HealthHazard® Evaluation Program

Evaluation of Exposures to Metals, Metalworking Fluids, Alcohols, and Volatile Organic Compounds at an Acrobatic Equipment Manufacturer

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Disclaimer

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Introduction

Request

We received a request from employees who work at a company that makes acrobatic equipment. They were concerned that exposures to the multiple substances used in or generated during production could be causing respiratory and skin irritation and related symptoms.

Workplace

The company manufactured custom acrobatic equipment used by performance artists. The production process included the following tasks:

- Cutting, grinding, milling, drilling, and deburring aluminum pipe
- Heating polyvinyl chloride (PVC) tubing
- Resin casting
- Soldering
- Welding
- Gluing
- Three-dimensional (3-D) printing
- Computer programming for lighting display

Employees used multiple substances including metalworking fluids, ultraviolet-cured glue, denatured alcohol, and soap to accomplish these tasks. During our visit, four company employees (three employees and the company owner) completed all production activities in an open plan workshop.

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

Our Approach

In February 2019, we spent two days at the facility to learn more from management and employees about the production process, work tasks, potential exposures, and health concerns. During our visit, we completed the following activities:

- Observed employees performing all production tasks needed to produce the custom acrobatic equipment.
- Evaluated the local exhaust ventilation systems.
- Collected task-based air samples for metalworking fluids, metals, alcohols, and volatile organic compounds.

- Held voluntary, confidential interviews with all employees to gather information about work history, tasks performed, personal protective equipment use, and health concerns and symptoms.

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

Our Key Findings

Employees reported experiencing symptoms that could be worsened by the materials and chemicals used in the production process

- At least one employee reported symptoms that included eye, nose, and throat irritation, or cough. However, we were not able to determine if these symptoms were caused by a specific exposure.
- By controlling exposures during the work process, the company and employees can possibly prevent further illness or a worsening of symptoms.

Personal task-based air samples showed employees were exposed to low levels of metals and volatile organic compounds

- The highest levels of metals were detected during welding.
- Isopropyl alcohol and ethanol were detected during PVC skinning and 3-D printing.

Workplace conditions and practices could be improved to reduce potential exposures

- We identified areas where engineering and administrative controls could be applied to reduce the potential for exposure.
- We observed inconsistent use of personal protective equipment.

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	↑ Enhanced image and reputation
↑ Better workplace morale	↑ Superior products, processes, and services
↑ Easier employee recruiting and retention	↑ May 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 personal protective equipment might be needed. Read more about the hierarchy of controls at 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* at https://www.osha.gov/shpguidelines/index.html.

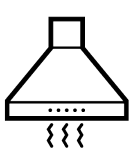
Recommendation 1: Install controls and improve work practices to reduce employee exposures to metals and volatile organic compounds.

Why? Employees reported concerns about the potential health effects of exposure to different components of the acrobatic equipment and substances used during assembly. Since the workspace was one open area, employees could be exposed to the materials their coworkers used during job tasks.

We identified the following:

- Welding operations were performed in the open work area, typically when other employees were not around.
- A filter change-out plan or schedule for the portable air filtration units used throughout the facility was not available.
- Guidance on the voluntary use of respiratory protection was not available.

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



Create a welding area with local exhaust ventilation to capture welding fumes at the source.

- Train employees how to properly use the local exhaust ventilation system.
- Establish an operations and maintenance program for the local exhaust ventilation system to ensure they continue to function properly.

Develop and follow a filter change-out schedule for the portable air filtration system based on the manufacturer's usage recommendations.

Develop a voluntary-use respirator program to ensure that the respirator itself will not be a hazard for employees.

- The program for voluntary use of half-face elastomeric air-purifying respirators should include medical evaluation of employees, developing and implementing schedules for maintaining the respirators including cleaning, disinfecting, storing, inspection, and repairing respirators. Provide employees with a copy of Appendix D of the Occupational Safety and Health Administration's (OSHA) Respiratory Protection Standard. Additional detail can be found in OSHA's Small Entity Compliance Guide for the Respiratory Protection Standard (osha.gov).

- Instruct employees who voluntarily wear respirators on how to wear them properly. The National Institute for Occupational Safety and Health (NIOSH) has publications for employees on how to wear filtering facepiece respirators such as disposable N95 respirators as well as other types of air-purifying respirators: How to Wear Your Filtering Facepiece Respirator (cdc.gov) and A Guide to Air-Purifying Respirators, DHHS (NIOSH) Publication No. 2018-176 (cdc.gov).

