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**FIELD ASSESSMENTS OF POTENTIAL DERMAL SENSITIZER
EXPOSURES AT AIR FORCE AIRCRAFT MAINTENANCE SHOPS**

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14. ABSTRACT Field assessments were performed at two aircraft maintenance shops to determine the presence and, if possible, surface concentrations of a selection of chemicals in operational settings that are known or suspected dermal sensitizers. The Hill AFB Low Observable Aircraft Structural Maintenance (LOASM) corrosion control shop and Wright-Patterson AFB 445 th Airlift Wing MXS maintenance shop were chosen because of analysis of industrial hygiene reports indicating that the presence of five potential dermal sensitizers were likely to be encountered during each sampling event: hexavalent chromium [Cr(VI)], epichlorohydrin (EpiChl), manganese dioxide (MnO ₂), hexamethylene diisocyanate (HMDI), and xylene. Cr(VI), HMDI, and xylene were detected in the air during specific processes at each shop. At both shops, the workers wore full face respirators and Tyvek suits during work processes, so air exposures were only representative of what their exposure would have been without that personal protective equipment (PPE) and not their actual exposure during each process. At both locations, Cr(VI) and total chromium (total Cr) were present in surface wipes associated with all processes. Furthermore, pre-process hand wipes collected at both shops had detectable chromium levels. Both findings indicated that there were residual chromium surface levels that couldn't be directly tied to a single instance of a specific process. Therefore, dermal chromium exposure had the potential to occur before or after active processes, especially if lesser amounts of PPE were worn during setup or cleanup that would increase the likelihood of dermal contact with work surfaces. Although some surface levels of chromium were present in transition areas, the levels were lower than the workrooms, which suggested effectiveness of controls to lower potential exposures in transition areas where less PPE was required. The lack of quantitative surface guidelines for comparison of Cr(VI) levels highlights the gap in knowledge about protective surface limits for dermal sensitizers present in Air Force maintenance shops, which is a gap that an associated risk assessment study is intended to attempt to help address.					
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1.0 SUMMARY

Field assessments were performed at two aircraft maintenance shops to determine the presence and, if possible, surface concentrations of a selection of chemicals in operational settings that are known or suspected dermal sensitizers. The Hill Air Force Base Low Observable Aircraft Structural Maintenance (LOASM) corrosion control shop and Wright-Patterson AFB 445th Airlift Wing MXS maintenance shop were chosen because of analysis of industrial hygiene reports indicating that the presence of five potential dermal sensitizers were likely to be encountered during each sampling event: hexavalent chromium [Cr(VI)], epichlorohydrin (EpiChl), manganese dioxide (MnO₂), hexamethylene diisocyanate (HMDI), and xylene. Trivalent Chromium [Cr(III)], a less potent sensitizer than Cr(VI), can also be present in processes where Cr(VI) is used. Other potential sensitizers including formaldehyde, nickel, acrolein, and cobalt have been identified in industrial hygiene reports as chemicals associated with processes that occur at aircraft maintenance shops. However, their presence was not expected to be associated with processes that were occurring during the sampling period, so samples were not collected for these substances.

Air and surface wipe samples were collected at the Hill Air Force Base LOASM shop during sanding, blasting, priming, and topcoat painting of an F-16 hardback stand on 17-19 May 2022. Air and surface wipe samples were collected at the Wright-Patterson AFB 445th MXS shop during priming and topcoat painting of C-17 aircraft components on 13-14 June 2022. On-body personal breathing zone (PBZ) air samples were collected from individuals participating in each process. Area air samples were collected in the work areas and in transition areas for each process. Hand wipe samples were collected before and after each process, while surface wipe samples were collected following each process.

At the Hill AFB LOASM shop, Cr(VI) was present in air samples collected during blasting and sanding processes, but not the painting processes, which was expected because of the lack of chromium in the primer that was used. Detectable HMDI levels were found in PBZ samples during topcoat painting. EpiChl, manganese (Mn), and xylene were not detected in any of the samples that were taken during or after painting. At the Wright-Patterson 445th MXS shop, Cr(VI) was present in air samples collected during the priming process, which was expected because the primer that was used contained Cr(VI). Approximately 24 hours after priming was completed, inhalable Cr(VI) was also detected in air samples collected in the paint booth during topcoat painting. Xylene was also detected at low levels during priming. EpiChl and Mn were not detected in any of the air samples that were taken during priming or topcoat painting. Inhalable Cr(VI) was also detected in area air samples collected in transition areas at the Wright-Patterson 445th MXS shop.

At both shops, the workers wore full face respirators and Tyvek suits during work processes, so air exposures were only representative of what their exposure would have been without that personal protective equipment (PPE) and not their actual exposure during each process. Although area samples detected inhalable Cr(VI) in the transition areas at the Wright-Patterson 445th MXS

shop, the personal exposure levels were unclear because levels directly associated with personnel time in these areas were not measured.

At both locations, Cr(VI) and total chromium (total Cr) were present in surface wipes associated with all processes. Furthermore, pre-process hand wipes collected at both shops had detectable chromium levels. Both findings indicated that there were residual chromium surface levels that couldn't be directly tied to a single instance of a specific process. Therefore, dermal chromium exposure had the potential to occur before or after active processes, especially if lesser amounts of PPE were worn during setup or cleanup that would increase the likelihood of dermal contact with work surfaces. Although some surface levels of chromium were present in transition areas, the levels were lower than the workrooms, which suggested effectiveness of controls to lower potential exposures in transition areas where less PPE was required. Mn was only present on one surface in the Wright-Patterson 445th MXS paint booth, a shelf underneath the primary worktable.

Current occupational guidance does not provide a specific threshold for Cr(VI) or Mn surface levels, with the Occupational Safety and Health Administration's (OSHA's) guidelines only stating that Cr(VI) levels should be reduced "as free as practicable," so a comparison of the sufficiency of the surface concentrations measured during this field assessment levels to a specific occupational standard cannot be made. However, this does highlight the gap in knowledge about protective surface limits for dermal sensitizers present in Air Force maintenance shops, which is a gap that an associated risk assessment study is intended to attempt to help address.

2.0 INTRODUCTION/BACKGROUND

Exposure to dermal sensitizers is a potential cause of allergic contact dermatitis for aircraft maintainers. A project entitled "Dermatitis and Skin Sensitization among Maintainers/Fabricators" was initiated with a goal of compiling a list of Air Force-relevant chemicals that the literature identifies as possibly being dermal sensitizers and using experimental and computational methods to provide evidence of their sensitization potential. Additionally, the project aimed to determine the presence or absence of dermal sensitizer exposure for a selection of these chemicals in operational settings and, if possible, evaluate their surface concentrations by performing field sampling at two Air Force aircraft maintenance facilities.

