Evaluation of Chromium, Hexavalent Chromium, Cadmium, and Isocyanate Exposures in an Aircraft Refinishing Plant

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Contents

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

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from the health and safety manager of an aircraft refinishing company. The manager was concerned about employee exposures to cadmium, chromium, hexavalent chromium, and isocyanates at one of their locations. We visited the company in December 2012 and November 2013.

What We Did

- We reviewed health and safety documents.
- We collected air, surface wipe, and bulk samples to evaluate exposure to chromium, hexavalent chromium, cadmium, and isocyanates.
- We examined the nasal passages of employees to check for signs of irritation, scarring, or ulceration.
- We collected urine samples from employees to measure chromium, cadmium, and isocyanates. We also collected blood samples to measure cadmium.
- We interviewed employees about their health and about workplace health and safety issues.
- We evaluated the ventilation in the paint stripping area, paint bays, and the paint mixing room.

What We Found

- Sanders and painters were overexposed to hexavalent chromium and cadmium in the air.
- The type of respirator worn was insufficient to protect employees against hexavalent chromium exposure.
- Fourteen of 38 employees had abnormal nasal exams (ulceration or irritation) consistent with effects of chromium exposure.
- Urinary cadmium, chromium, and isocyanate levels were below occupational exposure limits; no cadmium was found in blood samples.
- Chromium, hexavalent chromium, and cadmium were found in dust collected in nonproduction areas.
- Ventilation was inadequate in all bays.

We evaluated employee exposures to chromium, hexavalent chromium, cadmium, and isocyanates during aircraft stripping and painting. Sanders and painters were overexposed to airborne hexavalent chromium and cadmium. We measured low levels of chromium and cadmium in employee's blood and urine but found nasal tissue damage consistent with chromium exposure in some employees. The level of respiratory protection for some tasks and ventilation in all bays were inadequate. We recommended improving the respiratory protection program, ventilation, housekeeping, and medical surveillance.

What the Employer Can Do

- Improve ventilation in stripping and painting bays.
- Use sanders equipped with local exhaust ventilation.
- Medically monitor all production employees for hexavalent chromium and isocyanate exposures.
- Encourage employees to report possible work-related health concerns to their supervisor so steps can be taken to evaluate and control exposures.
- Encourage employees with possible work-related health concerns to seek care from a healthcare provider to determine work-relatedness.
- Reduce the spread of contaminants from production areas to nonproduction areas by:
  - Having employees wash their hands and arms before taking a break.
  - Having employees remove personal protective clothing and equipment before leaving work.
  - Improving employee training on hexavalent chromium and isocyanate hazards.
  - Requiring airline respirators for employees who apply primer or paint, or who do sanding.
- Require each employee wear a clean uniform each work day.
- Provide laundry services for employees' work clothes.

What Employees Can Do

- Report work-related health concerns to your supervisor so steps can be taken to evaluate and control exposures.
- Seek evaluation from a health care provider if you have symptoms to determine work-relatedness, preventive measures, and medical care.
- Tell your healthcare provider that you work with hexavalent chromium, cadmium, other metals, and isocyanates.
- Remove personal protective equipment and wash hands and arms before taking a break.
- Do not wear work clothing or shoes home or launder work clothing at home. Wear a clean uniform each day at work.

Abbreviations

µg	Microgram
µg/m³	Microgram per cubic meter
ACGIH®	American Conference of Governmental Industrial Hygienists
BEI®	Biological exposure index
cm²	Square centimeters
CFR	Code of Federal Regulations
HDA	1,6-hexamethylene diamine
HDI	Hexamethylene diisocyanate
LOD	Limit of detection
LFC	Lowest feasible concentration
MDC	Minimum detectable concentration
MAP	1-(9-anthracenylmethyl) piperazine
MQC	Minimum quantifiable concentration
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
PPE	Personal protective equipment
REL	Recommended exposure limit
SDS	Safety data sheet
TDI	Toluene diisocyanate
TLV®	Threshold limit value
TWA	Time-weighted average

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Introduction

The Health Hazard Evaluation Program received a request from a health and safety manager at an aircraft refinishing company who was concerned about exposure to chromium, hexavalent chromium, cadmium, and isocyanates during aircraft refinishing. During our initial visit in December 2012, we evaluated the ventilation system in the stripping bay, two paint spray bays, and the paint mixing room. We also collected air and surface wipe samples for metals and held confidential health interviews with employees. During a follow-up evaluation in November 2013, we collected personal air samples and surface wipe samples for chromium, hexavalent chromium, cadmium, and isocyanates; and did a more detailed evaluation of the ventilation systems. We collected urine and blood samples to test for cadmium, chromium (urine only), and isocyanates. We did nasal examinations to look for ulcerations, irritation, scarring, and perforations related to chromium exposure. We provided a written summary of our visits and preliminary recommendations in January 2013 and December 2013. We provided employees with the results of their nasal examination and air and skin surface sampling, and summary letters to the company, in December 2013, March 2014, April 2014, and March 2015. The March 2014 summary letter to the company provided recommendations for improved respiratory protection based on our sampling results. These sampling results and recommendations are summarized in this report.

Process

The aircraft refinishing company has a number of locations in the United States and provides services such as airframe repair and maintenance, major modifications, avionics installation and repair, interior refurbishment, and painting. At the site we evaluated, services consisted mostly of exterior refurbishment (painting) and some interior refurbishment. Forty employees normally worked 10-hour shifts in the painting department at the plant we evaluated. The painting department operated on first and second shift. It included a stripping bay, where employees chemically and abrasively removed aircraft paint, and two paint bays (Figure 1). The stripping bay, painting bays, and paint mixing room had mechanical downdraft (ceiling to floor) general ventilation to dilute and remove air contaminants. In the stripping bay, the following processes were performed: stripping (Figure 2), etching (acid cleaning of the surface), and application of Alodine™ (a chromate conversion coating used as a corrosion inhibitor and primer adhesion promoter). In the paint bays the following processes were performed: sanding, solvent wipedown, priming, and painting (Figures 3–5). All paints were mixed in the paint mixing room (Figure 5). Depending on the aircraft and the type of paint applied, a protective clear coat was applied over the base coat.

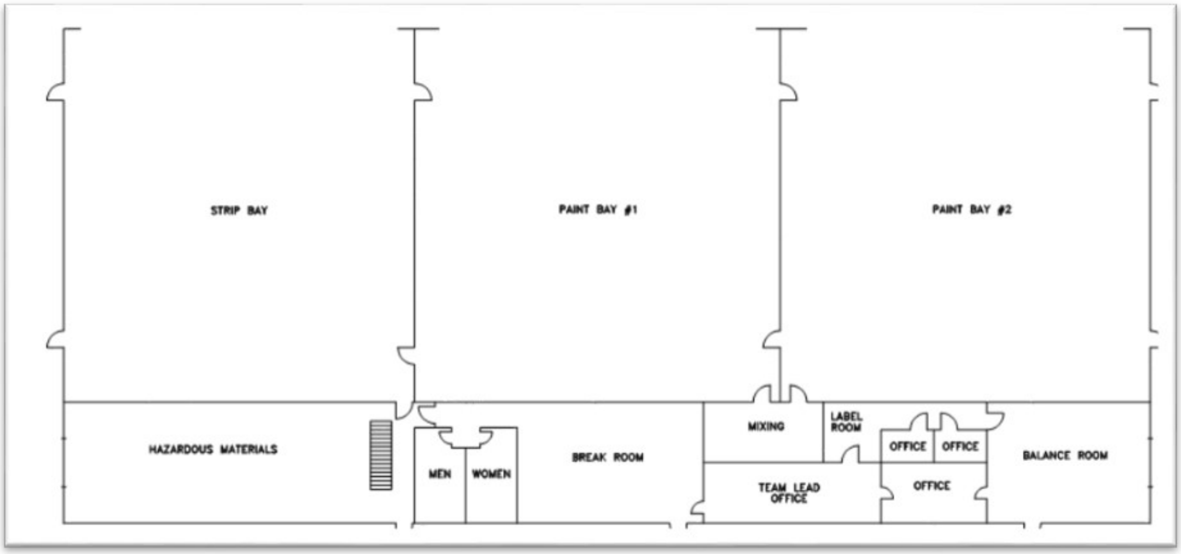

Figure 1. Plant layout during our first visit. Lockers were located inside the hazardous materials room. Drawing provided by aircraft refinishing company.

Figure 2. Liquid paint stripper applied to an airplane inside the stripping bay. Photo by NIOSH.

Figure 3. Employee spray painting inside a paint bay. Photo by NIOSH.

Figure 4. Employee mixing paint inside the paint mixing room. Photo by NIOSH.

Figure 5. Employees wearing coveralls with hood, goggles, gloves, and full facepiece air purifying respirators while sanding an airplane inside a paint bay with pneumatic sanders that do not have dust control. Photo by NIOSH.

Before painting, the aircraft was brought into the stripping bay where items not requiring paint removal were taped off for protection. An aromatic alcohol-based paint stripper (0.1%–5% corrosion inhibitor blend) was sprayed onto the entire aircraft and allowed to react with the paint for several hours. To promote the chemical reaction between the stripper and the paint, the temperature in the bay was increased to approximately 80°F. Employees used warm water to pressure wash the entire aircraft (Figure 6), and the paint stripping process was repeated if needed.

Figure 6. Employees wearing rain suits, full facepiece respirators, rubber boots, and gloves are rinsing an aircraft with water after degreasing inside the stripping bay. Photo by NIOSH.

After removing the paint, employees hand washed the aircraft with a degreaser followed by a water rinse. The entire aircraft was then sanded using handheld pneumatic palm sanders equipped with vacuum-assisted dust control. After sanding, the aircraft surface was wiped with paint thinner, then etched by spraying the surface with an aluminum corrosion remover containing phosphoric acid and isopropanol. After etching, employees sprayed Alodine™ onto the surface to inhibit corrosion. Alodine contains 30%–60% chromic acid, a chemical that contains hexavalent chromium.

After the Alodine coating was dry, employees moved the aircraft to a paint bay where it was coated with a primer, an antistatic paint, a base coat, stripes, and (when needed) a clear top coat. The paints were either acrylic or isocyanate-based. The primary isocyanate-based paint used during our evaluation contained monomeric and polymeric hexamethylene diisocyanate (HDI) as well as other organic solvents. After the paint dried for a few days employees washed and waxed the aircraft.

Methods

The objectives of this evaluation were to:

1. Identify work-related health concerns among employees.
2. Measure metal contamination on surfaces in production and nonproduction areas.
3. Measure employee exposure to hexavalent chromium, chromium, cadmium, and isocyanates.
4. Determine if employees had nasal tissue damage that could be related to chromium exposure.
5. Evaluate the effectiveness of engineering controls (e.g., ventilation), work practices, and personal protective equipment (PPE) in controlling employee exposures to hexavalent chromium, chromium, cadmium, and isocyanates.

Document and Records Review

We reviewed the company's health and safety plan, safety data sheets (SDSs), and industrial hygiene consultant reports. We also reviewed reports of employee urine chromium levels and nasal examination records from a medical surveillance program started by the company in June 2013. We reviewed the Occupational Safety and Health Administration (OSHA) Form 300 Log of Work-Related Injuries and Illnesses from the paint department, which included all employees who engaged in sanding, stripping, painting, and detailing of aircraft from 2008 to 2012.