- The OSHA Small Business Safety and Health Handbook provides guidance on voluntary respirator use and additional information on respiratory protection.

Recommendation 2: Reduce employee exposures to metalworking fluids.

Why? Exposure to metalworking fluids can cause a variety of health effects. Skin exposure can lead to or worsen symptoms of skin irritation or dermatitis. Breathing aerosols containing metalworking fluid can lead to or worsen symptoms of respiratory irritation (e.g., cough) and multiple medical conditions (e.g., chronic bronchitis, asthma, and hypersensitivity pneumonitis).

Although we did not find levels of metalworking fluid aerosols that exceeded recommended exposure limits, reducing employee exposures will prevent developing or worsening of irritation and medical conditions.

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

Continue to use engineering controls such as local ventilation, splash guards, and machine enclosures to reduce exposure to metalworking fluids and aerosols.

Develop and follow a cleaning, decontamination, and routine maintenance plan for the computer numerical control (CNC) machine. Include in this plan, the tramp oil removal equipment, metalworking recycling containers, and all instrumentation that contacts metalworking fluid during normal operations.

- When all components of the metalworking fluid system have been decontaminated, all used metalworking fluid should be disposed of and replaced with new metalworking fluid.
- Follow manufacturer's guidance regarding the addition of a biocide (a chemical substance that inhibits the growth of living organisms) to the metalworking fluid.

Train employees working with metalworking fluid on how to properly handle and use it. Include training about potential hazards and health effects of metalworking fluid exposure.

- Training should include how to avoid skin irritation by washing hands and arms up to the elbows to remove fluid; drying hands with clean, dry towels; and using moisturizers before and after work to keep the skin in good condition and help protect against the irritant effects of metalworking fluids. Also tell employees how to carefully select moisturizers, soaps, and skin cleaners. Suggest they avoid ingredients such as lanolin and fragrances, which are known allergens and can cause allergic contact dermatitis in sensitive individuals.
- Guidelines for metalworking fluid training are included in the NIOSH document What You Need to Know about Occupational Exposure to Metalworking Fluids.

Improve employee access to gloves and require them to wear them during tasks where metalworking fluid is used.

Encourage employees to change clothes if their clothing becomes soiled with metalworking fluid.

- Remove soiled clothing to reduce skin exposure, prevent irritation, and prevent developing dermatitis.
- Launder soiled clothing separately before wearing again.

Recommendation 3: Encourage employees with work-related health concerns to talk to their healthcare provider about their exposures to metals, volatile organic compounds, and metalworking fluids at work.

Why? Identifying symptoms early can reduce severity and lead to appropriate treatment if needed.

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

If needed, employees should seek care for work-related medical concerns from a healthcare provider knowledgeable in occupational medicine.

- The American College of Occupational and Environmental Medicine (https://acoem.org/Find-a-Provider) and the Association of Occupational and Environmental Clinics (http://www.aoec.org/index.htm) maintain databases of providers to help locate someone in your geographic area.
- Consider sharing a copy of this report with the healthcare provider.

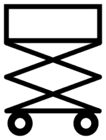
Recommendation 4: Address other health and safety issues we identified during our evaluation.

Why? A workplace can have multiple health hazards that cause worker illness or injury. Like the ones identified above, these hazards can potentially cause serious health symptoms, lower morale, and quality of life for your employees, and possibly increased costs to your business. We saw the following potential issues at your workplace:

- Some tasks resulted in employees working in awkward postures. Low work heights and non-adjustable workstations place workers at risk for musculoskeletal disorders.
- Employees mainly stood while completing production tasks. Using anti-fatigue mats for job tasks requiring prolonged standing, along with routine rotation of job duties, can help reduce muscle fatigue.
- Employees prepared and stored food and kitchen supplies in the production space close to where production activities occurred. Storing and preparing food in the production area may lead to food contamination and ingestion of materials and chemicals used during the production process.
- The production area did not have an eye wash station. Safety data sheets for multiple products used during production indicated that an eye wash station is necessary if eye contact occurs.

Although they were not the focus of our evaluation, these hazards could cause harm to your workers' health and safety and should be addressed.

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



Provide adjustable worktables so employees can customize the height to avoid awkward postures.

- The optimal adjustable hand-working height is 38"–47" above the standing surface.
- The height of a workstation should be fixed at 42" above the standing surface if an adjustable table is not available.