In an initial literature search that was performed for the study, 21 compounds were identified as sensitizers and it was determined that 58 compounds had insufficient information to determine sensitizing potential without additional experimentation. The potential that some of these chemicals may be present at the Hill AFB LOASM corrosion control shop and Wright-Patterson AFB 445th Airlift Wing MXS maintenance shop was then assessed through analysis of the memo "Industrial Hygiene Assessment, 727 LOASM/Corrosion Control, Buildings 20/48", a review of the Defense Occupational and Environmental Health Readiness System (DOEHRs) and Enterprise Environmental, Safety and Occupational Health Management Information System (EESOH-MIS)

data. Discussion of specific products used at the shops helped confirm the presence of certain chemicals. Altogether, this analysis indicated that five potential dermal sensitizers were likely to be encountered during each sampling event: Cr(VI), EpiChl, MnO₂, HMDI, and xylene. Other potential sensitizers including formaldehyde, nickel, acrolein, and cobalt have been identified in industrial hygiene reports as chemicals associated with processes that occur at aircraft maintenance shops. However, their presence was not expected to be associated with processes that were occurring during the sampling period, so samples were not collected for these substances.

The DOEHRS and EESOH-MIS data, summarized in Appendix A, indicated that Cr(VI) was present at the Hill AFB LOASM shop as a result of sanding and media blasting removal of old aircraft coatings that contain Cr(VI). Painting activities also occurred at the shop, and while no Cr(VI) was present in the current primer that is in use, Cr(VI) contamination may still have been present in some locations from previous use of chromated primers. Potential Cr(VI) exposures at the Wright-Patterson 445th MXS shop were expected to occur due to spray paint application of aircraft coatings that contain Cr(VI). Cr(VI) was present in the primer that was in use at the shop. It was also suggested that HMDI, EpiChl, MnO₂, and xylene exposures would be present as a result of priming and topcoat painting processes at both shops (Appendix A). Discussions with the shops about which processes would be occurring and the products to be used helped confirm the expected presence of these substances. HMDI was present in the topcoat paint, while xylene and EpiChl were present in the primer being used during the field sampling.

Cr(III), a less potent sensitizer than Cr(VI), can also be present in processes where Cr(VI) is used. To evaluate the ratio of Cr(VI) to Cr(III), two separate analyses were needed: Cr(VI) and total Cr. The paired Cr(VI) sample concentration could then be subtracted from the total Cr concentration. Depending on the physical state of the chemical at the time of exposure (i.e., vapor vs. particle), samples were collected using air sampling, wipe sampling, or a combination of both. Table 1 provides a description of the six chemicals for which sampling was performed and the type or types of sample collected for each chemical.

Table 1. Chemicals sampled at each maintenance shop and type of sample collected.

Chemical	Air (Passive)	Air (Active)	Surface Wipe	Hand Wipe
Cr(VI)		x	x	
Total Cr		x	x	x
EpiChl	x			
Mn		x	x	
HMDI		x		
Xylene	x			

Cr(VI): hexavalent chromium, Total Cr: total chromium, EpiChl: epichlorohydrin, Mn: manganese, HMDI: hexamethylene diisocyanate

3.0 METHODS

Samples were collected at the Hill AFB LOASM shop during sanding, blasting, priming, and topcoat painting of an F-16 hardback stand (Figure 1A and 1C) on 17-19 May 2022. Samples were collected at the Wright-Patterson AFB 445th Airlift Wing MXS maintenance shop during priming and topcoat painting of C-17 parts on 13-14 June 2022. The original plan for air sampling for the study called for primarily taking on-body air samples associated with different processes, and staging area samples nearby to backup measurements obtained from the on-body samples. However, the number of personnel involved during sampling was lower than was anticipated during the initial planning of the project, so additional non-process area samples were added to evaluate exposures in transition (PPE removal) and locker areas. PBZ air samples were collected from one individual participating in each process, and area air samples (Figure 1B) were collected in the work areas and in transition and locker areas for each process. Hand wipe samples were collected before and after each process, while surface wipe samples (Figure 1D) were collected following each process.

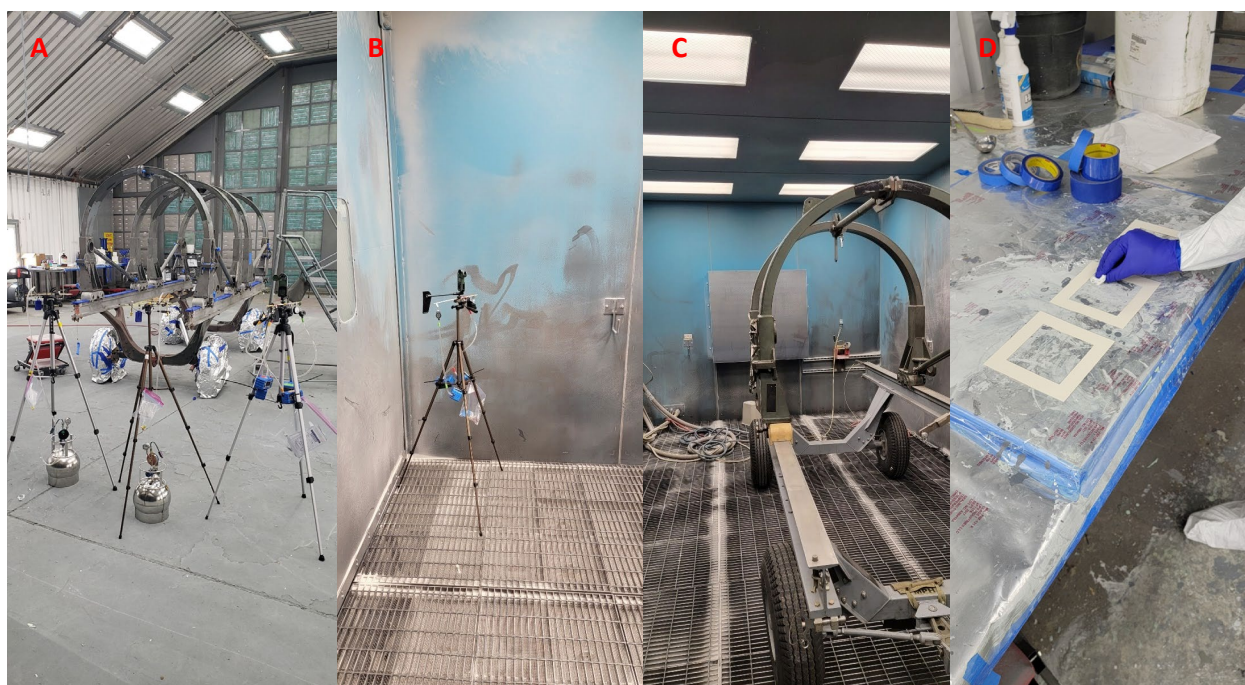


Figure 1. Images of area and wipe sampling performed during the Hill LOASM shop assessment.

