airborne Cr(VI) compounds in the workplace.

Although Cr is an essential trace element in humans, Cr(VI) is extremely toxic and designated as a human carcinogen [IARC 2012; NIOSH 2013; OSHA 2006]. Cr(VI) is associated with lung cancer and nasal and sinus cancer; nonmalignant respiratory effects include irritated, ulcerated, or perforated nasal septa. The NIOSH REL for Cr(VI) compounds is intended to reduce workers' risk of lung cancer associated with occupational exposure to Cr(VI) compounds over a 45-year working lifetime. It is expected that reducing airborne workplace exposures to Cr(VI) will also reduce the nonmalignant respiratory effects of Cr(VI) compounds, including irritated, ulcerated, or perforated nasal septa and other potential adverse health effects. Because of the residual risk of lung cancer at the REL, NIOSH further recommends that continued efforts be made to reduce Cr(VI) exposures to below the REL [NIOSH 2013]. The median airborne concentration of Cr(VI) in a study of U.S. workers, some of whom had nasal ulceration, was 20 $\mu g/m^3$, and the median time from employment to first diagnosis of nasal ulceration was less than a month [Gibb et al. 2000].

Dermal exposures to Cr(VI) can result in skin irritation, ulcers, skin sensitization, and allergic contact dermatitis. In addition to limiting airborne concentrations of Cr(VI) compounds, NIOSH recommends preventing dermal exposure to Cr(VI) in the workplace to reduce the risk of adverse dermal effects [NIOSH 2013].

NIOSH RELs for Cr include the NIOSH REL for Cr metal, Cr(II), and Cr(III) compounds of 500 $\mu g/m^3$. The NIOSH REL for all Cr(VI) compounds is 0.2 $\mu g/m^3$ [NIOSH 2007]. OSHA PELs for Cr and Cr compounds include the OSHA PEL for Cr metal and insoluble salts of 1,000 $\mu g/m^3$ [29 CFR 1910.1000, Table Z-1], the OSHA PEL for Cr(II) and Cr(III) compounds of 500 $\mu g/m^3$ [29 CFR

1910.1000, Table Z-1], and the OSHA PEL for Cr(VI) of 50 μg/m³ [29 CFR 1910.1026]. The ACGIH TLV is 50 μg/m³ for water soluble hexavalent chromium compounds and 10 μg/m³ for insoluble hexavalent chromium compounds [ACGIH 2019].

Urinary Cr levels are a measure of total Cr exposure. Total Cr is used as a marker of exposure even in situations where Cr(VI) is the primary concern. A review of the literature suggests that persons in the normal general population without occupational exposure to Cr or Cr(VI) often have urine Cr levels of 0.22–1.8 μg/L [ATSDR 2012]. Among persons exposed to Cr(VI) at work, the ACGIH BEI for Cr(VI) of 25 μg/L is based on the total Cr in a urine sample collected at the end of the shift at the end of the workweek. This BEI is based on the observed correlation with exposure to soluble Cr(VI) and applies to employees with a history of chronic Cr(VI) exposure. The ACGIH also has a BEI for Cr(VI) of 10 μg/L for the increase in total Cr over a single shift when comparing preshift and postshift Cr levels [ACGIH 2019]. OSHA does not have a legal requirement for levels of urine chromium.

Cobalt

Cobalt is an essential element and is present in the human diet in tiny amounts. Occupational cobalt exposure comes from metallurgical industries where metals containing cobalt are processed by grinding, drilling, and sanding. Cobalt is also used as a pigment in some artist supplies.

Cobalt is beneficial for humans in small amounts. It is a part of vitamin B12, an essential compound for maintaining health in humans. Cobalt helps with red blood cell production, the primary oxygen carriers in the human body, and has therefore been used to treat anemia or low levels of red blood cells [ATSDR 2004]. However, overexposure to cobalt can have harmful effects. The most common adverse health effects associated with overexposure to cobalt occur in the lungs and skin, but cobalt exposure may also cause harmful effects on the heart. Cobalt exposure has been associated with the development of occupational asthma and pneumoconiosis (a restrictive lung disease caused from inhaling dust), especially among those exposed to so-called "hard metal," a cobalt-tungsten carbide alloy [ATSDR 2004; Gheysens et al. 1985; Sjögren et al. 1980]. Some studies suggest that even low levels of cobalt exposure can lead to a decrease in lung function [Rehfisch et al. 2012]. Cobalt exposure has also been associated with skin rashes consistent with allergic contact dermatitis [ATSDR 2004; Sjögren et al. 1980; Swennen et al. 1993]. Evidence also indicates that overexposure to cobalt may cause heart problems such as reduced heart function [ATSDR 2004; Horowitz et al. 1988; Packer 2016].