Medical Assessment

During the first visit, we held confidential health interviews with employees. We randomly chose 20 employees on the first and second shifts from an employee roster. This sample population represented 50% of the workforce engaged in aircraft refinishing operations. We offered to interview any other interested employee who was not randomly selected. An additional 10 employees volunteered for interviews. We compared responses provided by employees in both groups. During the interviews, we asked about work history, acute and chronic health symptoms focusing on the skin and respiratory system, smoking history, and use of PPE.

During the second visit we conducted nasal tissue examinations and took blood and urine samples to determine the levels of chromium, cadmium, and isocyanate. All employees from the painting department were asked to participate. After getting written consent, we used a flashlight and nasal speculum to examine the nasal septum (the cartilage separating the two nostrils) for evidence of irritation, ulcerations, scar formations, or perforations (holes) that could be caused by chromium exposure. We defined "ulcerations" as lesions with erosion, swelling, or pitting of the nasal tissue. Scar formations were characterized by lesions with eroded nasal septum or evidence of healing. Nasal septum perforations were characterized as lesions that had a permanent, smooth edged "hole" through the nasal septum cartilage. We also examined the surrounding tissue for evidence of irritation or bleeding. We provided participants written results of the examination (either "normal" or "abnormal" nasal tissue) on site.

Each participant was asked to provide three urine samples, one before and one after their work shift on one day and one at the end of the workweek. We measured 1,6-hexamethylene diamine (HDA) in the preshift and postshift samples, and chromium and cadmium in the end of the workweek urine sample. We compared urine chromium levels from our testing with those from the June 2013 medical surveillance testing for employees who participated in both rounds. We also measured cadmium in a blood sample at the end of the workweek.

Each participant was also asked to provide one blood sample at the end of either their first or second shift. We analyzed the blood for biomarkers of isocyanurate (a common HDI polyisocyanate) as part of a separate research study. Employees who provided their blood for research purposes consented to not receiving their test results and personal identifying information was removed from these blood samples before sending them to the laboratory. Results of these blood tests and the research study are not provided in this report.

Industrial Hygiene Assessment

We took bulk samples of some of the products used to verify the presence of hexavalent chromium or isocyanates. The presence of hexavalent chromium in the stripper was confirmed by an analytical method described in Appendix A. Bulk samples of a catalyst, an activator, a hardener, and a conductive base coat were collected to determine the presence and type of isocyanate using NIOSH Method 5525 [NIOSH 2017].

We collected full-shift personal air samples for hexavalent chromium, chromium, cadmium, HDI, and HDI polyisocyanates only during the first shift because similar work was performed on the second shift. Our sampling methods are listed in Table 1. During each shift employees worked in the stripping bay, the paint bay, or both. The personal samples were collected as sequential task-based air samples over the work shift. We summed the results from employees' task-based air samples to determine their full-shift exposure.

We collected full-shift area air samples for cadmium, chromium, hexavalent chromium, HDI, and HDI polyisocyanate in both paint bays, the stripping bay, the paint mixing room, and the hazardous materials storage area. For quality control, we collected and analyzed for HDI and HDI polyisocyanates using side-by-side full-shift area air samples using two techniques. One technique drew air across one sample filter for the entire 10-hour shift; the second drew air across two sample filters sequentially, one in the morning and one in the afternoon. For these types of samples, we used a fiberglass filter impregnated with 1-(9-anthracenylmethyl) piperazine (MAP); analysis was by NIOSH Method 5525. An additional area air sample for isocyanates was collected at the same location and for the same time as the other area samplers using a denuder/filter combination air sampler known as the ASSET EZ-4 NCO (Supelco, Inc.). We wanted to evaluate the performance of the denuder/filter samplers in the field and to determine their potential use as an alternative to the MAP-treated filter method for isocyanates. We analyzed the denuder/filter samples using liquid chromatography/mass spectroscopy according to ISO Method 17734-1 Modified [ISO 2013].

Table 1. Air sampling methods

Analyte	Method*	Type of Sampler
Cadmium and chromium	NIOSH Method 7300†	Polyvinyl chloride filter cassette
Hexavalent chromium	NIOSH Method 7605†	Polyvinyl chloride filter cassette
HDI, HDI polyisocyanates	NIOSH Method 5525	Fiberglass MAP-impregnated filter cassette
HDI, HDI polyisocyanates	ISO Method 17734-1 Modified	ASSET EZ-4 NCO Denuder/filter

NIOSH = National Institute for Occupational Safety and Health

*As defined in the NIOSH Manual of Analytical Methods [NIOSH 2017]

†Prior to analysis, the inside of each filter sample cassette was wiped with a swab wetted with deionized water to collect particles that may have adhered to the inside wall of the cassette. The swab was then analyzed along with the sample filter as recommended by NIOSH [2010].

Using the methodologies described in Table 2, we took surface wipe samples in the production areas, warehouse, lunchroom, bathrooms, and offices to determine if chromium, cadmium, or hexavalent chromium migrated from the production area to nonproduction areas. We used a disposable 100 square centimeter (cm^2) template to outline the area sampled unless the area was irregularly shaped (e.g., respirator, door handle). In such cases we wiped an estimated 100 cm^2. We also collected a wipe sample from the inside of an employee's respirator that was stored inside a locker. To see if contaminants were present at the end of the work shift before employees left the plant, we also collected hand wipe samples (each employee wiped both hands including palms and backside for 30 seconds) from six employees for chromium or cadmium, and from four employees for isocyanates (Table 2). These samples were collected and analyzed using the CLI Labs, Inc. SWYPE colorimetric wipe.

Table 2. Wipe/surface sampling

Analyte	Method	Type of sampler
Cadmium and chromium	NIOSH Method 9102*	Disposable towelette
Hexavalent chromium	Sampling following OSHA ID 215 and analysis using NIOSH Method 7605*	Polyvinyl chloride filter
Isocyanates	Swype CLI lab colorimetric wipes	Skin: SKC 769-1033

*Following OSHA sampling and analytical methods [OSHA 2015a] and NIOSH Manual of Analytical Methods [NIOSH 2017].

We inspected the air handling units, supply air registers, exhaust outlets, and control boxes for each of the ventilation systems. We used quantitative and qualitative indicators to characterize the airflow in the stripping bay, paint bays, and the paint mixing room. We used a Shortridge VelGrid® Model ADM 860 C microanemometer to measure air velocities at locations where employees applied paint above, below, and on the sides of the aircraft. Measurements of air velocity were made approximately 3 feet from the surface of the aircraft. In addition, air velocity was measured at the opening of each supply inlet and exhaust outlet in each of the work areas. There were no ventilation system design specifications available with which to compare our measurements. To visualize airflow patterns, we used a Rosco Laboratories Inc. model 1500 fog machine to generate a visible "smoke" inside each of the bays. Finally, we determined whether work areas were under positive or negative pressure relative to adjacent areas using ventilation smoke tubes in the connecting doorways.

Statistical Analyses

We used the SAS Institute, SAS version 9.3 for all statistical analyses. We calculated descriptive statistics for interview data and personal sampling results. We examined the differences between preshift and postshift urine results (adjusted for creatinine levels) using the Wilcoxon signed rank test. We also compared urinary chromium levels of employees who participated in company-sponsored biological monitoring in June 2013 with levels we measured during our November 2013 site visit. Logistic regression models were constructed to examine the relationship between nasal examination results and work duration while adjusting for cigarette smoking. For the biological samples with mass values below the laboratory's limit of detection (LOD), we estimated mass by dividing the LOD by the square root of two [Hornung and Reed 1990]. Statistical significance was set at the 5% level using a two-tailed distribution for all tests.

Results

Documents and Records Review

The company had a written health and safety plan and hazard communication plans. The respiratory protection program described standard operating procedures to ensure the protection of each employee from respiratory hazards through the proper selection and use of respirators. The respiratory protection program required employees exposed to aerosols and solvents to use a 3M® 7000 series half-mask air purifying respirator equipped with organic vapor cartridges and an N95 particle prefilter. For employees working in a "nonhazardous" dusty environment (general nuisance dust), the program required the use of a 3M 7000 series half-mask air purifying respirator equipped with HT 7184 P100 particulate filters. When sanding aircraft, employees used a 3M 6000 series full facepiece air purifying respirator with HT 7184 P100 particulate filters and organic vapor cartridges. All stripping, painting, and priming activities required the use of a 3M 6000 series full facepiece airline respirator.

We reviewed industrial hygiene reports issued in April, May, and August 2012 by the company's insurance company. Full-shift personal and area air monitoring results from April and May 2012 showed that the highest dust levels occurred during aircraft sanding operations. The reports noted that dust accumulated on equipment surfaces and floors. Personal air sampling during sanding measured hexavalent chromium exposures exceeding 25 micrograms per cubic meter ($\mu g/m^3$), the OSHA permissible exposure limit (PEL) for the aircraft refinishing industry. Recommended control measures included using locally ventilated sanders. The insurance company did not sample for airborne isocyanates or hexavalent chromium during spray painting.

In its August 2012 report, the insurance company provided air sampling results for combustible dust. The sampling was done to assess the effectiveness of recently installed ventilated hand sanders in the stripping bay. No noticeable dust was released from the new sanders, and dust was not accumulating on equipment or floors. The hexavalent chromium concentrations on three personal air samples measured in August 2012 were lower than those measured in April and May 2012 and were below the OSHA PEL of 25 $\mu g/m^3$. In June 2013, 24 employees participated in biomonitoring and physical examinations by an occupational health contractor. The geometric mean chromium concentration in employees' urine was 3.57 µg per liter (range: 2.0–12.8 µg per liter); all results were below the American Conference of Governmental Industrial Hygienists (ACGIH) biological exposure index (BEI) of 25 µg per liter of urine.

Between 2008 and 2012, 15 entries for injuries were made on the OSHA Logs for the painting department. No illnesses were reported. Of the injuries, six were lacerations, seven were sprains/strains, one was a fracture, and one was for an employee who struck their knee on an object.

Medical Assessment

Of the 20 employees who were randomly selected for interviews, four declined. An additional 10 employees volunteered to be interviewed. In total, we interviewed 26 of the 40 employees in the painting department

Medical Interview Discussion for Randomly Selected Employees

All of the 16 randomly selected employees who participated were male. The average age was 37 years (range: 25–52 years). Employees had worked for this employer an average of

9 years (range: 1 month–21 years). A total of eight employees reported they had never smoked; of the eight who reported past smoking history, two were current smokers. A total of seven of 16 employees reported currently having sinus congestion, four reported nasal irritation, and four reported nosebleeds. One employee reported his nosebleed was worse during winter months, and two employees reported seasonal allergies that they felt made their sinus congestion worse. Four employees reported respiratory symptoms that occurred at work; three reported shortness of breath, chest tightness, and wheeze; two of these three employees reported all three symptoms. A total of three of these four employees reported additional allergies not related to work. The other employee who reported respiratory symptoms at work reported having asthma which began before employment at this company. A total of three employees reported ever having dermatitis; two of these reported dermatitis in the past 12 months and had been seen by a physician. These employees had not been evaluated for possible isocyanate sensitization. One employee reported having physician-diagnosed respiratory sensitization from isocyanates; we recommended that he inform his employer and not work with paints containing isocyanates.

Medical Interview Discussion for Employees Who Volunteered

Among the 10 employees who volunteered to be interviewed, demographic information and symptom prevalence were similar to the randomly selected group. All were male with an average age of 39 years (range: 23–57 years). Average length of employment was approximately 6 years (range: 1 month–13 years). A total of six employees reported they had never smoked; of the four who reported past smoking history, three were current smokers. Of the 10 employees, 4 reported sinus congestion, 3 nosebleeds, and 2 nasal irritation. Only one employee reported shortness of breath; no employees reported wheeze or asthma.