A) Area sample tripod placement next to the F-16 hardback stand in the Large Paint Booth. The rightmost tripod was used for sample collection for the present study, and the other two tripods were collecting samples for a separate study occurring during the same field assessment. **B)** Area sample tripod used for sample collection in the Blasting Booth. Tripod was placed in the corner of the booth in front of the stand in **C).** **D)** Surface wipe sampling the on worktable in the Large Paint Booth. Three separate templates placed side-by-side at each location were used for wipe sample collection for Cr(VI), total Cr, and Mn.

Cr(VI) exposures at the Hill AFB LOASM shop were only expected to be present during sanding and blasting of the old coating off of the stand, and not the application of new primer, because the primer used at the shop (Epoxy Polyamide Primer, MIL-DTF-53022F, Type IV, Class CL, Sherwin-Williams, Cleveland, OH) did not contain chromium. However, this primer did contain EpiChl and xylene, and the topcoat paint (CA82008 Activator Component, Desothane Polyurethane, MIL-PRF-85285 Rev. E, PPG, Pittsburgh, PA) contained HMDI, so sampling for these compounds were focused on priming and painting activities.

At the Wright-Patterson AFB 445th MXS shop, Cr(VI) exposures were only expected to be present during and after application of primer on aircraft components, because the primer used at the shop (Chromated Epoxy Polyamide Primer, MIL-PRF-23377K, Type I, Class C2, Sherwin-Williams, Cleveland, OH) contained chromium (strontium chromate, barium chromate). The primer also contained xylene. EpiChl and xylene were also listed as ingredients in the primer catalyst (Epoxy Polyamide Primer, MIL-PRF-23377K, Type I & II, Class C2, Sherwin-Williams, Cleveland, OH). The topcoat paint (CA82008 Activator Component, Desothane Polyurethane, MIL-PRF-85285 Rev. E, PPG, Pittsburgh, PA) contained HMDI, so HMDI exposures were anticipated during spray application of topcoat paint.

Cr(VI), total Cr, Mn, and HMDI active air samples were collected in the PBZ of exposed workers, as well as from stationary area samples using small Gilair pumps (Sensidyne, St. Petersburg, FL). For PBZ samples, pumps and associated tubing were affixed to a vest that the workers wore over their PPE (Figure 2A). Media were attached to the pumps via tubing and placed near the lapel to be close to the PBZ of each worker (Figure 2A). All pumps were pre- and post-calibrated using a Defender (MesaLabs, Lakewood, CO) calibration standard.

Pumps, media, and associated tubing were secured to a tripod during collection of active area air samples. Media was affixed to the head of the tripod, and the tripod head was extended to approximately 5' to capture exposures at PBZ height (Figure 2B). The tripod was placed in close proximity to the process being sampled, but far enough not to be in the way of the workers. A Kestrel Instruments 5500 Weather Meter (Nielsen-Kellerman Company, Boothwyn, PA) was attached to the top of each area sample to capture temperature and relative humidity data. All pumps were pre- and post-calibrated using a Defender (MesaLabs, Lakewood, CO) calibration standard.

Samples for Cr(VI) were collected on 25-millimeter (mm) polyvinyl chloride (PVC) filters in disposable inhalable samplers (DIS) operated at 2 liters per minute (LPM). Cr(VI) levels were analyzed using a modified OSHA ID-215 (version 2) method (Ku and Edie, 2006), using ion chromatography with post-column derivatization and ultraviolet detection. Airborne total Cr was collected using 25-mm PVC filters in DIS operated at 2 LPM. Samples were analyzed for total Cr using a modified National Institute for Occupational Safety and Health (NIOSH) Method 7303 (NIOSH, 2003c) with inductively coupled plasma mass spectrometry. Mn air samples were collected and analyzed using the same method as total Cr. HMDI air samples were collected using Isochek (SKC, Eighty Four, PA) cassettes operated at 1 LPM that contained two filters: one that

collected aerosol, and another that collected vapor-phase material. The samples were analyzed via a modified Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) Isochek method (IRSST, 2019). All samples were analyzed at SGS Galson, East Syracuse, NY.

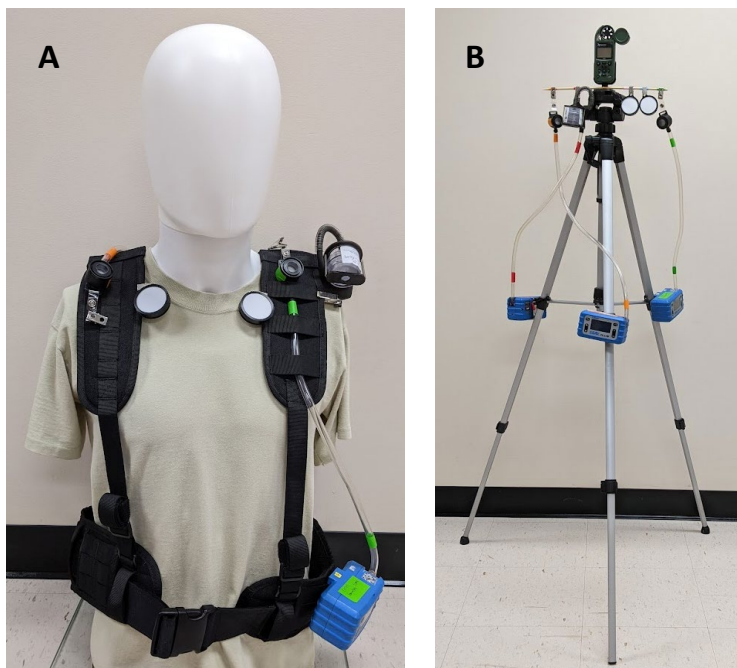


Figure 2. Images of on-body and area sampling equipment.

A) Vest worn by participants for sample collection during processes. Passive badges and active samplers were attached to shoulder straps, with the pumps for the active samplers connected to the belt at the waist (only one of three pumps visible). **B)** shows the same sampler setup on the tripods used for area sampling. Samplers were attached at approximately five feet high, with pumps for active samplers connected to the legs of the tripod. A temperature and humidity gauge was also attached to the top of the tripod.