Equip all standing work areas with anti-fatigue mats to prevent muscle fatigue, low back pain, and stiffness in the neck and shoulders from prolonged standing.

- Mats should be ≥0.5" thick and have an optimal compressibility of 3%–4%. They should also have beveled edges to minimize trip hazards and be placed at least 8" under a workstation to prevent uneven standing surfaces.
- Mats should cover the entire area in which the employee moves while performing work tasks. Replace them when they appear worn out or are damaged.

Keep food, food preparation areas, and kitchen supplies separate from the production space.

Create a labeled eye wash station in the production area.

- A faucet in the sink already located in the production space can be modified to also serve as an eye wash station.

Supporting Technical Information

Evaluation of Exposures to Metals, Metalworking Fluids, Alcohols, and Volatile Organic Compounds at an Acrobatic Equipment Manufacturer

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Section A: Workplace Information

Building

The company rented space in a single-story concrete block building built in 1960, which had many prior industrial uses. There was a large, open work area with a smaller connected area that contained an office, 3-D printer, and meeting space. The space had one connecting door to the rest of the building complex, which led to a corridor with restrooms. Although other businesses used space in the building, none were immediately adjacent to the work area.

Employee Information

Total employees at time of evaluation: 4

Median hours worked per week: 33 hours (range: 15–55 hours)

Median age: 30 years (range: 22–37 years)

Median job tenure: 17 months (range: 1–32 months)

Process Description

Employees performed multiple tasks to make the hardware for each customized piece of acrobatic equipment. Each piece had computer software developed and installed to customer specifications.

Cutting and Milling Aluminum Pipe

Using a miter saw, employees cut aluminum pipe sections to a specified length. Employees then placed the pipe into an enclosed computer numerical control (CNC) milling machine with a hood. A pump sprayed semi-synthetic metalworking fluid (MWF) into the CNC milling machine. MWF was recirculated using a sump kept under the machine. Most tasks completed with the CNC milling machine were completed with the doors closed; however, some tasks required the doors to be open. A local exhaust with a carbon air filter was located in the corner of the CNC machine enclosure. During tasks where the machine doors were open, employees installed a splash guard to prevent spray. At times, employees used compressed air to clean the work surfaces inside the CNC machine.

Hand Drilling, Tapping, and Deburring Aluminum Pipe

Employees clamped aluminum pipe sections to a worktable and used handheld drills and other tools to drill holes into the sections. Drilling created aluminum shavings, which employees attempted to collect by hand in a towel. While drilling holes into the pipe, employees manually applied metal cutting oil. Finally, employees deburred the pipe sections by holding them to an electric deburring wheel.

Die Grinding

Employees used a handheld die grinder to drill holes into the aluminum pipe. A vacuum was used to collect aluminum shavings and other small pieces created during grinding. Employees also used the vacuum to clean aluminum material off the worktable and their clothes after completing the task. A portable WEN air filtration unit (Model 3410) with a 5-µm pre-filter and 1-µm pleated filter was used during the dust generating activities.

Soldering, Resin Casting, and Attaching Electronic Components

Employees soldered light-emitting diode (LED) components into long strings that they laid on a molding table. They then mixed resin and quickly poured it onto the LED components, smoothing the resin. This was left to dry for about 24 hours. The LED strips were then attached to the aluminum pipe using ultraviolet (UV) cured glue. A small, portable local exhaust ventilation hood system was available to use during the soldering process. Employees used the system during one round of environmental sampling.

PVC Skinning

Employees used a handheld heater to heat the polyvinyl chloride (PVC) pipe. Then they sprayed the inside with either denatured alcohol or soap as a lubricant. With the pipe anchored to a floor stand, employees manually slid the PVC pipe onto the aluminum pipe.

Welding

An employee welded sections of aluminum pipe and other metal components using tungsten inert gas (TIG) welding equipment, occasionally using a metal workbench for support. Only one person welded and did so when all other employees were out of the workspace. The welding operation took place every few months depending on the production schedule. Welding work was done in the open work area.

Section B: Methods, Results, and Discussion

We focused on the following objectives during our site visit:

- Evaluate employee exposures to metals, MWFs, alcohols, and volatile organic compounds (VOCs) during the production process.
- Characterize symptoms, medical conditions, and health concerns experienced by employees.
- Identify engineering controls, administrative controls, and personal protective equipment (PPE) that may be useful in controlling exposures.