Concerns Shared by Some Employees in Both Groups

Occupational safety and health concerns mentioned by some employees in both groups included poor ventilation in the aircraft stripping and paint bays, being uncomfortable when wearing PPE during the summer months, and working in a dusty environment. Some employees also expressed concern about their lack of knowledge and training about the health effects from chemicals they used, although many reported being aware of working with potentially dangerous chemicals. Some employees mentioned that dust from their work clothes accumulated in their personal vehicles and wondered whether this was safe for them or their family. They were also unsure if it was safe to launder their work uniforms at home.

Most employees we interviewed believed that the safety culture in the stripping and paint bays had improved in the last year, but questioned why they had to purchase PPE if it was considered "more protective" than necessary for the job, based on company air sampling results. For example, full facepiece air purifying respirators were preferred by most production employees engaged in sanding and painting tasks because this type of respirator also afforded eye and face protection. However, because this level of protection was reportedly not necessary given the exposure levels measured by the company, this style of respirator was not required or offered by the company. Therefore, employees had to purchase their own full facepiece respirator. After our visit, the company reconsidered this policy and began providing full facepiece air purifying respirators to employees engaged in such activities at no cost. Some employees reported they had not been fit-tested for their respirator. Despite employees being trained on how to properly care for and clean their respirator, all indicated they rarely followed these procedures. When we inspected several respirators we found them dirty and stored improperly. All interviewed employees reported using the other required PPE such as nitrile gloves, hearing protection, protective coveralls, and safety glasses provided by the company. Most employees mentioned that the nitrile gloves tore easily.

Two NIOSH physicians examined the nasal septum and surrounding inner nasal tissue of 38 employees. Fourteen (37%) exams had abnormal findings, with six exams finding evidence of septal ulceration and eight showing evidence of redness, swelling, or bleeding. The probability of having an abnormal nasal exam was not statistically linked to length of employment at this company ($P = 0.94$) or urine chromium levels ($P = 0.38$), before and after controlling for smoking.

All HDA (HDI metabolite) urine sample results were well below the ACGIH BEI of 15 µg per gram of creatinine as an end of shift limit (Table 3). The change in HDA geometric mean levels over the work shift was not statistically significant.

Table 3. HDA urine concentrations at start and end of shift, in µg per gram of creatinine (29 samples were available for comparison)

Time	GM* HDA concentration	Range
Start of shift (n = 34)	0.070†	0.006–3.0
End of shift (n = 32)	0.094†	0.007–1.39
ACGIH BEI	15	

*Geometric mean, a measure of central tendency, or the “middle” value in a set of values.

†For the 25 samples where results were below the LOD we used the LOD divided by the square root of 2.

The geometric mean chromium concentration in employees’ urine was 0.74 µg per liter of urine (range: 1.0 to 7.8 µg per liter), well below the ACGIH BEI of 25 µg per liter of urine. Chromium was not detected in 10 of the 36 urine samples (< 1.0 µg per liter). Overall, geometric mean urinary chromium levels were higher in June 2013 than those we measured.

Most (32 of 36) employees’ urine tests did not have detectable levels of cadmium. Four employees’ urine tests found detectable but very low levels of cadmium (< 1 µg per gram of creatinine), well below the OSHA and ACGIH BEI limits of 3 µg per gram of creatinine. No cadmium was found in any of the employees’ blood samples (n = 31).

Industrial Hygiene Assessment

Bulk Samples

Analysis of a bulk sample of the chemical stripper confirmed the presence of hexavalent chromium (8.5 milligrams per kilogram – 0.00085%). We found HDI and HDI polyisocyanates in all four bulk samples of paint components that we analyzed, but no toluene diisocyanate (TDI). This finding was unexpected because the antistatic base coating listed TDI on its SDS as an ingredient of an epoxy resin. It is possible that the TDI was embedded in the resin and there were no active isocyanate groups.

Air Sampling

Personal full-shift time-weighted-average (TWA) air sample results for chromium and cadmium are summarized in Table 4, and more detailed results for personal and area air samples (including hexavalent chromium) are provided in Appendix B, Tables B1 to B7. Appendix C discusses occupational exposure limits (OELs) and health effects for chromium, cadmium, and hexavalent chromium.

Table 4. Summary of personal full-shift TWA air samples for chromium and cadmium, in µg/m^3

Location	Tasks	Chromium	Cadmium
Stripping bay	Sanding, water washing, etching, Alodine application	22	2.0
	Sanding, water washing, etching	9.7	0.46
	Sanding, stripper application, degreasing	20	3.3
	Sanding, stripper application	19	0.20
Paint bays	Masking, sanding, taping, painting stripes, clear coat	2.0	0.060
	Masking, sanding, taping	2.3	0.060
	Masking, sanding, taping, painting stripes, clear coat	2.7	0.14
	Sanding	49	10
	Sanding	30	8.3
	Taping, sanding, wiping down, mixing and spraying single-stage paint	5.1	0.15
	Spraying single-stage paint	4.0	0.16
	Taping, sanding, wiping down, mixing and spraying single-stage paint	3.7	0.14
Stripping bay and paint bays	Sanding, water washing, etching, Alodine application	52	2.4
	Hand sanding in stripping bay; Power sanding in paint bay	340	2.4
	Hand sanding in stripping bay; Power sanding in paint bay	120	3.5
NIOSH REL		500	LFC
OSHA PEL		1000	5
ACGIH TLV		500	10

LFC = Lowest feasible concentration

PEL = Permissible exposure limit

REL = Recommended exposure limit

TLV = Threshold limit value

No full-shift personal air samples for chromium exceeded any OELs for total chromium (Table 4). It should be noted, however, that hexavalent chromium was present in some samples; exposure to hexavalent chromium may exceed OELs despite total chromium levels being below OELs. Employees performing hand and power sanding in the stripping and paint bays had the highest full-shift chromium concentrations. The highest task-based personal air sample concentration for chromium (720 $\mu g/m^3$) occurred during 279 minutes of hand sanding in the stripping bay combined with 176 minutes of power sanding in paint bay 2 (Appendix B, Table B3). Two of the 15 full-shift TWA air samples for cadmium exceeded the OSHA PEL (5 $\mu g/m^3$) and both occurred in paint bay 1 during sanding (Table 4).

The full-shift area air sampling results for chromium and cadmium, shown in Appendix B, Table B4, suggest that metal contamination is migrating to nonproduction areas, including offices. The highest area air concentration measured in the office area was for chromium (1.1 $\mu g/m^3$), which was measured during the second day of sampling, and coincided with the application of primer, antistatic coating, and sanding of an aircraft in paint bay 2. The highest overall area air chromium concentration was also measured on the second day in the paint bay 2 (100 $\mu g/m^3$) where sanding and green primer spraying occurred.

For hexavalent chromium, all eleven personal full-shift TWA air samples exceeded the NIOSH REL of 0.2 $\mu g/m^3$, and five full-shift samples exceeded the OSHA PEL of 25 $\mu g/m^3$ (Figure 7 and Tables B5–B7 in Appendix B). The full-shift hexavalent chromium concentrations ranged from 4.6 to 330 $\mu g/m^3$.

The highest task-based hexavalent chromium concentrations occurred during hand and power sanding in paint bay 2 (120 $\mu g/m^3$ and 800 $\mu g/m^3$) and during the spraying of green primer (1,100 $\mu g/m^3$ and 1,500 $\mu g/m^3$) (Figure 8) and Tables B5–B7 in Appendix B.

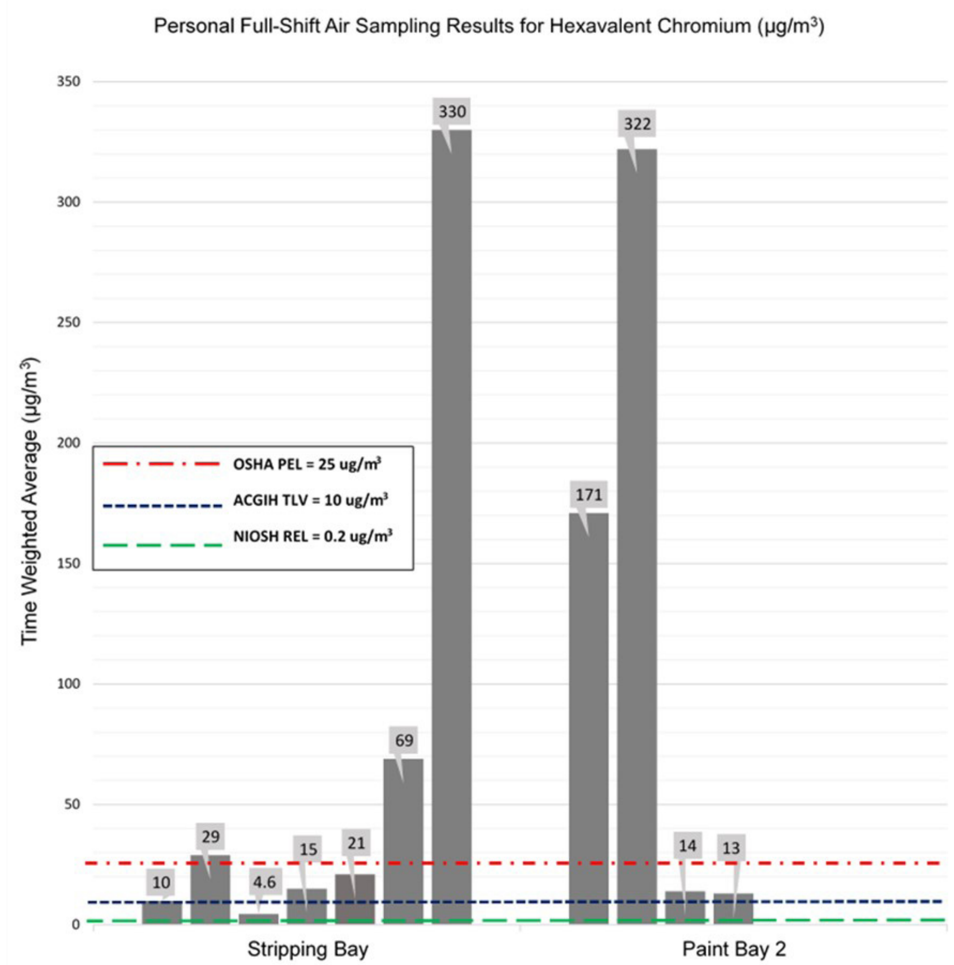

Figure 7. Full-shift personal TWA exposures in the stripping bay and paint bay 2.