EpiChl and xylene were collected with passive dosimeter badges in both the PBZ and as area samples. Each analyte was collected on its own badge type. Badges were affixed to maintainers' lapels to capture PBZ exposure. For area samples, badges were affixed to the head of a tripod (Figure 2B) which was at approximately 5' to simulate human PBZ exposure. A single tripod was used to collect active and passive samples for each process at each sampling location. The EpiChl badge contained activated charcoal as the adsorbent and was analyzed following NIOSH Method 1010 (NIOSH, 1994). The xylene badge contained activated carbon as the adsorbent and was analyzed following NIOSH Method 1501 (NIOSH, 2003a). Analysis of all badges took place at Advanced Chemical Sensors, Longwood, FL.

Surface levels of Cr(VI), Total Cr, and Mn were evaluated by surface wipes that were collected following each process. High contact surfaces surrounding maintainers' work areas and transition areas where PPE was doffed and stored were wiped in 100 square centimeters (cm²) increments using disposable templates. Surface wipe samples for Cr(VI) were collected on 37-mm diameter PVC filters with 5- μ m pore size (SKC, Ltd, Eighty Four, PA) in compliance with OSHA Method

W4001 (Edie, 2001). GhostWipes™ (SKC, Ltd, Eighty Four, PA) were used to collect total Cr samples from surfaces. GhostWipes™ were comprised of a non-woven polyvinyl alcohol fiber that was moistened with deionized water. Lead wipes were used to collect Mn samples. Two wipe samples were collected at each square. The purpose of the second wipe was to ensure collection of any residual material that was not collected by the first wipe.

Each square was wiped using the NIOSH wipe sampling method 9102 (NIOSH, 2003d). For each wipe, the unfolded wipe was moved across the surface using firm pressure in an overlapping “S” pattern to cover the entire surface with horizontal strokes. The exposed side of the wipe was folded in, then the same pattern was performed using vertical strokes. The exposed side of the wipe was folded in again, and the same pattern was performed using horizontal strokes. Finally, the exposed side of the wipe was folded in and the wipe was placed in a ~15 mL plastic vial. Clean gloves were worn at the start of sampling, and gloves were changed in between samples so that new clean gloves were worn for each sample.

Maintainers had their hands wiped before and after processes where Cr(VI) and total Cr exposures were anticipated to occur. Common hand wipe or wash methods were not compatible with Cr(VI) analysis, so only total Cr was available for analysis. Sampling media (Ghostwipe™) was identical to that used in surface wiping for total Cr. Before participants donned their PPE, researchers wearing clean gloves wiped the entirety of the right hand of a participant with a single Ghostwipe™ to establish background analyte levels. After the researcher donned a new pair of clean gloves, a second wipe of the entire hand was performed. The wipe was then folded and placed in a ~15 mL plastic vial. After completing a task and following any decontamination procedures, researchers wiped the right hand of the participant to determine if any contaminant was transferred during the work task or PPE doffing. The methods used for the post-process hand wipe were the same as for the pre-process hand wipe.

Wipe samples were shipped to third party laboratories and analyzed within approximately one to two weeks of collection. Cr(VI) and Mn samples were analyzed at SGS Galson, East Syracuse, NY. Cr(VI) wipes were analyzed with a modified OSHA W4001 method (Edie, 2001) using ion chromatography with post-column derivatization and ultraviolet detection. Mn samples were analyzed using a modified EPA SW846 3051A/6010C/NIOSH 9102 method (EPA, 2007a; EPA, 2007b; NIOSH, 2003d). Total Cr wipes were analyzed at ALS Environmental, Salt Lake City, UT, with a modified NIOSH method 7300 (NIOSH, 2003b) using inductively-coupled plasma mass spectrometry. Data were reported as microgram (µg) per wipe. The total µg of material present in each square of the template was calculated from the sum of the two wipes that were collected per square.

This study was reviewed by the Air Force Research Lab/711th Human Performance Wing institutional review board and assigned Not Research status. As such, no personally identifiable data were collected, and it was not possible to determine individual maintainer’s exposures post-trip.

4.0 RESULTS

4.1 Hill AFB LOASM Shop

Cr(VI) was present in air samples during the sanding and blasting processes, but not the painting processes, which was expected because of the lack of chromium in the primer that was used. Inhalable Cr(VI) was detected at an average of 0.5 microgram per cubic meter ($\mu\text{g}/\text{m}^3$) from on-body air samples taken during the sanding process, and was measured at $30 \mu\text{g}/\text{m}^3$ from the only on-body sample collected during media blasting (Table 2). While the area samples collected from the booth during sanding did not detect any Cr(VI) in the air, the limit of detection (LOD) for the sampling was $0.43 \mu\text{g}/\text{m}^3$, which was only slightly lower than the Cr(VI) concentration measured from the on-body sampling. Therefore, it is possible that concentrations at the area samplers, which were set back from the work process by a few feet, were just below this LOD.

The Cr(VI) area sample taken in the booth during blasting that found an inhalable Cr(VI) level of $10 \mu\text{g}/\text{m}^3$ that supported the blasting-associated on-body concentration of $30 \mu\text{g}/\text{m}^3$, with the difference in concentrations potentially due to the distance of the area sampler from the process and the extra sampling time after the process had concluded. The blasting process lasted 47 minutes, while the area sample was collected for 179 minutes. Assuming that the entire Cr(VI) exposure occurred during the 47 minutes of blasting, the area sample corresponded to a concentration of $38 \mu\text{g}/\text{m}^3$ during that time. However, it is likely that additional Cr(VI) occurred after the process was over and while material was still lofted into the air, and therefore the estimating that all Cr(VI) was collected only during active blasting may overestimate the concentration during that time.

No total Cr was detected in airborne samples from on-body or booth samples collected during either sanding or blasting (Table 2). This result does not correspond with the Cr(VI) data, but the disagreement may be due to the large differences in limits of detection between the methods used to analyze the two types of chromium, as opposed to actual discrepancies in Cr levels present. In all cases where Cr(VI) was detected, the total Cr limits of detection were larger than the measured Cr(VI) concentrations (Table 2), so total Cr could have been present at those levels but unable to be quantified by the analytical method used. No airborne Cr(VI) or total Cr was detected during priming or topcoat painting processes (Table 2), but this result was expected because neither process used Cr(VI) as a component of the paint. No Cr(VI) or total Cr was detected in any media and field blanks, indicating that background levels of Cr were not present in the media or as a contaminant of handling during sampling (Table 2). No detectable Cr(VI) or total Cr was measured from area samples in transition areas, and detectable Mn was not present in any samples collected during any processes (Table 2).