Methods: Exposure Assessment

Metals

We collected one task-based personal sample during the grinding process and several area samples throughout the workshop for various tasks, including welding, over a two-day period. The samples were collected using 37-millimeter diameter, 0.8-micrometer (μm) pore-size, mixed cellulose ester with plastic dome filters and pumps calibrated at a flow rate of 2 liters per minute (LPM). We analyzed each sample for aluminum, copper, iron oxide, lead, and zinc using NIOSH Method 7303 [NIOSH 2023].

Volatile Organic Compounds

We collected task-based samples for qualitative identification of VOCs. Samples were collected on thermal desorption tubes with sampling pumps calibrated at a flow rate of 0.1 LPM. Samples were analyzed by modified NIOSH Method 2549 [NIOSH 2023]. Additional samples were collected on charcoal tubes at a flow rate of 0.1 LPM for quantification of specific VOCs based on the results of the thermal desorption tube analysis. The charcoal tubes were analyzed for alpha(α)-pinene, methyl isobutyl ketone, acetone, xylenes, and ethyl acetate using NIOSH Methods 1501/1552 [NIOSH 2023].

One personal air sample for isopropyl alcohol and ethanol was collected during the skinning process. Two area air samples for isopropyl alcohol and ethanol were collected during 3-D printer usage and skinning with alcohol. The air samples were collected on charcoal tubes with sampling pumps calibrated at a flow rate of 0.1 LPM. Samples were analyzed using NIOSH Method 1400 [NIOSH 2023].

Metalworking Fluids

We collected task-based area samples at four locations around the CNC machine using tared polytetrafluoroethylene filters in cassettes with sampling pumps calibrated at 1.6 LPM. The air samples were analyzed using NIOSH Method 5524 [NIOSH 2023].

Results: Exposure Assessment

Metals

Results from the short-term personal sample for the grinding process are presented in Table C1. We found a quantifiable level of aluminum and iron oxide. We did not detect (ND) copper, lead, or zinc oxide. We cannot compare the short-term air sampling results to full-shift occupational exposure limits

(OELs) since the sample did not cover the entire shift, but the sampling results show the exposures for that task. The full-shift OELs are provided for information.

The results for the area air samples are shown in Table C2. The detected concentrations are low for the different areas. The highest concentrations of aluminum and iron oxide were detected during the soldering process without the local exhaust and during the welding activities. Detectable but not quantifiable levels of lead and zinc oxide were detected during the bending process.

Volatile Organic Compounds

The major compounds identified from the qualitative thermal desorption tube analyses included acetone, α-pinene, decane, ethanol, ethyl acetate, isopropanol, methanol, methyl isobutyl ketone, nonane, and xylenes. Using charcoal tubes, we found detectable but not quantifiable levels of ethyl acetate and methyl isobutyl ketone during the UV-cured gluing (Table C3). We found a low level of methyl isobutyl ketone during the resin casting process (Table C3). We did not detect α-pinene, acetone, or xylenes. We noted that because area air samples are not personal air samples collected directly on an employee, the NIOSH recommended exposure limits (RELs) do not directly apply to the results for exposure monitoring purposes. However, area air samples can highlight areas with higher exposure risk.

The personal air sample results collected during PVC skinning (Table C4) show detectable concentrations of isopropyl alcohol (0.4 parts per million [ppm]) and ethanol (50 ppm). We cannot compare the short-term sample to full-shift OELs since the sample did not cover the entire shift. However, the sampling results showed the exposures for that task. For reference, the full-shift OELs are provided in Table C4. Area air sampling results for isopropyl alcohol and ethanol, collected on the workbenches during the PVC skinning and 3-D printing processes, are shown in Table C5. Detectable levels of isopropyl alcohol (121 ppm) and detectable but not quantifiable levels of ethanol were found for 3-D printing. Detectable levels of ethanol (100 ppm) and detectable but not quantifiable levels of isopropyl alcohol were found for PVC skinning.

Metalworking Fluids

No particulates were detected for the four MWF air samples on the tared filters at a limit of detection of 30 micrograms per sample. The filters used in the sample collection had not been cleaned according to the laboratory method for MWFs, so the analytical laboratory did not run the chemical analysis.

Methods: Facility and Ventilation Observations, Document and Health and Safety Program Reviews

During our site visit, we observed the facility processes along with the work practices and procedures of the four employees actively performing various tasks during the workday. We reviewed the safety data sheets for the chemicals used in the facility. We also learned about measures that the employer implemented to minimize employees' exposures during the various tasks including general and local ventilation and a portable air filtration unit.