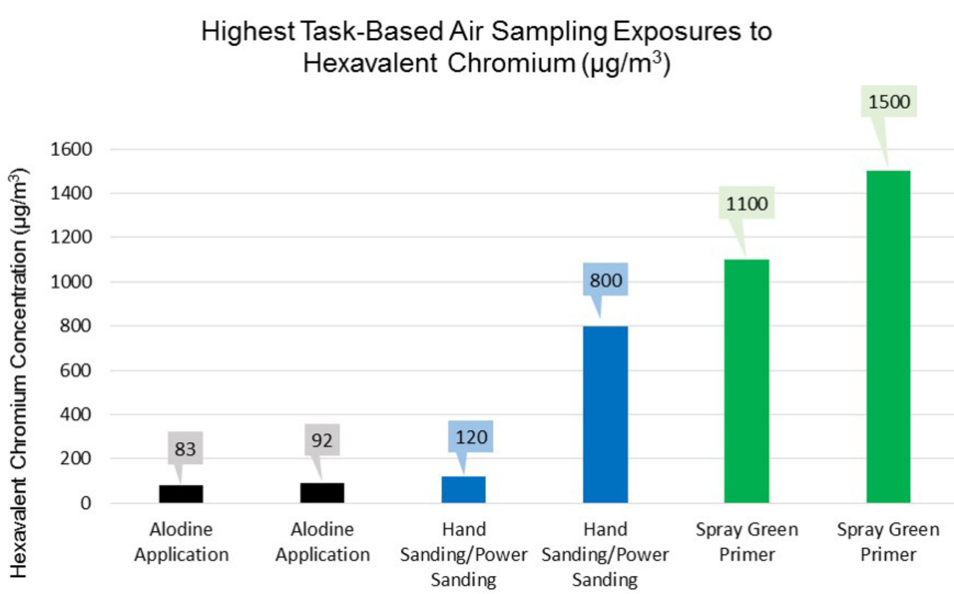

Figure 8. Tasks that generated the highest airborne exposures to hexavalent chromium.

Personal air sample concentrations of HDI are summarized in Table 5, and more detailed HDI air sampling results are shown in Appendix B, Tables B9–B11. All HDI results were below the lowest OELs set by NIOSH and ACGIH.

Table 5. Ranges of personal full-shift TWA air monitoring for isocyanates over 3 days, in mg/m^3

Task	Number of samples	HDI	HDI polyisocyanates
Taping, sanding, wiping with lacquer thinner, mixing, painting single stage	3	4.4–14	89–140
Taping, sanding, mixing, painting stripes and clear coat	2	0.56–0.65	15–20
Sanding, wiping with lacquer thinner, mixing, spray primers	4	ND	< 0.68–1.1
Sanding	3	ND	ND
Occupational exposure limit		35 (NIOSH, ACGIH)	None

ND = Not detected. For these samples the minimum detectable concentration (MDC) was 0.16 mg/m^3 for HDI and 0.20 µg/m^3 for HDI polyisocyanates.

We collected six sets of full-shift area air samples for HDI using different sampling media across 3 days in the paint bays and the stripping bay. The intent of this sampling was to compare methods but because of a laboratory error, the results from the Asset EZ-4 NCO samplers are not reported. These samples were left in the desorbing solution too long at the laboratory, which resulted in a lower, more variable recovery percentage (e.g., 30% to 80%). This error may have caused the analyte of interest (HDI and HDI polyisocyanate) to precipitate out of solution. However, we were able to compare results for the six sets of side-by-side MAP filters (Table 6).

Table 6. Comparison of full-shift and short-term, sequential area air samples for HDI*, in μg/m^3

Location and tasks	Sampling time (minutes)	HDI		HDI polyisocyanate	
		Short-term	Full-shift TWA	Short-term	Full-shift TWA
Paint bays					
Bay 1, painting stripes	622	NA	[0.08]	NA	1.9
	342 280	ND ND	ND	1.1 3.2	2.0
Bay 1, painting stripes	623	NA	[0.06]	NA	1.9
	342 281	ND ND	ND	1.1 3.2	2.0
Bay 1, painting fuselage	421	NA	1.0	NA	26
	178 130	0.5 2.0	1.1	17 70	39
Bay 2, priming	621	NA	ND	NA	[0.13]
	399 222	ND [0.21]	[0.08]	ND ND	ND
Stripping bay					
Sand, etch, Alodine application	590	NA	ND	NA	ND
	326 253	[0.13] ND	ND	ND ND	ND
Paint stripping	583	NA	ND	NA	ND
	283 300	ND ND	ND	ND ND	ND

NA = not applicable

ND = not detected, less than the MDC of 0.1 μg/m^3 for HDI or HDI polyisocyanate.

[ ] = Values in brackets indicate a sample result that was between the MDC and the minimum quantifiable concentration (MQC). The MDC's ranged from 0.05 μg/m^3 to 0.23 μg/m^3. The MQCs ranged from 0.14 μg/m^3 to 0.66 μg/m^3; more uncertainty is associated with these values. Note: For samples found to be ND, we assumed zero when calculating short-term or full-shift TWAs.

*Area air samples collected side-by-side using 3 filters. The first filter sampled for a full-shift (up to approximately 10 hours). The remaining two filters sampled approximately one half of the shift each (e.g., one sample represents the first half of the shift; a second sample represents the second half of the shift). Some samples were collected over time periods that were sometimes longer or shorter than exactly one half of a 10 hour shift.

The results of the area air samples for HDI and HDI polyisocyanate (full-shift or two sequential short-term air samples) using the MAP filters ranged from ND to 39 μg/m^3 (Table 6). Most of the short-term and full-shift air samples collected during isocyanate paint spraying showed similar results. However, a small difference was noted when comparing the sum of the short-term samples with the full-shift TWA sample during fuselage painting. In this comparison, the HDI concentrations were consistent, but the polyisocyanate concentrations (short-term) did not add up to the concentration measured on the full-shift sample.

Results of the surface wipe samples for chromium, cadmium, and hexavalent chromium are presented in Appendix B, Table B8. Cadmium levels ranged from 0.12–250 μg/100 cm^2, with the highest level found on top of a barrel in the stripping bay. Samples analyzed for chromium ranged from 0.32–3,300 µg/100 cm^2 with the highest level found on top of the same barrel in the stripping bay. All surfaces that we sampled tested positive for hexavalent chromium (range: 0.12–9.3 µg/100 cm^2) with the highest level found on a desk in the stripping bay. Other areas that had metal surface contamination, ranked from highest to lowest, were the hazardous waste room workstation, the outside door surface of a locker, the men's bathroom door handle, the surface of a table and refrigerator handle in the break room, and desk and table surfaces in two offices. We found cadmium, chromium, and hexavalent chromium on the inside surface of a half-mask respirator stored in a locker. We also found chromium and cadmium on the hands of all six of the employees we sampled at the end of their shift before they left for the day. Isocyanates were detected (detection limit was 20 µg per wipe sample) on one of four skin wipe samples taken from four paint bay employees after painting with isocyanate paints before they left for the day.

Ventilation Assessment

The stripping bay was approximately 75 feet wide × 72 feet long × 26 feet high. Unconditioned outdoor air was delivered through two ceiling-mounted air handling units. Each unit inflated a plastic perforated tube plenum that distributed the outdoor airflow horizontally across the ceiling (Figure 9). Another air handling unit provided heated air through two louvered supply openings on the wall opposite the bay door (Figure 9). There were six floor level filtered exhaust outlets, three along each side wall of the stripping bay (Figure 10). With all supply and exhaust fans running, the bay was observed to be under positive pressure relative to adjacent areas, meaning that air flowed from the stripping bay into adjacent areas. Ventilation smoke visualization tests showed turbulent airflow patterns, little removal of the smoke, and multiple areas of little air movement, a situation that could result in a buildup of air contaminants. We measured the air velocity at the face of each of the six exhaust outlets and found the velocities to be very consistent (approximately 1,000 feet per minute each) except for one outlet. This outlet had a face velocity approximately half that measured at the other exhaust outlets; its fan was operating at a lower speed than the others. We also noticed objects such as barrels and telescopic booms blocking the exhaust outlets.

Figure 9. An aircraft parked in the stripping bay. Outdoor air was provided by a ceiling-mounted air handler and distributed through perforated, flexible plastic ducts (top right). Conditioned air was supplied through two wall fans in front of aircraft. The location of outdoor and conditioned air supplies created turbulence and reduced the effectiveness of the floor mounted exhaust ventilation system. Photo by NIOSH.

Figure 10. Stripping bay floor level exhaust with paint arresting filters (green filter media covering exhaust hood). Photo by NIOSH.

Each paint bay was approximately 75 feet wide × 75 feet long × 26 feet high. Each was under negative pressure relative to adjacent areas, meaning that air flowed into the paint bay. Sixty-three ceiling-mounted air supply registers delivered filtered, conditioned outdoor air from a plenum located above the ceiling. This design directed the supply air downward towards the top of the aircraft at air velocities ranging from 300 to 400 feet per minute. In-floor exhaust ventilation grates ran parallel to and on each side of the aircraft fuselage, producing exhaust air velocities ranging from 70 to 100 feet per minute. The desired air velocity in a work area surrounding an aircraft is 100 feet per minute [OSHA 2013a].

The design configuration of the paint bays was intended to deliver ceiling-to-floor airflow to the work area, and then exhaust the contaminated air out of the bay through a filtered exhaust system. Using the Roscoe fog machine, we observed that the ventilation system delivered air to the top of the fuselage, but the airflow pattern was turbulent. We also noticed little to no air movement at and below wing level, and very little capture of the fog at the floor exhaust (Figures 11 and 12).

Figure 11. Measuring air velocity and airflow through each of the supply registers in paint bays 1 and 2. Photo by NIOSH.

Figure 12. Measuring air velocity and airflow through a paint bay exhaust grates. Photo by NIOSH.

Using ventilation smoke tubes we determined that the 2,700-cubic-foot paint mixing room (24.5 feet wide × 8.4 feet long × 8.4 feet high) was under positive pressure relative to the two paint bays when the spray bay ventilation system was not operating. We did not evaluate the pressure difference between the paint room and the paint bay when the spray bay ventilation system was operating, so any change in the air pressure differential between these two areas under those conditions is unknown. The total supply airflow rate delivered to the paint mixing room through two registers located in the corners adjacent to the workbench was about 570 cubic feet per minute. A single exhaust outlet on the wall opposite the workbench exhausted air to the outside at 50 cubic feet per minute—a large imbalance. Such an imbalance could result in some of the air contaminants generated in the paint room migrating to other areas such as the adjacent spray bay or office area. This configuration did not result in any airflow short-circuiting. We calculated that there were approximately 12 air changes per hour occurring in the paint mixing room.

Observations

We saw 10 employees applying the stripper, etcher, or Alodine wearing rain suits (84% polyvinyl chloride and 16% polyester), rubber boots, nitrile gloves, and full facepiece air purifying respirators equipped with organic vapor cartridges. Other employees used N95 prefilters and organic vapor cartridges for protection against particulate and vapors when sanding and using lacquer thinner to wipe down surfaces; however, we observed that the prefilters were not changed prior to each use. When not in use, coveralls and rain suits were stored in the production area on hangers, and rubber boots were stored on shelves by the rain suits. Respirators (some clean, others not) were stored in plastic bags in lockers in the production area.

During the two site visits we observed employees wearing a disposable Tyvek® suit, full facepiece airline respirator, and nitrile gloves when mixing paints. During painting tasks, employees wore a disposable Tyvek suit, elastomeric full facepiece respirator with organic vapor cartridges, and N95 prefilters or a full facepiece, pressure-demand airline respirator, cotton hood, and latex or nitrile gloves. During spray painting, some employees taped the joint between their gloves and suit and also where their suit met their shoes to protect their skin from the paint. During sanding, employees wore a long or short sleeve cotton coverall uniform, an elastomeric half-mask respirator with organic vapor cartridges and N95 prefilters, hearing protection (plugs and/or earmuffs), safety glasses, and latex gloves. No protective gloves or respirators were used when applying tape to the aircraft before painting because the employees reported the gloves made it difficult to handle the tape. During our second site visit, we noticed employees wearing full facepiece respirators during sanding.