The NIOSH REL for cobalt is 0.05 mg/m³ [NIOSH 2007]. The OSHA PEL for cobalt metal, dust, and fume is 0.1 mg/m³ [29 CFR 1910.1000, Table Z-1]. The ACGIH TLV for elemental cobalt and inorganic cobalt compounds is 0.02 mg/m³ [ACGIH 2019].

A review of the medical literature suggests that persons in the normal general population without occupational exposure to cobalt often have urine cobalt levels of 0.04–2 μg/L [ATSDR 2004]. Persons taking multivitamin pills containing cobalt, and those who have undergone total hip replacement have been shown to have increased cobalt excretion in the urine [ACGIH 2019]. Among persons exposed to cobalt and inorganic cobalt compounds at work, the ACGIH BEI for urine cobalt is 15 μg/L in a urine sample collected at the end of the shift at the end of the workweek [ACGIH 2019]. OSHA does not have a legal requirement for levels of urine cobalt.

Nickel

Nickel metal is a hard, lustrous, silvery-white colored element. It is used in alloys, nickel plating, ceramic coloring, and batteries. Nickel is particularly useful in alloys because of the corrosion and heat resistance, hardness, and strength that it provides [ATSDR 2005].

Although trace amounts of nickel are essential for human health, overexposure to nickel can have harmful effects. Allergic reactions from direct skin contact with nickel, such as development of a rash at the site of the nickel contact, are the most common harmful health effect in humans. More serious harmful health effects have been noted among working populations who are chronically overexposed to nickel. Inhalation of nickel-containing dust and fumes may cause asthma attacks in workers who are sensitized to nickel or may lead to chronic bronchitis or reduced lung function over time [ATSDR 2005]. Nickel is also considered a cancer-causing agent, with chronic overexposures to insoluble nickel compounds leading to nasal sinus and lung cancer [ATSDR 2005; IARC 2012].

The NIOSH REL for nickel, based on its designation as a potential occupational lung carcinogen, is 0.015 mg/m^3 [NIOSH 2007]. The OSHA PEL for nickel metal and insoluble and soluble nickel compounds is 1 mg/m^3 [29 CFR 1910.1000, Table Z-1]. The ACGIH TLV for insoluble nickel compounds (i.e., nickel sulfide and nickel oxide) is 0.2 mg/m^3, for soluble nickel compounds and nickel subsulfide is 0.1 mg/m^3, and for elemental nickel is 1.5 mg/m^3 [ACGIH 2019]. All the TLVs for nickel are applicable to the inhalable fraction of employee exposures to particulates.

A review of the literature suggests that persons in the normal general population without occupational exposure to nickel often have urine nickel levels of < 4 µg/L [WHO 1996]. Although there are no established OELs in the United States for levels of nickel in the urine, the Finnish Institute of Occupational Health has set a Biomonitoring Action Limit (similar to an ACGIH BEI) for nickel of 5.9 µg/L (0.1 micromoles per liter) in a postshift urine sample collected at the end of the workweek [Finnish Institute of Occupational Health 2017].

Noise

Noise-induced hearing loss (NIHL) is an irreversible condition that progresses with noise exposure. It is caused by damage to the nerve cells of the inner ear and, unlike some other types of hearing disorders, cannot be treated medically [Berger et al. 2003]. More than 22 million U.S. workers are estimated to be exposed to workplace noise levels above 85 dBA [Tak et al. 2009]. NIOSH estimates that workers exposed to an average daily noise level of 85 dBA over a 40-year working lifetime have an 8% excess risk of material hearing impairment. This excess risk increases to 25% for an average daily noise exposure of 90 dBA [NIOSH 1998]. NIOSH defines material hearing impairment as an average of the hearing threshold levels for both ears that exceeds 25 dB at frequencies of 1,000 Hz; 2,000 Hz; 3,000 Hz; and 4,000 Hz.

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

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

Employees exposed to noise should have baseline and yearly hearing tests to evaluate their hearing thresholds and determine whether their hearing has changed over time. Hearing testing should be done in a quiet location, such as an audiometric test booth, where background noise does not interfere with accurate measurement of hearing thresholds. In workplace hearing conservation programs, hearing thresholds must be measured at 500 Hz; 1,000 Hz; 2,000 Hz; 3,000 Hz; 4,000 Hz; and 6,000 Hz. Additionally, NIOSH recommends testing at 8,000 Hz [NIOSH 1998]. The OSHA hearing conservation standard requires analysis of changes from baseline hearing thresholds to determine if the changes are substantial enough to meet OSHA criteria for a standard threshold shift (STS). OSHA defines an STS as a change in hearing threshold (relative to the baseline hearing test) of an average of 10 dB or more at 2,000 Hz; 3,000 Hz; and 4,000 Hz in either ear [29 CFR 1910.95]. If an STS occurs, the company must determine if the hearing loss also meets the requirements to be recorded on the OSHA Form 300 Log of Work-Related Injuries and Illnesses [29 CFR 1904.1]. In contrast to OSHA, NIOSH defines an STS as a change in the hearing threshold level of 15 dB or more (relative to the baseline hearing test) at any test frequency in either ear measured twice in succession [NIOSH 1998].