Results: Facility and Ventilation Observations, Document and Health and Safety Program Reviews

We saw no general ventilation systems for the work areas. Outdoor air was provided to the workspace using a window air-conditioning unit in the rear window of the large work area. We saw no filter change protocol for the portable WEN air filtration unit.

We observed a central air filtration unit mounted on the ceiling in the middle of the large work area and a fixed cyclone local exhaust unit directly over the grinding/welding area. Heating was provided during the colder seasons with a natural gas heating unit mounted on the ceiling.

We saw no visible splashing on the floor when the machine was run with the door to the enclosure open. The company had not established a set protocol for changing the MWF, and employees reported the coolant reservoir tank had a buildup of residual material. We saw a microwave and refrigerator in the main production area. We did not see a labeled eye wash station for employees to use.

Methods: Employee Interviews and Observations

We conducted confidential, semi-structured interviews with all four company employees. During the interviews, we asked each employee about the following topics:

- Demographics
- Work history
- Tasks performed on a regular basis
- PPE use
- Symptoms and medical conditions
- Health concerns

In cases where an employee reported seeking medical care for a medical condition, we requested permission to review the employee's medical records.

We also observed employees while they worked, paying special attention to potential exposures and their use of exposure controls such as PPE.

Results: Employee Interviews and Observations

Demographics, Work History, and PPE Use

The four interviewees had a median age of 30 years (range: 22–37 years) and had been working at the company for a median 17 months (range: 1–32 months). Employees worked a median 33 hours per week (range: 15–55 hours).

All employees reported wearing closed-toed shoes while at work. Employees mainly reported wearing short-sleeved shirts while working. All employees reported using gloves, safety glasses, hearing protection, a protective jacket, and a respirator depending on the task they were completing.

Through observation, we saw that employee glove use was variable when performing tasks involving potential skin contact with MWF. We observed one employee voluntarily use a half-face, air purifying respirator with a P100 cartridge for particulates while die grinding. The respirator was stored in an open cubby in the production area; the employee returned the respirator to this storage location at the end of use. The company did not have respirator storage, filter change, or cleaning policies in place.

Symptoms, Medical Conditions, and Health Concerns

At least one employee reported experiencing eye, nose, and throat irritation, or cough. Multiple employees reported experiencing either dry, scaly, or irritated skin since starting work at the facility. In addition, multiple employees reported a history of asthma or eczema prior to working at the facility.

Management and employees expressed commitment to ensuring a safe and healthy workplace and were specifically interested in ways to control exposures that could cause or exacerbate respiratory or skin conditions. Multiple employees also expressed concern about the potential for unintentionally carrying exposures home from work, commonly referred to as take-home exposure. At least one employee mentioned concern that plans to expand fabrication may lead to greater exposures in the limited workspace.

Discussion

We did not identify concerning levels of exposure to metals, VOCs, or MWFs during this evaluation. Many of the work tasks were of short duration (less than 1 hour). Although we found low levels of exposures, opportunities existed for improved exposure control using engineering controls, administrative controls, and PPE. The Occupational Safety and Health Administration (OSHA) and the National Institute of Occupational Safety and Health (NIOSH) developed a Small Business Safety and Health Handbook (osha.gov) to help small businesses develop safety and health plans to improve the occupational work environment [OSHA/NIOSH 2022].

We found low exposure levels for metals during the grinding and welding operations. The highest levels were detected during welding. The same workspace was used for both tasks. The workstation was used by multiple employees. However, the workstation had fixed dimensions and therefore may not optimally fit all the employees using it, potentially leading to awkward postures while working with each piece of equipment. The central air filtration and local exhaust units likely helped reduce particulate levels but were not located next to where the actual tasks were being performed. Positioning the local exhaust closer to the work tasks would improve its ability to capture air contaminants. Additional information concerning potential exposure and health issues associated with welding can be found in Section D.

Exposures to VOCs were low during our site visit. Isopropyl alcohol was one of the VOCs that was used in the 3-D printing process; the levels detected in this evaluation were similar or higher than those detected in other 3-D printer surveys of 3-D printing operations [NIOSH 2017; Stefaniak et al. 2017]. VOCs are a large class of chemicals that contain carbon and have a sufficiently high vapor pressure to allow some of the compound to exist as a gas at room temperature. These chemical compounds are commonly used for tasks such as cleaning, painting, printing, degreasing, thinning, and extraction.