Employees were required to wear air purifying respirators with organic vapor cartridges and N95 prefilters during sanding tasks and were encouraged to change them on a schedule developed by the company. However, we do not know how the company generated the changeout schedule. Many of the employees reported they changed the prefilters every 2 days and the organic vapor cartridges every 2 weeks. Employees also reported writing the changeout date on the cartridge to remind them when to change it. We were informed that the team leads encouraged employees to clean their respirators every day and wash them every 2 weeks; however, we saw no employees cleaning their respirator, with the exception of using compressed air to blow dust off the respirator. Many of the hoods worn during sanding and painting interfered with the respirator seal. We noticed only one employee doing a respirator seal check.

None of the bays had local exhaust ventilation systems. However, some pneumatically powered vacuum hand sanders in the stripping bay were equipped with fabric bags to capture dust. We saw some stripping bay employees emptying the dust collection bags between jobs while others did not. Also, some hand sanders in the paint bays were not equipped with dust capturing bags. We did not see employees checking airline pressure prior to putting on their airline respirator. Also, we did not see a pressure gauge on the airline supply hose manifold, as required by OSHA.

Employees only had one door to access the production bays, and all employees had to go through the stripping bay and paint bay 1 to get to paint bay 2 (Figure 1). This layout required all personnel who needed to enter either paint bay or the paint mixing room to travel through contaminated areas. Movement between bays was controlled by using caution tape around the aircraft and placing "closed" signs on the door when stripping or painting occurred. However, temporary isolation of a bay was not always followed. We observed some employees wearing no PPE when they walked through the bays while sanding was underway.

Employee lockers were located inside the paint mixing room and the hazardous materials room. Personal items such as street clothes, food, and beverages, along with PPE, were kept inside these lockers. We observed respirators stored inside lockers that were dusty; some of these respirators were not stored inside a sealed container. On our second visit, we noted that the lockers from the hazardous materials room had been relocated to a separate room with large sinks for washing hands and respirators.

During our second visit, we observed more employees removing PPE (suit or coveralls, respirator, gloves, hearing protection) before breaks than we did during our first visit. Employees were required to remove their PPE prior to using lavatories and entering break areas. However, because the breaks were only 15 minutes, and there was congestion around the PPE storage area, some employee breaks were cut short because of the time it took to remove their PPE. We also saw some employees not washing their hands before lunch, and others wearing their PPE when using the bathroom or when entering other nonproduction areas.

We saw employees dry sweeping the floor in the production areas during both site visits and using compressed air to remove dust from work clothing during our second site visit, a practice not permitted by OSHA. We also observed janitorial personnel dry sweeping floors in the nonproduction areas. We observed open containers of paint thinner that were sometimes left inside the paint bays. The concrete floor in the stripping bay was unsealed and therefore difficult to clean. We saw employees using ladders unsafely (e.g., standing on the top step of a ladder and moving the ladder while standing on it). Even though the company had a fall protection program, we saw employees working 10–20 feet off the floor without fall protection (e.g., working atop an aircraft engine).

Discussion

Hexavalent Chromium, Cadmium, and Chromium

The most significant finding of this evaluation were the employee overexposures to hexavalent chromium. The highest TWA personal exposures reached 1,600 times the NIOSH REL and more than 13 times the OSHA PEL. On a task basis, the highest exposures were measured when employees worked with the Alodine stripping agent or the green primer. Although not to the same degree, we also measured airborne overexposures to cadmium.

The level of respiratory protection used was not appropriate for the high hexavalent chromium exposures that we measured although the biomonitoring results suggest that they did afford some protection. On the basis of our air sample results, elastomeric half-mask (Assigned Protection Factor of 10) or full facepiece (Assigned Protection Factor of up to 50) respirators do not sufficiently reduce employee exposure to hexavalent chromium during sanding tasks in the stripping and paint bays.

Although we measured very high airborne exposures to hexavalent chromium, urine levels of chromium (which reflect very recent exposure due to the short half-life of chromium in urine) were below the OELs. However, evidence of nasal tissue damage is consistent with long-term hexavalent chromium exposure [Gibb et al. 2000; NIOSH 2013]. Likewise, we measured overexposures to cadmium, but most of the urinary and blood cadmium levels were nondetectable. Employees reported respiratory symptoms and mucous membrane irritation, including dermatitis and respiratory sensitization during health interviews. Some of these effects could be caused or exacerbated by short-term exposures to isocyanates, metal (chromium) dust, or organic solvents present in this workplace [Nemery 1990; NIOSH 1996, 2013]. The most frequent respiratory effect associated with isocyanate exposure is asthma due to sensitization [Lockey 2015; Markowitz 2005; NIOSH 2006]. After sensitization, any exposure, even to levels below OELs, can produce an asthmatic response that may be life threatening [NIOSH 1978, 1996, 2006]. Although few skin symptoms were reported, skin exposure to organic solvents, isocyanates, and hexavalent chromium can result in skin irritation, skin sensitization, and allergic contact dermatitis [Goossens et al. 2002; NIOSH 1978, 2013; Rosenberg et al. 1997]. Other factors that may contribute to skin rashes are sweating during the summer months, the use of PPE, or exposure to chemicals in the workplace.

Isocyanates

We found low amounts of urinary isocyanates that did not increase over the work shift. Furthermore, the personal isocyanate air samples did not exceed the NIOSH or ACGIH OEL, and area air samples showed no migration of either HDI or HDI polyisocyanates to other work areas where these chemicals are not used. In addition, the comparison of isocyanate area air samples (short-term versus full-shift) showed good agreement and further support our findings of low concentrations when painting aircraft. Non-occupational sources of exposure to aliphatic isocyanates include consumer products used in crafts, furniture, or other home projects, as well as auto body painting.

We noticed a small difference in isocyanate air concentration when comparing the sum of two short-term area samples with the full-shift area air sample. A possible explanation for such a result involves the time between sample collection and the in-field sample extraction step. HDI polyisocyanate samples collected over a long period of time (e.g., 10 hours) prior to extraction in the field may experience losses due to curing because the derivatization reaction for reactive isocyanate aerosols on filters is not totally efficient. The desired derivatization reaction can occur efficiently once the sample is extracted, but some losses will likely have already occurred. Conversely, when shorter duration samples are collected, the time these polyisocyanates reside on the filter is less, which allows the sample to be placed into the derivatizing solution faster. Therefore, the shorter duration samples are expected to generate more accurate estimates of concentration.

Ventilation

During our second visit, we measured the effectiveness of the ventilation systems in controlling employee exposures to chromium, cadmium, and isocyanates. We concluded that all bays and the paint mixing room could use ventilation improvements. We found turbulent airflow patterns in the stripping bay along with variable air velocities. Also, due to the positive pressure relationship between this bay and adjacent areas, air contaminants may migrate to other areas (both production and nonproduction). To reduce such a possibility, it may be necessary to either reduce the amount of air supplied to the area, increase the exhaust fan flow rate by increasing the fan speed, or a combination of both. The stripping bay would require a substantial ventilation system retrofit to reduce the turbulence caused by the existing system configuration. If possible, all stripping operations should be conducted in a bay with better contaminant control equipment and better ventilation. To reduce turbulence and better control air contaminants in the stripping bay, it is necessary to create laminar airflow to help direct contaminants towards the exhaust outlets. The ceiling-to-floor airflow pattern shown in Figures 13 and 14 illustrates the concept of directional, laminar airflow.

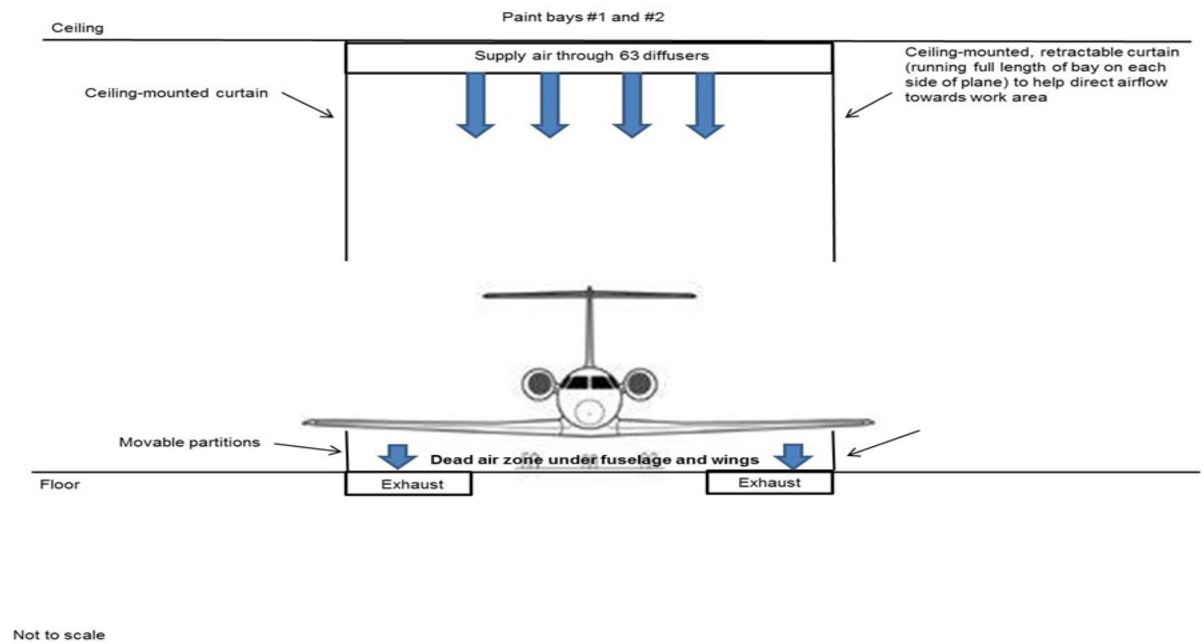

Figure 13. Schematic drawing of aircraft, suggested curtains and moveable partitions to help channel airflow from ceiling to floor. Drawing by NIOSH.

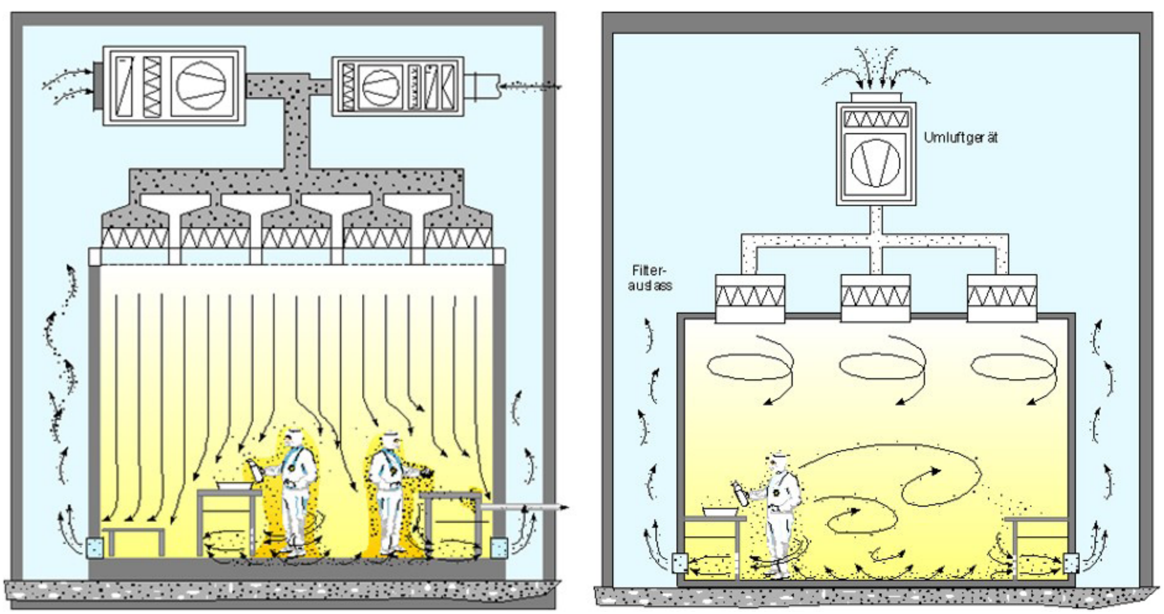

Figure 14. Laminar (image on left) vs. turbulent (image on right) downdraft ventilation. Drawing from Wikipedia at http://en.wikipedia.org/wiki/Cleanroom.