Chromium was found in surface wipes collected following all processes. Cr(VI) concentrations ranged from 0.001 to 0.075 micrograms per square centimeter ($\mu\text{g}/\text{cm}^2$), while total Cr concentrations ranged from 0.01 to $2.28 \mu\text{g}/\text{cm}^2$ (Table 3). The highest Cr concentrations were

associated with the Large Paint Booth, which was where sanding and painting activities occurred. The highest Cr concentrations found at the facility were measured from the folding table adjacent to the sanding/painting work area, the top of the tool cabinet in the booth, and the top of a tool cabinet that was just outside the booth in a storage room (Table 3). However, no painting with chromated primer occurred during the visit, which suggested that the chromium present in the Large Paint Booth after completion of priming and topcoat painting was residual material from the sanding process that had occurred in that booth on the previous day, or material that accumulated from processes performed prior to the sampling event.

Table 2. Air sampling results for Cr(VI), total Cr, and Mn at Hill AFB.

The top panel displays the on-body samples collected during each process, the middle displays the area samples collected in the work area associated with each process, and the bottom panel shows other air samples collected during the sampling event. Samples that were below the LOD are displayed as “<value” with the value indicating the LOD for that method and sampling time. N/A indicates not applicable.

Vest Air Samples	No. of CrVI/Cr	Avg. CrVI Sampling	Avg. [CrVI]	Avg. Cr Sampling	Avg. [Cr]	No. of Mn	Avg. Mn Sampling	Avg. [Mn]
	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)	Time (min)	($\mu\text{g}/\text{m}^3$)	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)
Sanding	3	79	0.495	81	<48	0	N/A	N/A
Blasting	1	47	30	40	<94	0	N/A	N/A
Housekeeping	2	16	<2.3	16	<235	0	N/A	N/A
Priming	2	58	<0.64	57	<66	0	N/A	N/A
Topcoat	2	73	<0.51	73	<52	0	N/A	N/A
Booth Air Samples	No. of CrVI/Cr	Avg. CrVI Sampling	Avg. [CrVI]	Avg. Cr Sampling	Avg. [Cr]	No. of Mn	Avg. Mn Sampling	Avg. [Mn]
	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)	Time (min)	($\mu\text{g}/\text{m}^3$)	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)
Sanding	1	86	<0.43	84	<44	0	N/A	N/A
Blasting	1	179	10	178	<21	0	N/A	N/A
Priming	1	198	<0.19	197	<19	1	197	<0.4
Topcoat	1	253	<0.15	253	<15	1	253	<0.3
Other Air Samples	No. of CrVI/Cr	Avg. CrVI Sampling	Avg. [CrVI]	Avg. Cr Sampling	Avg. [Cr]	No. of Mn	Avg. Mn Sampling	Avg. [Mn]
	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)	Time (min)	($\mu\text{g}/\text{m}^3$)	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)
Transition	4	242	<0.16	273	<15	0	N/A	N/A
Laundry Area	3	262	<0.15	262	<15	0	N/A	N/A
Field Blanks	3	N/A	<0.074 (μg)	N/A	<7.5 (μg)	1	N/A	<0.15 (μg)
Media Blanks	6	N/A	<0.074 (μg)	N/A	<7.5 (μg)	2	N/A	<0.15 (μg)

Elevated chromium levels were also found on surfaces in transition areas associated with PPE removal. Surfaces near the blasting suit locker area where the blasting suits were doffed, in addition to the hazardous waste trash bin lid, had higher levels of chromium relative to other non-workroom areas in the facility (Table 3). The lowest chromium surface concentrations were associated with areas of the facility away from active work, such as surfaces in the Large Paint Booth located far from the work area or areas in the laundry room outside of the PPE-recommended areas (Table 3). Table 4 displays the average Cr(VI) and total Cr concentrations associated with each type of area within the facility, and these averages also follow the trend of being lower in “cleaner” areas away from active work where controls are in place to prevent chromium contamination from work areas. No detectable Mn (LOD of $0.15 \mu\text{g}/\text{cm}^2$) was found on any surface wipe samples collected at the same locations listed in Table 3.

Table 3. Wipe sampling results for Cr(VI) and total Cr at Hill AFB.

Results are listed by sample location, the process after which sampling occurred, and the type of location within the facility. Surface levels of Cr(VI) and total Cr are listed in μg (representing total μg over the 100 cm^2 sample area) and $\mu\text{g}/\text{cm}^2$. The difference between total Cr and Cr(VI) and percent Cr(VI) of total Cr were also calculated for each location. Samples that were below the LOD are displayed as “<value” with the value indicating the LOD for that method and sampling time. N/A indicates not applicable.

Location	Process	Location Type	CrVI (μg)	CrVI ($\mu\text{g}/\text{cm}^2$)	Total Cr (μg)	Total Cr ($\mu\text{g}/\text{cm}^2$)	Total Cr-CrVI (μg)	% CrVI
Large Paint Booth - Work Table	Sanding	Workroom	0.09	0.001	1.7	0.02	1.6	5.5
Large Paint Booth - Folding Table	Sanding	Workroom	ND	ND	311	1.50	ND	ND
Large Paint Booth - Rolling Stool	Sanding	Workroom	0.09	0.001	0.7	0.01	0.6	12.7
Laundry Room - Metal Sink Counter	Blasting	Laundry Area	0.12	0.001	4.6	0.05	4.5	2.6
Blasting Suit Locker Area - Folding Chair	Blasting	Transition	0.66	0.007	2.0	0.02	1.3	33.2
Blasting Suit Locker Area - Plastic Media Barrel	Blasting	Transition	0.85	0.009	1.7	0.02	0.9	48.9
Main Room - Top of Short Chemical Storage Cabinet	Blasting	Transition	0.36	0.004	0.6	0.01	0.3	59.0
Large Paint Booth - Work Table	Priming	Workroom	0.69	0.007	1.2	0.01	0.5	57.0
Large Paint Booth - Top of Tool Cabinet	Priming	Workroom	1.55	0.016	55	0.55	53.5	2.8
Large Paint Booth Storage Room - Top of Tool Cabinet	Priming	Transition	1.47	0.015	35	0.35	33.4	4.2
Large Paint Booth - Work Table	Top Coat	Workroom	0.08	0.001	0.8	0.01	0.8	9.4
Large Paint Booth - Folding Table	Top Coat	Workroom	7.50	0.075	228	2.28	220.5	3.3
Main Room - Hazardous Waste Bin Lid	Top Coat	Transition	0.50	0.005	10.2	0.10	9.7	4.9
Laundry Room - Trash Can Lid	Top Coat	Laundry Area	0.28	0.003	1.2	0.01	0.9	23.5
Day 1 Field Blank	N/A	N/A	<0.071	N/A	<0.13	N/A	N/A	N/A
Day 2 Field Blank	N/A	N/A	<0.071	N/A	<0.13	N/A	N/A	N/A
Day 3 Field Blank	N/A	N/A	<0.071	N/A	0.14	N/A	N/A	N/A
Media Blanks	N/A	N/A	<0.071	N/A	<0.13	N/A	N/A	N/A

Cr(VI) levels on the surfaces at each location were only a fraction of total Cr concentrations, with the percent Cr(VI) of total Cr ranging from 2.6 to 59% (Table 3). Although this could suggest that there were significant amounts of Cr(III) present at each location, differences in the sampling efficiency between the PVC filters and Ghostwipes™ could account for an underestimate of Cr(VI) levels compared to what was actually present. The PVC filters had a propensity to tear on surfaces that were not completely smooth, which limited the pressure that could be applied on these surfaces to abrade material onto the filter. Additionally, the Ghostwipes™ came moistened with deionized water and were fibrous, which allowed for additional trapping of material compared to the smooth, dry PVC filters.