Occupational exposure criteria exist for some individual VOCs, but do not exist for VOCs as a group [NIOSH 2007].

Inhalation and dermal exposure are both important routes of exposure to VOCs in the workplace [Cone 1986]. Most VOCs cause skin irritation because they remove fat from the skin. VOCs may cause minimal to mild irritation of the respiratory system [Rosenberg et al. 1997]. This irritation is usually restricted to the upper airways, mucous membranes, and eyes, and it generally resolves quickly without long-term effects [Rosenberg et al. 1997]. Most VOCs can cause acute, nonspecific central nervous system depression. The symptoms of significant acute solvent exposure are like those from drinking too many alcoholic beverages, including headache, nausea and vomiting, dizziness, slurred speech, impaired balance, poor concentration, disorientation, and confusion. These symptoms go away quickly upon cessation of exposure [Guidotti 2010, Chapter 10]. Subtle, reversible decrements in performance on attention and reaction time testing have been observed with acute exposures to solvents but may not be directly attributable to nervous system dysfunction since similar effects are seen when the main effect of exposure is headache or eye irritation [Guidotti 2010, Chapter 10].

Although we did not find detectable airborne levels of MWFs, we observed that employees had skin exposure to MWFs when adjusting the parts that were being machined as well as when cleaning the CNC machine. Skin contact with MWFs is known to cause allergic contact dermatitis, irritant contact dermatitis, or oil folliculitis (irritation or infection of hair follicles) depending on the chemical composition, additives and contaminants, type of metal being machined, and the exposed individual's tendency for developing allergies [Chew and Maibach 2003; Slodownik et al. 2008]. Limiting skin exposure is critical to preventing allergic and irritant skin disorders related to MWF exposure. Studies have shown that about one in four employees diagnosed with occupational contact dermatitis will have persistent symptoms despite treatment or job change [Cvetkovski et al. 2006; Jungbauer et al. 2004]. Additional information about MWFs, contact dermatitis, and tips to reduce or prevent work-related contact dermatitis are given in Section D.

Limiting exposure to MWF aerosols is also prudent because previous exposures to some MWFs have been associated with increased risk of some types of cancer [NIOSH 2013]. Colbeth et al. [2023] found that exposure to water-based synthetic MWF was associated with an increased risk of rectal and prostate cancers, and exposure to soluble MWF was associated with an increased risk of non-Hodgkin lymphoma and prostate cancer. Although changes in the formulation and use of MWFs in the last several decades have reduced the cancer risk from MWF exposure, it is not known if these actions have eliminated the risk [NIOSH 2013].

The employees expressed concerns over the possibility of taking contaminants home from the workplace. In 1992, the U.S. Congress passed the Workers' Family Protection Act (29 U.S.C. 671a) that required NIOSH to study take-home contamination from workplace chemicals and substances. 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 the removal of toxic substances or contaminated items from the workplace.

Limitations

This evaluation had a cross-sectional design. This means that information on exposures and health outcomes was collected at a single point in time, and we may not have seen all the production processes. This design may not accurately capture changes in exposures or symptoms over time. In addition, our assessment was designed to assess the presence of symptoms or adverse health outcomes that employees had experienced prior to or at the time of our visit. Because employees were relatively young and had worked with these exposures for only a short time, this evaluation is unable to capture symptoms or health effects that may occur following long-term, low-level exposure to the agents evaluated. The analytical sampling methods available to evaluate exposures were developed for full-shift exposures and may not be able to accurately measure short-term exposures based on the limit of detection for a chemical or metal collected. Finally, the production process used at this facility was unique; findings from this evaluation may not be generalizable to other facilities.

Conclusions

Our task-based and area air sampling results showed that levels of exposure to metals, VOCs, and MWFs were low in the facility. However, employees had experienced and were concerned about eye, nose, and throat irritation, and cough they thought were related to workplace exposures. Although exposures were found to be low, we recommended implementing additional controls to reduce potential exposures. In addition, because many production tasks did not take long to complete and varied from day to day, employees should report new, persistent, or worsening symptoms to facility management and to their personal healthcare provider.