We also found turbulent airflow patterns and variable air velocities in the paint bays. Creating laminar airflow would reduce turbulence and improve contaminant control by directing contaminants towards the exhaust outlets. Applying laminar airflow in the paint bays would involve installing ceiling-mounted, retractable curtains that are attached at the outer edge of the array of air supply registers and run the length of the bay. These curtains should hang down to a height approximately halfway to the floor. This configuration will improve the channeling of the airflow to the work zone and the exhaust grates. Additionally, moveable, floor-standing partitions brought alongside the outside edge of the exhaust grates and extending to an adjustable height that would clear the underside of an aircraft wing would improve contaminant capture by the exhaust ventilation system. This overall configuration is expected to function essentially as a ceiling-to-floor air shower (Figure 13). The paint mixing room ventilation system needs to be balanced so that the air changes per hour (supply and exhaust) are approximately 10 to 12 and the overall pressure balance is slightly negative relative to adjacent areas [ACGIH 2010].

Changes to the layout of the building seem to have reduced the migration of contaminants into nonproduction areas. However, because surface contamination was detected in nonproduction areas during the second visit, additional efforts may be needed to minimize the spread of contamination. Using chromium detected on surfaces during the second visit as an example, the highest contamination was in the production area (3,300 µg/100 cm^2 on a barrel in the stripping bay), followed by the surfaces just outside the production area (220 µg/100 cm^2 on a desk near the stripping solution pump), then in the common break area (6.4 µg/100 cm^2 on a break room table and 5.5 µg/100 cm^2 on the microwave touch pad). We noticed PPE donning and doffing procedures, personal hygiene guidelines, and housekeeping were improved on the second visit.

Other Observations

Overexposures in air to cadmium in the stripping and paint bays, along with higher than expected area air sample results for chromium and cadmium, suggest that these metals may be migrating from production to nonproduction areas. We determined that the spread of contamination of these metals into nonproduction areas could be due to a positive air pressure relationship between the production and nonproduction areas that would allow air to move from the production areas to the nonproduction areas and the lack of a clearly delineated "clean" and "contaminated" area. Employees not removing contaminated PPE prior to entering a nonproduction area, and poor ventilation control of particulates, could account for the presence of these contaminants in the air and surfaces in areas such as the break room and offices.

We noted most of the recommendations made during our first visit were implemented. We commend the company for its efforts in improving health and safety, most notably by building a room with lockers and shower facilities, providing uniforms to production employees, providing a laundry service for the uniforms, providing elastomeric full face respirators for use during sanding (instead of half-mask respirators), and starting a medical surveillance program for hexavalent chromium exposure. Further, after we completed our second visit, the company reported to us that they continued to improve health and safety protocols and installed supplied-air respirators in the stripping bay.

Conclusions

Employee exposure to airborne hexavalent chromium and cadmium in the stripping and paint bays exceeded OELs. Employees in these areas are also exposed to isocyanates.
Most employees had low but detectable levels of chromium in their urine. Fourteen of 38 employees had nasal tissue damage that is consistent with cumulative workplace exposure to hexavalent chromium. Employees reported respiratory symptoms such as chest tightness and wheeze, sinus congestion, irritation and nosebleeds, and one employee reportedly was diagnosed with isocyanate sensitization. The respirators employees wore during stripping and sanding operations were not sufficiently protective considering the high hexavalent chromium exposures that we measured. Employees should wear full facepiece supplied-air respirators during these tasks. The ventilation in the stripping and paint spray bays did not effectively control and remove air contaminants. We found chromium, hexavalent chromium, and cadmium on surfaces throughout the workplace, suggesting that contaminants were migrating from production to nonproduction areas. We found chromium, hexavalent chromium, and cadmium on hands of employees during breaks and just before leaving the workplace indicating that improved hygiene was needed.

Recommendations

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

Our recommendations are based on an approach known as the hierarchy of controls. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and PPE may be needed. Many of the recommendations made here were previously communicated to the company through a series of letters.

Elimination and Substitution

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

1. Use paint stripping and paint primer products that do not contain hexavalent chromium.

Engineering Controls

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

1. Use locally exhausted hand sanders in the paint bays. Empty dust collection bags on the sanders as needed throughout the work day.
2. Consult a qualified ventilation engineer to improve the ventilation systems in the stripping and paint bays. Written requirements for spray booth or spray area ventilation can be found in the Occupational Safety and Health Administration General Industry Standards Part 1910.94 and in the American National Standards Institute Z9.3-2007 [ANSI/ASSE 2007] and ACGIH [2010].
3. Improve the ventilation systems in production areas. Examples include the following:
    - Stripping bay: use portable, local exhaust ventilation systems near areas of the aircraft undergoing sanding. The portable local exhaust ventilation systems should be equipped with high-efficiency particulate air filters.
    - Paint bays: install curtains extending down from the ceiling to better direct the supply air from the ceiling to the aircraft and eventually into the floor exhausts. Also consider positioning moveable partitions as described in the report along the length of the fuselage to direct airflow into the exhaust inlets (Figure 11).
    - Paint mixing room: increase the exhaust airflow rate so that the room is under negative pressure relative to the adjacent paint bays.

Administrative Controls

The term administrative control refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Require employees report to their supervisor or the director of the medical monitoring program any suspected work-related symptoms or illnesses so that steps can be taken to address needed workplace controls. Encourage employees who report symptoms such as nasal swelling or congestion, frequent nosebleeds, or nasal ulcers to seek a follow-up evaluation and treatment from a healthcare provider, preferably one with training in occupational medicine.
2. Encourage employees to report to a healthcare provider if they are engaged in other activities that involve exposure to metals and isocyanates such as spray painting and sanding automobiles to document their exposures and guide their medical assessment.
3. Confirm that the medical monitoring program for hexavalent chromium includes the following elements for all paint department employees as described in the NIOSH

Criteria for a Recommended Standard, Occupational Exposure to Hexavalent Chromium:

- Occupational and medical history including information on conditions such as skin sensitization, occupational asthma, and occupational dermatitis.
- Physical examinations with specific emphasis on respiratory system, skin checks for dermatitis and regular checks of the nasal septum. For new employees, these should be conducted at the beginning of employment, after 6 months on the job, and then annually.
- Annual lung-function testing and a baseline chest radiograph within 3 months of hiring.

4. Include employees exposed to isocyanates in the medical surveillance program. General recommendations for medical monitoring are as follows:
   - Preplacement, annual, and exit general medical examinations with:
     i. Special emphasis on the respiratory system.
     ii. Medical history including an extensive work history, history of pre-existing respiratory conditions such as asthma, and a smoking history.
     iii. Spirometry–more information for employers and employees can be found in the OSHA Spirometry Information sheet and the OSHA Spirometry Worker Information sheet.
   - Employees with a history of respiratory conditions or dermatitis should be informed of the potential for increased health risks associated with exposure to isocyanates.
   - Isocyanate-sensitized individuals should be assigned to areas where exposure to isocyanates is not expected. More information can be found in Appendix H of the the OSHA Instruction document on the National Emphasis Program-Occupational Exposure to Isocyanates.
5. Evaluate how employees move between production and nonproduction areas with the focus on minimizing the potential spread of contaminants. One approach would be to require employees to remove their contaminated PPE in a specific area (e.g., the locker room) and wash their hands and arms before entering a nonproduction area.
6. Inform laundry and janitorial personnel about the potential hazards of handling contaminated clothing. Personnel should be trained on measures to minimize their exposure, for example by using as a minimum a coverall, protective gloves, and safety glasses and wet cleanup methods.
7. Use employee lockers in the paint mixing room exclusively for storing PPE, paint guns, and other work materials; do not store personal items, food, or drinks in this area.
8. Use work boots exclusively in the production area. Work boots should be cleaned and stored in the locker room before employees proceed to nonproduction areas. Alternatively, employees could be offered disposable booties to wear over work boots before entering nonproduction areas.

9. Stop dry sweeping dust on the floors. Do not use compressed air to clean dust from any work surface or employee clothing. Instead, use a vacuum equipped with high efficiency particulate air filters or a wet mopping or wiping technique for surface cleaning.
10. Include a respirator cartridge change-out schedule in the written respiratory program.
11. Allow employees more time during breaks and at the end of their shift to wash, change clothing, and clean respirators.
12. Do not use compressed air to clean respirators. Doing so could damage valves and seals and result in reduced protection.
13. Include the following in regular health and safety training for employees:
    - Information on hexavalent chromium, cadmium, isocyanates, and other potentially hazardous compounds.
    - Training on SDSs and product labels.
    - Routine and emergency procedures for hazardous chemical exposures.
    - Potential adverse health effects from hazardous chemical exposures.
14. Encourage smoking cessation in active smokers.
15. Enforce ladder safety. According to OSHA, the top of a stepladder should not be used as a step [CFR 1926.1053(b)(13)], and ladders should not be moved, shifted, or extended while occupied [CFR 1926.1053(b)(11)].
16. Enforce the fall protection program. According to OSHA, fall protection must be used when working at heights of 4 feet or more [OSHA 2015b].
17. Seal the concrete in the stripping bay to make it easier to clean. Smoother, less porous, and ideally nonskid surfaces should be considered as alternatives for improved floor cleaning.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of PPE requires a comprehensive program and a high level of employee involvement and commitment. The right PPE must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, PPE should be used until effective engineering and administrative controls are in place. Because chromium, cadmium, and isocyanates were sometimes detected in the bays and paint mixing room, employees should wear respiratory protection to minimize exposure, even if they are not working in these areas.

1. Create and enforce a more effective respiratory protection program. Ensure employees are trained on proper respirator cleaning, storage, use, and maintenance procedures. Managers should periodically conduct spot checks to ensure compliance with all respiratory protection program policies and procedures.
2. Require all employees who apply primer or paint and those who conduct sanding

operations to use a full facepiece supplied-air respirator.

3. Use a full facepiece air purifying respirator with an organic vapor cartridge and P100 prefilter for other jobs in the paint bays.
4. Install a pressure gauge on all airline supply manifolds and ensure that the air pressure meets the manufacturer specification.
5. Provide nitrile or other appropriate chemical resistant gloves for use in each bay. Latex gloves should not be used because they are not protective against isocyanate paints and can cause allergic reactions in sensitive individuals [Ceballos et al. 2014].