The NIOSH REL for noise is 85 dBA, as an 8-hour TWA. For calculating exposure limits, NIOSH uses an 80 dBA threshold and a 3-dB time/intensity trading relationship or exchange rate. Noise below the threshold level is not integrated by the noise dosimeter during measurements. The exchange rate expresses how much the sound level could increase or decrease while keeping the risk of hearing loss the same, if the exposure duration was simultaneously decreased or increased. For example, a 3-dB exchange rate requires that noise exposure time be halved for each 3-dB increase in noise levels. NIOSH considers noise measured using the 3-dB exchange rate to more accurately relate noise exposures to hearing loss risk [NIOSH 1998]. Using the NIOSH criterion, an employee can be exposed to 88 dBA for no more than 4 hours, 91 dBA for 2 hours, 94 dBA for 1 hour, 97 dBA for 0.5 hours, etc. For extended work shifts, NIOSH adjusts the REL to 84.5 dBA for a 9-hour shift, 84.0 dBA for a 10-hour shift, 83.6 dBA for an 11-hour shift, and 83.2 dBA for a 12-hour work shift. NIOSH recommends the use of hearing protection and the implementation of a hearing loss prevention program when noise exposures exceed the REL [NIOSH 1998].

The OSHA noise standard specifies a PEL of 90 dBA and an AL of 85 dBA, both as 8-hour TWAs. For calculating exposure limits, OSHA uses a 90 dBA threshold and a 5-dB exchange rate for PEL measurements and an 80 dBA threshold and 5-dB exchange rate for AL measurements. Using the OSHA criterion, an employee may be exposed to noise levels of 95 dBA for no more than 4 hours, 100 dBA for 2 hours, 105 dBA for 1 hour, 110 dBA for 0.5 hours, etc. Exposure to impulsive or impact noise must not exceed 140 dB peak noise levels. OSHA does not adjust the PEL for extended work shifts. However, the AL is adjusted to 84.1 dBA for a 9-hour shift, 83.4 dBA for a 10-hour shift, 82.7 dBA for an 11-hour shift, and 82.1 dBA for a 12-hour work shift. OSHA requires implementation of a hearing conservation program when noise exposures exceed the AL [29 CFR 1910.95]. More details on the OSHA noise standard are available at https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.95.

Welding Fumes

The effect of welding fumes on an individual's health can vary depending on the length and intensity of the exposure and the specific metals involved. Of particular concern are welding processes involving stainless steel, cadmium or lead-coated steel, and metals, such as manganese, iron, nickel, chrome, zinc, and copper. Fumes from these metals are considerably more toxic than those encountered when welding iron or mild steel. Epidemiologic studies and case reports of employees exposed to welding emissions have shown an excessive incidence of acute and chronic respiratory diseases [NIOSH 1988]. These illnesses include metal fume fever, pneumonitis, pulmonary edema, and lung cancer. Exposure to manganese has been associated with Parkinson-like health effects, such as poor hand-eye coordination, motor slowing, increased tremor, reduced response speed, mood disturbance, and possible memory and intellectual loss [Antonini et al. 2006; Bowler et al. 2006; Lundin et al. 2014; Racette et al. 2012; Welch et al. 2004].

The content of welding fumes depends on the base metal being welded, the welding process, and parameters such as voltage and amperage, the composition of the consumable welding electrode or wire, the shielding gas, and any surface coatings or contaminants on the base metal. The flux coating (or core) of the electrode/wire may contain up to 30 organic and inorganic compounds. In general, welding fume constituents may include minerals, such as silica and fluorides, and metals, such as arsenic, beryllium, cadmium, chromium, cobalt, nickel, copper, iron, lead, magnesium, manganese, molybdenum, tin, vanadium, and zinc [NIOSH 1988; Welding Institute 1976]. OSHA has not established a PEL for total welding fumes; however, PELs have been set for individual welding fume constituents (e.g., iron, manganese) [29 CFR 1910.1000]. NIOSH has concluded that it is not possible to establish an exposure limit for total welding emissions because the composition of welding fumes and gases varies greatly, and the welding constituents may interact to produce adverse health effects. Therefore, NIOSH recommends controlling total welding fume to the lowest feasible concentration and meeting the exposure limit for each welding fume constituent [NIOSH 2007]. In addition to welding fumes, many other potential health hazards exist for welders. Welding operations can produce gaseous emissions, such as carbon monoxide, ozone, nitrogen dioxide, and phosgene (formed from chlorinated solvent decomposition) [NIOSH 1988; Welding Institute 1976]. Welders can also be exposed to hazardous levels of ultraviolet radiation from the welding arc if welding curtains or other precautions are not used.

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