Section C: Tables

Table C1. Task-based personal air sample results for selected metals during February 2019 (micrograms per cubic meter)

Location	Time (minutes)	Aluminum	Copper	Iron oxide	Lead	Zinc oxide
Grinding	51	21	ND	13	ND	ND
NIOSH REL		15,000	1,000	10,000	50	5,000
OSHA PEL		10,000	1,000	5,000	50	5,000
ACGIH TLV		1,000	1,000	5,000	50	2,000
MDC		0.8	0.4	2.0	1.0	0.4
MQC		3.0	1.3	6.4	3.8	1.2

ND = Not detected, i.e., result is below the MDC; MDC = Minimum detectable concentration; MQC = Minimum quantifiable concentration; REL = Recommended exposure limit; PEL = Permissible exposure limit; TLV = Threshold limit value.

A sample volume of 0.266 cubic meter was used to calculate the MDC and MQC.

Table C2. Area air sample results for selected metals during February 2019 (micrograms per cubic meter)

Process	Time (minutes)	Aluminum	Copper	Iron oxide	Lead	Zinc oxide
Cutting saw	379	[0.8]	[0.4]	12.1	ND	ND
Bending	379	[0.8]	ND	[3.7]	[1]	[0.4]
Grinding table	51	10	ND	7.3	ND	ND
Soldering bench	57	86	ND	609	ND	ND
Soldering bench — New exhaust	79	[2.4]	ND	ND	ND	ND
Welding	33	9.4	ND	ND	ND	ND
Welding	33	89	ND	673	ND	ND
MDC		0.8	0.4	2.0	1.0	0.4
MQC		3.0	1.3	6.4	3.8	1.2

ND = Not detected, i.e., result is below the MDC; MDC = Minimum detectable concentration; MQC = Minimum quantifiable concentration

Values in brackets indicate concentrations between the MDC and MQC. Brackets are used to indicate there is more uncertainty associated with these values. An average sample volume of 0.266 cubic meters was used to calculate the MDC and MQC.

Table C3. Area air sampling results for selected volatile organic compounds during February 2019

Job/Activity	Time (minutes)	Total volume (liters)	Ethyl acetate (ppm)	Methyl isobutyl ketone (ppm)
UV-cured gluing	93	3.99	[0.03]	[0.03]
Resin pouring next to table	14	1.42	ND	0.23
MDC (for a 3-liter air sample)			0.015	0.011
MQC (for a 3-liter air sample)			0.046	0.035

MDC = Minimum detectable concentration; MQC = Minimum quantifiable concentration; ppm = Parts per million

Values in brackets are estimates because they are between the MDC and MQC.

Table C4. Personal breathing zone air sampling results for isopropyl alcohol and ethanol during February 2019

Job/Activity	Time (minutes)	Total volume (liters)	Isopropyl alcohol (ppm)	Ethanol (ppm)
PVC skinning with alcohol	34	3.31	0.4	50
MDC (for a 3.5-liter air sample)			0.035	0.12
MQC (for a 3.5-liter air sample)			0.28	3.61
NIOSH REL			400	1,000
OSHA PEL			400	1,000
ACGIH TLV			200	1,000 (STEL)

MDC = Minimum detectable concentration; MQC = Minimum quantifiable concentration; ppm = Parts per million; REL = Recommended exposure limit; PEL = Permissible exposure limit; TLV = Threshold limit value; STEL = Short-term exposure limit

Table C5. Area air sampling results for isopropyl alcohol and ethanol during February 2019

Job/Activity	Time (minutes)	Total volume (liters)	Isopropyl alcohol (ppm)	Ethanol (ppm)
Alcohol bath for 3-D printer	39	4.04	121	[0.8]
PVC skinning with alcohol—workbench	34	3.24	[0.2]	100
MDC (for a 3.5-liter air sample)			0.035	0.12
MQC (for a 3.5-liter air sample)			0.28	3.61

MDC = Minimum detectable concentration; MQC = Minimum quantifiable concentration; ppm = Parts per million

Values in brackets are estimates because they are between the MDC and MQC.

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 (STEL) ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

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

- The U.S. Department of Labor OSHA permissible exposure limits (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 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.
- Another set of OELs commonly used and cited in the United States is the American Conference of Governmental Industrial Hygienists' threshold limit values (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 2023].

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.

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. Epidemiologic studies and case reports of employees exposed to welding emissions have shown an excess incidence of acute and chronic respiratory diseases [Antonini 2003; de Perio et al. 2022; NIOSH 1988]. These diseases include metal fume fever, pneumonitis, pulmonary edema, and lung cancer.