Appendix A: Analytical Method to Identify Hexavalent Chromium in Bulk Material

All beakers and watch glasses used in the analysis were rinsed with 10% nitric acid followed by deionized water and dried. The liquid stripper was poured onto a clean watch glass and baked in an oven until fully dry. The dried product was scraped off the watch glass, transferred into a tared beaker, and weighed. Then 1.5 milliliters of magnesium sulfate/phosphate buffer solution was added to the beaker followed by 5.0 milliliters of filter extraction solution. The beaker was swirled to ensure mixing. The beaker was covered with a watch glass and heated in a water bath at approximately 100°C for 90 minutes. The beaker was removed from the water bath and allowed to cool to room temperature. The solution was transferred to a 15-milliliter centrifuge tube and brought to a 10-milliliter final volume using deionized water. The same extraction procedure was repeated; according to OSHA ID-215 two separate extractions steps are required for bulk samples. The samples were allowed to settle overnight. Finally, the results of the two extraction steps were added together for a final sample and analyzed by ion chromatography with ultraviolet visible spectroscopy detection.

Appendix B: Tables

Table B1. Task-based and full-shift personal air sampling results for chromium and cadmium, in µg/m³ (November 2013, Day 1)

Location	Task	Sampling time (minutes)	Chromium concentration		Cadmium concentration	
			Task	Full-shift TWA*	Task	Full-shift TWA*
Stripping bay	Sanding/water washing/etching	451	16	22	2.0	2.0
	Alodine application	21	150		ND†	
	Strip bay sanding/water washing/etching	413	NA‡	9.7	NA	0.46
Paint bay 1 and stripping bay	Sanding	120	160	52	2.9	2.4
	Sanding/water washing/etching	330	49		2.4	
	Alodine application	20	110		2.5	
Paint bay 1	Masking, sanding, taping, dust control, painting stripes	336	1.9	2.0	[0.070]§	0.060
	Painting stripes, clear coat and color	221	2.0		ND¶	
	Masking, sanding, taping, dust control	311	2.2	2.3	[0.050]	0.060
	Sanding, remained in staging area	179	2.3		[0.080]	
	Masking, sanding, taping, dust control, painting stripes	217	3.8	2.7	0.21	0.14
	Painting stripes, clear coat and color	225	1.6		[0.070]	
NIOSH REL				500		Lowest feasible
OSHA PEL				1000		5
ACGIH TLV				500		10

*TWA = Employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

†Not detected; sample result was below the MDC for cadmium of 0.470 µg/m³ for this task.

‡Not applicable

§Values in brackets indicate concentrations above the MDC of 0.03–0.06 µg/m³ but below the MQC of 0.07–0.14 µg/m³. There is more uncertainty associated with these values.

¶Not detected; sample result was below the MDC for cadmium of 0.050 µg/m³ for this task.

Table B2. Task-based and full-shift personal air sampling results for chromium and cadmium, in µg/m³ (November 2013, Day 2)

Location	Task	Sampling time (minutes)	Chromium concentration		Cadmium concentration	
			Task	Full-shift TWA*	Task	Full-shift TWA*
Stripping bay	Sanding, stripper application, degreasing	449	20	20	3.3	3.3
	Sanding, stripper application	338	27	19	0.22	0.20
	Sanding, stripper application	159	3.4		0.13	
Paint bay 1	Sanding	154	79	49	14	10
	Sanding	177	22		7.2	
	Sanding	299	40	30	12	8.3
	Sanding	180	13		2.8	
NIOSH REL				500		Lowest feasible
OSHA PEL				1,000		5
ACGIH TLV				500		10

*TWA = Employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

Table B3. Task-based and full-shift personal air sampling results for chromium and cadmium, in µg/m^3 (November 2013, Day 3)

Location	Task	Sampling time (minutes)	Chromium concentration		Cadmium concentration	
			Task	Full-shift TWA*	Task	Full-shift TWA*
Paint bay 1	Taping, sanding, wiping down, dust control, mix and spray single stage paint	291	6	5.1	0.2	0.15
	Spray single stage paint	88	2.3		ND†	
Paint bay 1	Spray single stage paint	215	4.8	4.0	0.19	0.16
	Spray single stage paint	87	2.3		ND	
Paint bay 1	Taping, sanding, wiping down, dust control, mix and spray single stage paint	294	4.1	3.7	0.15	0.14
	Spray single stage paint	99	2.4		ND	
Stripping bay, paint bay 2	Hand sanding in stripping bay, Power sanding in paint bay 2	279	91	340	3.7	2.4
	Hand sanding in stripping bay, Power sanding in paint bay 2	176	720		0.40	
Stripping bay, paint bay 2	Hand sanding in stripping bay, Power sanding in paint bay 2	280	93	120	4.3	3.5
	Hand sanding in stripping bay, Power sanding in paint bay 2	140	220		1.8	
NIOSH REL				500		Lowest feasible
OSHA PEL				1,000		5
ACGIH TLV				500		10

*Employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

†Not detected; sample result was below the MDC for cadmium of 0.10 µg/m^3.

Table B4. Full-shift* area air sampling results for chromium and cadmium, in µg/m³

Location	Day 1		Day 2		Day 3	
	Chromium	Cadmium	Chromium	Cadmium	Chromium	Cadmium
Paint bay 1	0.7	[0.02]†	17	0.07	0.59	ND‡
Paint bay 2	NS§	NS	100	ND	NS	NS
Mixing room	1.4	[0.04]	0.88	[0.02]	0.78	[0.02]
Stripping bay	10	0.31	0.39	ND	NS	NS
Hazardous materials room	1.4	0.12	0.90	0.05	0.89	[0.03]
Office	0.49	ND	1.1	[0.02]	0.32	ND

*Sampling times ranged from 583 minutes to 620 minutes.

†Values in brackets indicate an air concentration was detected below the MQC of 0.1–0.2 µg/m³ for chromium and 0.04–0.08 µg/m³ for cadmium. There is more uncertainty associated with these values.

‡Not detected; sample result was below the MDC of 0.03–0.07 µg/m³ for chromium or 0.02–0.03 µg/m³ for cadmium.

§Not sampled

Table B5. Task-based and full-shift personal air sampling results for hexavalent chromium, in µg/m³ (November 2013, Day 1)

Location	Task	Sampling time (minutes)	Concentration	Full-shift TWA*
Stripping bay	Sanding	123	11	10
	Sanding, water washing, etching	327	5.4	
	Alodine application	21	83	
Stripping bay	Sanding	120	62	29
	Sanding, water washing, etching	331	14	
	Alodine application	19	92	
Stripping bay	Sanding, water washing, etching	458	4.6	4.6
NIOSH REL				0.2
OSHA PEL				25
ACGIH TLV†				10

*TWA = Employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

†TLV for insoluble hexavalent chromium (10 µg/m³) should be applied to exposure during sanding tasks; for Alodine application, the TLV for soluble hexavalent chromium (50 µg/m³) should be used. Note: Both insoluble and soluble compounds may be present in any sample; therefore, we used the most conservative OEL for comparison purposes.

Table B6. Task-based and full-shift personal air sampling results for hexavalent chromium (μg/m³) (November 2013, Day 2)

Location	Task	Sampling time (minutes)	Concentration	Full-shift TWA*
Stripping bay	Stripper application, sanding, degreasing	448	15	15
Stripping bay	Stripper application, sanding	264	27	21
	Stripper application, sanding	159	11	
Paint bay 2	Sanding, wiping with lacquer thinner, cutting body filler from seams, sweeping, dust control	286	1.5	170
	Spray green primer	80	1,100	
	Spray white primer, mixing paint	160	4.0	
Paint bay 2	Sanding, wiping with lacquer thinner, cutting body filler from seams, sweeping, dust control	282	0.98	320
	Spray green primer	114	1,500	
	Spray white primer, mixing paint	152	2.9	
Paint bay 2	Sanding, wiping with lacquer thinner, sweeping, dust control	310	1.6	14
	Spray anti-static coating, spray white primer	259	29	
Paint bay 2	Sanding, wiping with lacquer thinner, sweeping, dust control	305	0.88	13
	Spray antistatic coating, spray white primer	261	27	
NIOSH REL				0.2
OSHA PEL				25
ACGIH TLV†				10

*Employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

†TLV for insoluble hexavalent chromium (10 μg/m³) should be applied to exposure during sanding and spraying green primer. Note: Both insoluble and soluble compounds may be present in any sample; therefore, we used the most conservative OEL for comparison purposes.

Table B7. Task-based and full-shift personal air sampling results for hexavalent chromium (µg/m³) (November 2013, Day 3)

Location	Task	Sampling time (minutes)	Concentration	Full-shift TWA*
Stripping and paint bay	Hand sanding in stripping bay, power sanding in paint bay 2	279	30	330
	Hand sanding in stripping bay, power sanding in paint bay 2	176	800	
Stripping and paint bay	Hand sanding in stripping bay, power sanding in paint bay 2	227	37	69
	Hand sanding in stripping bay, power sanding in paint bay 2	140	120	
NIOSH REL				0.2
OSHA PEL				25
ACGIH TLV†				10

*TWA = Employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

†TLV for insoluble hexavalent chromium (10 µg/m³) should be applied to exposure during sanding. Note: Both insoluble and soluble compounds may be present in any sample; therefore, we used the most conservative OEL for comparison purposes.

Table B8. Surface sampling results for cadmium, chromium, and hexavalent chromium (μg/100 cm^2)

Location	Item sampled	Site visit #1			Site visit #2		
		Cadmium	Chromium	Hexavalent chromium	Cadmium	Chromium	Hexavalent chromium
Production	Outer rain suit surface worn in stripping bay	NS	NS	NS	0.7	17	NS
	Top of barrel in stripping bay	NS	NS	NS	250	3,300	NS
	Pump desk in stripping bay	4.5	41	9.2	8.7	220	9.3
	Locker exterior	0.15	2.5	3.9	0.27	2.3	0.82
Between production and nonproduction	Inside surface of half-mask respirator	4.2	43	0.6	NS	NS	NS
	Locker exterior	NA	NA	NA	[0.22]*	0.7	0.86
	Hazardous materials room door	NS	NS	NS	0.51	11	NS
	Break room door	NS	NS	NS	0.28	6.3	0.57
Nonproduction	Restroom door handle	1.9	22	2.4	NS	NS	NS
	Break room table top	0.42	5.2	0.4	0.72	6.4	0.25
	Microwave oven door	0.31	3.9	0.63	0.46	5.5	0.51
	Refrigerator handle	ND	0.36	0.51	NS	NS	NS
	Copy machine	[0.12]	1.6	NS	NS	NS	NS
	Water fountain	0.29	6.2	0.92	NS	NS	NS
	Conference room table top	[0.13]	0.93	0.32	NS	NS	NS
	Office 1 desk top	[0.037]	[0.32]	0.12	NS	NS	NS
	Office 2 desk top	0.44	2.9	0.52	0.11	0.74	0.20
	Balance room desk top	NS	NS	NS	3.5	4.4	0.82
LOD		0.05	0.1	0.03	0.01	0.04	0.02
Limit of quantification		0.15	0.42	0.032	0.048	0.15	0.079

NA = Not applicable; clean lockers installed after first site visit.

NS = We did not sample these locations.

*Value in brackets indicates concentration above the LOD but below the limit of quantification. There is more uncertainty associated with these values.