Table 4. Summary of Cr(VI) and total Cr air concentrations at Hill AFB.

Average +/- standard deviation of each location type are represented. The only Cr(VI)-generating processes that took place at the facility during the sampling event were sanding and media blasting.

CrVI Process	Location Type	# of samples	CrVI ($\mu\text{g}/\text{cm}^2$)	Total Cr ($\mu\text{g}/\text{cm}^2$)	%CrVI of Total Cr
	Laundry Area	2	0.002 ± 0.001	0.029 ± 0.024	13.0 ± 14.8
Sanding, Blasting	Transition	5	0.008 ± 0.004	0.099 ± 0.145	30.0 ± 25.0
	Workroom	7	0.017 ± 0.029	0.837 ± 0.937	14.2 ± 21.5

Hand wipes for total Cr were collected immediately prior to and after each process. Overall, average total Cr levels were higher prior to the processes than afterwards, with an average reduction of $1.7 \pm 3.1\ \mu\text{g}$ of Cr (Table 5). Blasting was the only process during the sampling event for which there was a higher concentration of chromium measured from hand wipes taken after the process, with an increase of $1.3\ \mu\text{g}$ on the one sample that was collected (Table 5). The highest

average pre-process hand wipes were measured before sanding and housekeeping processes, with the housekeeping process occurring shortly after completion of blasting (Table 5). Additionally, total Cr was measured on hand wipe samples taken before and after priming and topcoat painting, neither of which involved the use of Cr(VI).

Table 5. Total Cr on hand wipe samples at Hill AFB.

Average +/- standard deviation of total Cr on hand wipe samples collected before and after each process, and the change in total Cr between hand wipe samples collected before and after each process. Values represent the µg of total Cr collected from the hand at each timepoint. “n” indicates the sample size

Process	n	Total Cr Before (µg)	Total Cr After (µg)	Change in Total Cr (µg)
Sanding	3	7.7 ± 11.3	6.9 ± 9.7	-0.8 ± 1.5
Blasting	1	1.0 ± N/A	2.4 ± N/A	1.3 ± N/A
Housekeeping	2	9.2 ± 1.7	2.4 ± 1.6	-6.8 ± 3.3
Priming	2	1.8 ± 1.0	1.3 ± 0.0	-0.5 ± 1.0
Top Coat	2	2.8 ± 0.7	2.0 ± 1.1	-0.8 ± 1.8
All	10	5.2 ± 6.3	3.4 ± 5.2	-1.7 ± 3.1

Chromium was present in surface wipes associated with all processes, as well as pre-process hand wipes that had comparable chromium levels to post-process hand wipes, which indicated that there was residual presence of surface chromium in work and transition areas that wasn't necessarily only associated with specific single instances of processes that occurred immediately prior to sampling. Hand wipe samples were unable to be taken before workers entered some of the work and transition areas of the facility to move equipment or setup for certain processes, so dermal chromium exposure could have occurred during these preparatory activities. The lack of increase in total Cr levels after most processes does suggest that wearing of PPE and PPE removal procedures were sufficient to prevent transfer of material to hands during or immediately after processes.

No detectable xylene or EpiChl was measured from passive badge samples worn on-body during priming and topcoat processes, or from area samples located adjacent to the work area during each process. Detectable HMDI monomer levels of 0.7 µg/m³ were found in one of two on-body samples worn during topcoat painting, however, no HMDI oligomer was measured in the same sample (Table 6). Both HMDI monomer and oligomer were detected at levels of 0.5 µg/m³ and 8 µg/m³, respectively, from the area sample that was collected during topcoat painting (Table 6). No HMDI was detected during priming in either on-body or area samples. The Isochek sampling method used to collect HMDI has a limit of 15 liters of sample collection, and with a sampling rate of 1 LPM and the sampling times listed in Table 6, the maximum sample volume was exceeded for all samples, indicating that the levels obtained may not be truly representative of sample concentrations. However, the results still indicate the presence of airborne HMDI as an exposure during topcoat painting.

Table 6. Air sampling results for xylene, EpiChl, and HMDI at Hill AFB.

The top panel displays the on-body samples collected during each process, the middle displays the area samples collected in the work area associated with each process, and the bottom panel shows other air samples collected during the sampling event. Samples that were below the LOD are displayed as “<value” with the value indicating the LOD for that method and sampling time. N/A indicates not applicable.

Vest	No. of Xylene/EpiChl	Avg. Passive Badge	[Xylene]	[EpiChl]	No. of Isochek	Avg. IsoChek	HMDI Monomer	HMDI Oligomer
Air Samples	Samples	Sampling Time (min)	(ppm)	(ppm)	Samples	Sampling Time (min)	($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)
Priming	2	58	<0.8	<0.8	2	38	<1	<1
Topcoat	2	74	<0.7	<0.7	2	73	0.7, <0.4	<0.5
Booth	No. of Xylene/EpiChl	Avg. Passive Badge	[Xylene]	[EpiChl]	No. of Isochek	Avg. IsoChek	HMDI Monomer	HMDI Oligomer
Air Samples	Samples	Sampling Time (min)	(ppm)	(ppm)	Samples	Sampling Time (min)	($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)
Priming	1	200	<0.3	<0.3	1	197	<0.2	<0.2
Topcoat	1	257	<0.2	<0.2	1	255	0.5	8
Other	No. of Xylene/EpiChl	Avg. Passive Badge	[Xylene]	[EpiChl]	No. of Isochek	Avg. IsoChek	HMDI Monomer	HMDI Oligomer
Air Samples	Samples	Sampling Time (min)	(ppm)	(ppm)	Samples	Sampling Time (min)	($\mu\text{g}/\text{m}^3$)	($\mu\text{g}/\text{m}^3$)
Transition	4	275	<0.2 to <0.3	<0.2 to <0.3	4	272	<0.1 to <0.2	<0.1 to <0.2
Laundry Area	3	263	<0.2 to <0.3	<0.2 to <0.3	3	262	<0.1 to <0.2	<0.1 to <0.2
Field Blanks	3	N/A (Based on 4 hours)	<0.2	<0.2	3	N/A	<0.03 (μg)	<0.03 (μg)
Media Blanks	4	N/A (Based on 8 hours)	<0.1	<0.1	4	N/A	<0.03 (μg)	<0.03 (μg)