Airborne welding fume concentrations vary greatly between workplaces [Korczynski 2000; Susi et al. 2000; Tharr et al. 1997]. 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 (core) of the electrode/wire may contain several organic and inorganic compounds. 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, individual welding fume constituents (e.g., iron, manganese) have PELs (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 fumes to the lowest feasible concentration and meeting the exposure limit for each welding fume constituent [NIOSH 2010].

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 [Korczynski 2000].

Metalworking Fluids

MWFs are complex mixtures used to cool, lubricate, and remove metal chips from tools and parts during machining of metal stock. There are three main types of MWFs: straight, soluble, and synthetic. MWFs often contain other substances, including biocides, corrosion inhibitors, metal fines, tramp oils, and biological contaminants [Burton et al. 2012; NIOSH 1998]. Inhalation of the aerosol from MWFs may irritate the throat, nose, and lung. Inhaling MWF aerosol has been associated with chronic bronchitis, asthma, hypersensitivity pneumonitis, B-cell lymphocytic bronchiolitis, alveolar ductitis, and emphysema (BADE), and worsening of preexisting respiratory problems [Burton et al. 2012; Nett et al. 2021]. Hypersensitivity pneumonitis is a spectrum of granulomatous, interstitial lung diseases that occur after repeated inhalation and sensitization to one or more of a wide variety of microbial agents (bacteria, fungi, or amoebae), animal proteins, and low-molecular-weight chemical antigens [Centers for Disease Control and Prevention 1996; Zacharisen et al. 1998].

Skin contact with MWFs may cause allergic contact dermatitis or irritant contact dermatitis, depending on the chemical composition, additives and contaminants, and type of metal being machined, as well as the exposed individual's tendency for developing allergies [NIOSH 1998]. NIOSH recommends limiting exposures to MWF aerosols to 0.4 milligrams per cubic meter for the thoracic particulate mass, as a TWA concentration for up to 10 hours per day during a 40-hour workweek [NIOSH 1998]. The NIOSH REL is intended to prevent or greatly reduce respiratory disorders associated with metalworking fluid exposure.

Contact Dermatitis

Contact dermatitis, both irritant and allergic, is an inflammatory skin condition caused by skin contact with agents such as chemical irritants (irritant contact dermatitis) or allergens (allergic contact dermatitis) [Li and Li 2021]. Irritant contact dermatitis is skin inflammation due to direct cell damage from a chemical or physical agent, while allergic contact dermatitis is a delayed immune reaction. Usually, only a small percentage of people are susceptible to skin allergens. In contact dermatitis, the skin initially turns red and can develop bumps and small, oozing blisters. After several days, crusts and scales form. Stinging, burning, and itching often occur. With no further contact with the agent, the dermatitis usually disappears in 1 to 3 weeks. With chronic exposure, deep fissures, scaling, and darkening of the skin can occur.

Exposed areas of the skin, such as hands and forearms, have the greatest contact with irritants or allergens and are most affected. It is often impossible to clinically distinguish irritant contact from allergic contact dermatitis, as both can have a similar appearance and both can result in an acute, subacute, or chronic condition. Irritant contact dermatitis can be caused by many factors. The most common skin irritant at work is "wet work," defined as exposure of skin to liquid for more than 2 hours per day; the use of occlusive gloves for more than 2 hours per day; or frequent hand washing [Chew and Maibach 2003; Karagounis and Cohen 2023; Slodownik et al. 2008]. Other common causes of irritant contact dermatitis include soaps and detergents, solvents, food products, cleaning agents, plastics and resins, petroleum products and lubricants, metals, and machine oils and coolants [Chew and Maibach 2003; Li and Li 2021; NIOSH 2018; Slodownik et al. 2008].

Preventing Contact Dermatitis

Avoiding irritants and allergens and wet work is the first step in dermatitis prevention. Liberal use of skin moisturizers helps to prevent contact dermatitis by maintaining a healthy skin barrier and can aid in repairing this barrier if it has been compromised [Bauer et al. 2018; Chew and Maibach 2003; Karagounis and Cohen 2023].

The following list provides strategies in the prevention of occupational contact dermatitis [NIOSH 1988]:

- Identifying irritants and allergens.
- Substituting chemicals that are less irritating or allergenic.
- Establishing engineering controls to reduce exposure.
- Emphasizing personal and occupational hygiene including handwashing with lukewarm water and mild cleansers without perfume, coloring, or antibacterial agents.
- Establishing educational programs to increase awareness in the workplace.
- Using PPE, such as gloves and special clothing.

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