Table B9. Task-based and full-shift personal air sampling results for HDI and HDI polyisocyanates, in µg/m³ (November 2013, Day 1)

Location	Task	Sampling time (minutes)	HDI		HDI polyisocyanates	
			Task	Full-shift TWA*	Task	Full-shift TWA
Paint bay 1	Masking, sanding, painting stripes	334	[0.25]†	0.56	7.0	15
	Spray painting stripes, retaping	165	0.87		17	
	Painting stripes/clear coat	221	0.79		25	
Paint bay 1	Masking, sanding, painting stripes	333	0.27	0.65	8.4	20
	Spray painting stripes, retaping	167	0.84		19	
	Painting stripes/clear coat	57	1.1		38	
Paint bay 1	Masking, sanding, taping	312	ND‡	ND	ND	ND
	Power Sanding	178	ND		ND	
NIOSH REL				35		None
OSHA PEL				None		None
ACGIH TLV				35		None

*Employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

†Value in brackets indicates concentration above the MDC of 0.09 µg/m³ but below the MQC of 0.26 µg/m³. There is more uncertainty associated with these values.

‡Not detected; sample results were below the MDC of 0.10–0.17 µg/m³ for HDI and 0.13–0.22 µg/m³ for HDI polyisocyanates.

Table B10. Task-based and full-shift personal air sampling results for HDI and HDI polyisocyanates, in μg/m³ (November 2013, Day 2)

Location	Task	Sampling time (minutes)	HDI		HDI polyisocyanates	
			Task	Full-shift TWA*	Task	Full-shift TWA
Paint bay 1	Sanding	299	ND†	ND	ND	ND
	Sanding	160	ND		ND	
Paint bay 1	Sanding	289	ND	ND	ND	ND
	Sanding	77	ND		ND	
	Sanding	63	ND		ND	
Paint bay 2	Sanding, wiping with lacquer thinner, cutting body filler from seams, sweeping	287	ND	ND	0.16	1.1
	Spray green primer	126	ND		2.0	
	Spray white primer, mixing	165	[0.31]‡		1.9	
Paint bay 2	Sanding, wiping with lacquer thinner, cutting body filler from seams, sweeping	282	ND	ND	ND	1.0
	Spray green primer	114	ND		1.9	
	Spray white primer, mixing	157	[0.30]		2.1	
Paint bay 2	Sanding, wiping with lacquer thinner, sweeping	305	ND	0.16	ND	0.68
	Spray antistatic coating	106	ND		ND	
	Spray white primer	155	0.58		2.5	
Paint bay 2	Sanding, wiping with lacquer thinner, sweeping	310	ND	ND	ND	0.80
	Spray antistatic coating	109	ND		ND	
	Spray white primer	159	[0.38]		2.8	
NIOSH REL				35		None
OSHA PEL				None		None
ACGIH TLV				35		None

*TWA = employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

†Not detected; sample results were below the MDC of 0.10–0.47 μg/m³ for HDI and 0.13–0.63 μg/m³ for HDI polyisocyanates.

‡Values in brackets indicate concentrations above the MDC of 0.19 μg/m³ but below the MQC of 0.56 μg/m³. There is more uncertainty associated with these values.

Table B11. Task-based and full-shift personal air sampling results for HDI and HDI polyisocyanates, in µg/m³ (November 2013, Day 3)

Location	Task	Sampling time (minutes)	HDI		HDI polyisocyanates	
			Task	Full-shift TWA*	Task	Full-shift TWA
Paint bay 1	Taping, sanding, wiping with lacquer thinner, mixing paint, spray paint single stage	301	5.9	10	100	140
	Spray paint single stage	89	26		290	
Paint bay 1	Taping, sanding, wiping with lacquer thinner, mixing paint, spray paint single stage	292	4.5	4.4	80	89
	Spray paint single stage	58	4.0		130	
Paint bay 1	Taping, sanding, wiping with lacquer thinner, mixing paint, spray paint single stage	299	8.3	14	100	140
	Spray paint single stage	99	31		260	
NIOSH REL				35		None
OSHA PEL				None		None
ACGIH TLV				35		None

*Employee's full-shift TWA was calculated by multiplying the duration of a task by the concentration measured for that task and then dividing the sum of these values by the total sampling time for all tasks.

Appendix C: Occupational Exposure Limits and Health Effects

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

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended STEL or ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

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

- The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, 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 ACGIH TLVs. The TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2017].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen

Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) PPE (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Chromium and Hexavalent Chromium

Employees at this company were exposed to chromium and hexavalent chromium during paint stripping and application of anticorrosive and primer coating. While chromium is an essential trace element in humans, hexavalent chromium is extremely toxic and is designated a human carcinogen [IARC 2012; NIOSH 2013; OSHA 2013b]. Hexavalent chromium is associated with lung cancer and nasal and sinus cancer; nonmalignant respiratory effects include irritated, ulcerated, or perforated nasal septa. Dermal exposures to hexavalent chromium can result in skin irritation, ulcers, skin sensitization, and allergic contact dermatitis [NIOSH 2013]. The median airborne concentration of hexavalent chromium 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].

OELs for chromium include the NIOSH REL of 500 $\mu g/m^3$ (up to a 10-hr TWA) and the OSHA PEL (8-hour TWA) of 1,000 $\mu g/m^3$. The results for hexavalent chromium were compared to the NIOSH REL of 0.2 $\mu g/m^3$ and the OSHA PEL of 25 $\mu g/m^3$ for the painting of aircraft and large aircraft parts [29 CFR 1910.1026(f)(1)]. The ACGIH TLV-TWA is 50 $\mu g/m^3$ for water soluble hexavalent chromium compounds and 10 $\mu g/m^3$ for insoluble hexavalent chromium compounds.

Urinary chromium levels are a measure of chromium exposure; chromium is used as a marker even in situations where hexavalent chromium is the primary concern. The World Health Organization has a guidance limit of excretion of 20 μg of chromium per liter of urine at the end of the shift [WHO 1996]. The ACGIH BEI for urinary chromium is 25 μg per gram creatinine, with the sample to be collected at the end of the shift at the end of the workweek [ACGIH 2017]. This BEI is based on the observed correlation with exposure to soluble hexavalent chromium and applies to employees with a history of chronic hexavalent chromium exposure. Population background levels of chromium are expected to range from 0.2 to 2.0 μg chromium per liter of urine [Paustenbach et al. 1997].

Cadmium

Employees may inhale cadmium dust when sanding, grinding, or scraping cadmium-metal alloys or cadmium-containing paints [ACGIH 2007]. In addition to inhalation, cadmium may be absorbed via ingestion; non-occupational sources of cadmium exposure include cigarette smoke and dietary intake [ACGIH 2007]. Inhaled cadmium can irritate the nose and throat, and the lungs may be affected by repeated or prolonged exposure to dust particles. At higher exposure concentrations, cough, chest pain, sweating, chills, shortness of breath, and weakness may develop [ACGIH 2017]. Long-term or repeated exposures have been associated with lung and kidney damage and cadmium is considered a human carcinogen [ATSDR 2012].

Early symptoms of cadmium exposure may include mild irritation of the upper respiratory tract, a sensation of constriction of the throat, a metallic taste and/or cough. Short-term exposure effects of cadmium inhalation include cough, chest pain, sweating, chills, shortness of breath, and weakness [Thun et al. 1991]. Short-term exposure effects of ingestion may include nausea, vomiting, diarrhea, and abdominal cramps [Thun et al. 1991]. Long-term exposure effects may include loss of the sense of smell, ulceration of the nose, emphysema, kidney damage, mild anemia, and an increased risk of cancer of the lung, and possibly of the prostate [ATSDR 2012]. Blood cadmium levels measure recent exposure in the past few months [Franzblau et al. 2005; Lauwerys and Hoet 2001], while urinary cadmium levels can measure longer-term exposure (several years) [Lauwerys and Hoet 2001].

Cadmium in urine is the most widely used biological measure of chronic exposure while cadmium in blood is an indicator of acute exposure. Non-occupationally exposed populations who are nonsmokers have been found to have median cadmium concentrations in blood ranging from 0.4 to 1.0 micrograms per liter; smokers have concentrations ranging from 1.4 to 4.5 micrograms per liter [Elinder 1985]. The ACGIH BEI is 5 μg per gram creatinine for cadmium in urine and 5 micrograms per liter for cadmium in blood [ACGIH 2017]. The OSHA PEL-TWA for cadmium is 5 $\mu g/m^3$ and the ACGIH TLV is 10 $\mu g/m^3$. NIOSH considers cadmium to be an occupational carcinogen. In 2016, NIOSH published a chemical carcinogen policy that stated that there is no safe level of exposure to a carcinogen; accordingly NIOSH will not set a REL for chemical carcinogens [NIOSH 2017].

The OSHA cadmium standard also requires a preplacement examination and medical surveillance on any employee who is or may be exposed to an airborne concentration of cadmium at or above 2.5 μg/m^3 as an 8-hour TWA, for more than 30 days per year [29 CFR 1910.1027]. For employees meeting the OSHA cadmium exposure criteria, periodic surveillance is also required 1 year after the initial exam and at least biennially after that [29 CFR 1910.1027]. Periodic surveillance shall include the biological monitoring; history and physical examination; a chest x-ray (frequency to be determined by the physician after the initial x-ray); pulmonary function tests; blood tests for blood urea nitrogen, complete blood count, and creatinine; a urinalysis; and a prostate examination for men over 40. The frequency of periodic surveillance is determined by the results of biological monitoring and medical examinations. Termination of employment examinations identical to the periodic examinations are also required. The employer is required to provide the employee with a copy of the physician's written opinion from these exams and a copy of biological monitoring results within 2 weeks of receipt.

Isocyanates

Diisocyanates are a group of highly reactive, low-molecular-weight aromatic and aliphatic compounds, characterized by two isocyanate functional groups (N=C=O). The most common diisocyanates include the aliphatic compounds, HDI and isophorone diisocyanate, and the aromatic compounds, TDI and methylene diisocyanate. Diisocyanates are widely used in the production of polyurethane materials such as foams, adhesives, resins, elastomers, binders, and coatings.

Exposure to isocyanates can be irritating to the skin, mucous membranes, eyes, and respiratory tract [Lockey et al. 2015; NIOSH 1978, 2006]. The most frequent respiratory effect associated with isocyanate exposure is asthma due to sensitization [Lockey et al. 2015; Markowitz 2005; NIOSH 2006]. Contact dermatitis (both irritant and allergic forms) is less common and can result in symptoms such as rash, erythema, and itching [Goossens et al. 2002]. An employee with isocyanate-induced asthma exhibits the traditional symptoms of acute airway obstruction such as coughing, wheezing, shortness of breath, tightness in the chest, and nocturnal awakening [NIOSH 1978, 1986]. Isocyanate-induced asthma occurs with variable latency following the initial exposure, although characteristically the asthma develops within 2 years of exposure [Markowitz 2005]. The asthmatic reaction may occur minutes after exposure (immediate onset) and/or several hours after exposure (delayed onset) [Chan-Yeung and Lam 1986; NIOSH 1986]. After sensitization, any exposure, even to levels below OELs, can produce an asthmatic response that may be life threatening [NIOSH 1978, 1996, 2006].

Diagnosis of isocyanate-induced asthma requires a thorough occupational history. As with other asthmatic conditions, pulmonary function tests may be within normal limits between asthmatic episodes. The prevalence of diisocyanate-induced asthma in exposed employees is believed to be 5%–10% [Bernstein 1996; Chan-Yeung and Malo 1995]. The only effective intervention for employees with isocyanate-induced asthma is cessation of all isocyanate exposure. This can be accomplished by removing the employee from the work environment where isocyanate exposure occurs. NIOSH and ACGIH have OELs for HDI of 35 μg/m^3 as a full-shift TWA. OSHA does not have a PEL for HDI. None of the three organizations (NIOSH, ACGIH, OSHA) publishes an OEL for HDI polyisocyanates.

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