4.2 Wright-Patterson AFB 445th MXS Shop

Cr(VI) was present in air samples collected from the paint booth during both priming and topcoat painting processes. Inhalable Cr(VI) was detected at an average of 1.6 $\mu\text{g}/\text{m}^3$ from on-body air samples taken during priming, and was measured at 4.7 $\mu\text{g}/\text{m}^3$ from area samples collected in the paint booth (Table 7). Inhalable Cr(VI) was also detected at a concentration of 0.21 $\mu\text{g}/\text{m}^3$ in the booth during topcoat painting by area sampling, which occurred approximately 24 hours after the priming process. The on-body air sample did not detect Cr(VI) during topcoat painting, but the LOD was 0.29 $\mu\text{g}/\text{m}^3$, which was just above the Cr(VI) concentration measured by the area sampling. Although the topcoat paint did not contain any chromated compounds, it is possible that Cr(VI) was re-aerosolized from surfaces in the booth during topcoat painting.

Measurable levels of inhalable Cr(VI) were found in the transition area where PPE was removed after completion of priming. Detectable amounts of inhalable Cr(VI) were also measured on the day of the priming process in the locker area where PPE was not required. Inhalable Cr(VI) was measured at a concentration of 0.59 $\mu\text{g}/\text{m}^3$ in the PPE removal area in between the paint booth and the locker room, and was present at a concentration of 0.18 $\mu\text{g}/\text{m}^3$ in the locker room (Table 7). Detectable levels of inhalable Cr(VI) were not present in these areas during topcoat painting that occurred on the subsequent day.

No inhalable total Cr was detected in airborne on-body or booth samples collected during either painting process (Table 7). This result does not correspond with the inhalable Cr(VI) data, but the disagreement may be due to the large differences in limits of detection between the methods used to analyze the two types of chromium, as opposed to actual discrepancies in Cr levels present. In all cases where Cr(VI) was detected, the total Cr limits of detection were larger than the measured Cr(VI) concentrations (Table 7), so total Cr could have been present at those levels but unable to be quantified by the analytical method used. Inhalable Mn was not present at detectable levels in

any samples collected during either process (Table 7). No Cr(VI), total Cr, or Mn was detected in any media and field blanks, indicating that background levels of Cr were not present in the media or as a contaminant of handling during sampling (Table 7).

Table 7. Air sampling results for Cr(VI), total Cr, and Mn at WPAFB.

The top panel displays the on-body samples collected during each process, the middle displays the area samples collected in the work area associated with each process, and the bottom panel shows other area and blank samples collected during the sampling event. Samples that were below the LOD are displayed as “<value” with the value indicating the LOD for that method and sampling time. N/A indicates not applicable.

Vest Air Samples	No. of Cr/CrVI	Avg. CrVI Sampling	[CrVI]	Avg. Cr Sampling	Avg. [Cr]	No. of Mn	Avg. Mn Sampling	Avg. [Mn]
	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)	Time (min)	($\mu\text{g}/\text{m}^3$)	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)
Priming	1	147	1.6	148	<25	0	N/A	N/A
Topcoat	1	125	<0.29	126	<30	0	N/A	N/A
Booth Air Samples	No. of Cr/CrVI	Avg. CrVI Sampling	[CrVI]	Avg. Cr Sampling	Avg. [Cr]	No. of Mn	Avg. Mn Sampling	Avg. [Mn]
	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)	Time (min)	($\mu\text{g}/\text{m}^3$)	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)
Priming	1	257	4.7	267	<19	1	257	<0.28
Topcoat	1	200	0.21	201	<19	1	203	<0.29
Other Air Samples	No. of Cr/CrVI	Avg. CrVI Sampling	[CrVI]	Avg. Cr Sampling	Avg. [Cr]	No. of Mn	Avg. Mn Sampling	Avg. [Mn]
	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)	Time (min)	($\mu\text{g}/\text{m}^3$)	Samples	Time (min)	($\mu\text{g}/\text{m}^3$)
PPE Removal Area	2	232	0.59, <0.15	199	<20	2	234	<0.37
Locker Room	2	230	0.18, <0.19	230	<17	2	200	<0.38
Field Blanks	2	N/A	<0.074 (μg)	N/A	<7.5 (μg)	2	N/A	<0.15 (μg)
Media Blanks	4	N/A	<0.074 (μg)	N/A	<7.5 (μg)	2	N/A	<0.15 (μg)

Cr was found in surface wipes collected following both processes. Cr(VI) concentrations ranged from 0.003 to 4.4 $\mu\text{g}/\text{cm}^2$, while total Cr concentrations ranged from 0.003 to 86 $\mu\text{g}/\text{cm}^2$ (Table 8). The highest Cr concentrations were associated with the paint booth, which was where spray application of chromated primer occurred. The highest Cr concentrations found at the facility were measured from the table used to hold the component being sprayed, the worktable immediately adjacent to the painting area, and a shelf underneath that worktable (Table 8). While both the paint application table and worktable had visible yellow primer present on their surfaces, the shelf underneath the worktable did not. This shelf, which had the highest surface concentrations of Cr in the facility and was being used to store boxes of tools or supplies, did however have a visible layer of accumulated dust that was at least a few millimeters thick. This shelf also had the only detectable Mn found in the facility, with a surface concentration of 0.5 $\mu\text{g}/\text{cm}^2$ (Table 8). Although some of the surface samples containing Cr were collected after topcoat painting, it was apparent that this was residual material from the priming process that had occurred in that booth on the previous day or material that accumulated from processes performed prior to the sampling event.

Elevated Cr levels were also found on surfaces in transition areas associated with PPE removal but were not nearly as high as Cr levels on most workroom surfaces (Table 9). Average surface levels of Cr(VI) and total Cr were 0.022 ± 0.017 and 0.053 ± 0.049 $\mu\text{g}/\text{cm}^2$, respectively, on the lids of hazardous waste bins located in the PPE removal transition rooms (Table 8). The lowest chromium surface concentration measured was associated with the locker room area of the facility that was away from active Cr work and outside of the PPE-controlled area (Table 8). Table 9 displays the average Cr(VI) and total Cr concentrations associated with each type of area within the facility,

and these averages also follow the trend of being lower in “cleaner” areas away from active work where controls were in place to prevent chromium contamination from work areas. No detectable Mn (LOD of 0.15 µg/cm²) was found on any of the surface wipe samples collected outside of the workroom (Table 8).

Table 8. Wipe sampling results for Cr(VI) and total Cr at WPAFB.

Results are listed by sample location, the process after which sampling occurred, and the type of location within the facility. Surface levels of Cr(VI) and total Cr are listed in µg (representing total µg over the 100 cm² sample area) and µg/cm². The percent Cr(VI) of total Cr was also calculated for each location. Samples that were below the LOD are displayed as “<value” with the value indicating the LOD for that method and sampling time. N/A indicates not applicable, ND indicates not determined.

Location	Process	Location Type	CrVI (µg)	CrVI (µg/cm ²)	Total Cr (µg)	Total Cr (µg/cm ²)	% CrVI	Mn (µg)	Mn (µg/cm ²)
Paint Booth - Work Table	Priming	Workroom	86	0.86	860	8.60	10.0	<15	<0.15
Paint Booth - Hazardous Waste Barrel Top	Priming	Workroom	6.1	0.061	66	0.66	9.2	<15	<0.15
Paint Booth - "Steel Repair" Work Cart	Priming	Workroom	2.9	0.029	23	0.23	12.4	<15	<0.15
PPE Removal Area - Hazardous Waste Bin	Priming	PPE Removal	3.3	0.033	8.8	0.09	38.0	<15	<0.15
Respirator Cleaning Area - Hazardous Waste Bin	Priming	PPE Removal	0.99	0.010	1.8	0.02	55.6	<15	<0.15
Paint Booth - Paint Application Table	Priming	Workroom	220	2.2	2470	24.7	8.9	<15	<0.15
Paint Booth - Work Table	Top Coat	Workroom	17	0.17	205	2.05	8.0	<15	<0.15
Paint Booth - Shelf Under Work Table	Top Coat	Workroom	440	4.4	8600	86	5.1	52	0.5
Locker Room - PPE Storage Cabinet Shelf	Top Coat	Locker Area	0.25	0.003	0.28	0.003	90.0	ND	ND
Day 1 Field Blank(s)	N/A	N/A	0.1	N/A	<0.13, <0.13	N/A	N/A	<15	N/A
Day 2 Field Blank(s)	N/A	N/A	0.091	N/A	<0.13, 0.15	N/A	N/A	<15	N/A
Media Blanks	N/A	N/A	N/A	N/A	<0.13	N/A	N/A	<15	N/A

Cr(VI) levels on the surfaces at each location were only a fraction of total Cr concentrations, with the percent Cr(VI) of total Cr ranging from 5.1 to 90% (Table 8). Although this could suggest that there were significant amounts of Cr(III) present at each location, differences in the sampling efficiency between the PVC filters and Ghostwipes™ could account for an underestimate of Cr(VI) levels compared to what was actually present. The PVC filters had a propensity to tear on surfaces that were not completely smooth, which limited the pressure that could be applied on these surfaces to abrade material onto the filter. Additionally, the Ghostwipes™ came moistened with deionized water and were fibrous, which allowed for additional trapping of material compared to the smooth, dry PVC filters.

Table 9. Summary of air concentrations of Cr(VI) and total Cr at WPAFB.

Average +/- standard deviation of each location type are represented. The only Cr(VI)-generating process that took place at the facility during the sampling event was priming.

CrVI Process	Location Type	# of samples	CrVI (µg/cm ²)	Total Cr (µg/cm ²)	% CrVI of Total Cr
Priming	Locker	1	0.002 ± N/A	0.003 ± N/A	90 ± N/A
	Transition	2	0.022 ± 0.017	0.053 ± 0.049	46.8 ± 12.5
	Workroom	6	1.29 ± 1.74	20.37 ± 33.45	9.0 ± 2.4

Hand wipes for total Cr were collected immediately prior to and after each process. Overall, average total Cr levels were higher following the processes compared to beforehand, with an increase of 0.40 µg occurring after priming and an increase of 0.82 µg occurring after topcoat painting (Table 10). The increase in hand surface level of chromium occurred after topcoat painting

despite the paint containing no Cr. The total Cr hand wipe sample collected prior to topcoat painting was greater (1.01 µg) than the pre-process hand wipe sample collected the day before prior to priming (0.21 µg, Table 10), which could be related to increased presence of Cr from priming that occurred the day prior to topcoat painting.

Table 10. Total Cr on hand wipe samples at WPAFB.

Average ± standard deviation of total Cr on hand wipe samples collected before and after each process, and the change in total Cr between hand wipe samples collected before and after each process. Values represent the µg of total Cr collected from the hand at each timepoint. “n” indicates the sample size

Process	n	Total Cr Before (µg)	Total Cr After (µg)	Change in Total Cr (µg)
Priming	1	0.21	0.61	0.40
Top Coat	1	1.01	1.83	0.82

Cr was present in surface wipes associated with both processes, as well as pre-process hand wipes, which indicated that there was potential for Cr contamination to persist on work surfaces at the facility, and that Cr levels were not necessarily only associated with processes that occurred the day of sampling. Hand samples were unable to be taken before workers entered some of the work and transition areas of the facility to move equipment or setup for certain processes, so dermal Cr exposure could have occurred during these preparatory activities. The increase in total Cr levels after both processes suggests that transfer of material to the hands occurred during processes or immediately after processes during PPE removal.

No detectable EpiChl was measured from passive badge samples worn on-body during priming and topcoat processes, or from area samples located adjacent to the work area during each process (Table 11). Detectable xylene at a concentration of 0.41 parts per million (ppm) was found in one on-body passive sample worn during priming. However, no xylene was measured in the priming area sample collected from the paint booth (Table 11). No HMDI was detected in on-body or area samples that were collected during priming or topcoat painting, despite HMDI being a component of the topcoat paint (Table 11). The Isochek sampling method used to collect HMDI had a limit of 15 liters of sample collection. With a sampling rate of 1 LPM and the sampling times listed in Table 11, the maximum sample volume was exceeded for all samples, indicating that the levels obtained may not be truly representative of sample concentrations. However, the results still indicated the absence of airborne HMDI as an exposure during topcoat painting. Detectable levels of HMDI, xylene, or EpiChl were not present in area samples collected in transition areas and the locker room during both processes.

Table 11. Air sampling results for xylene, EpiChl, and HMDI at WPAFB.

The top panel displays the on-body samples collected during each process, the middle displays the area samples collected in the work area associated with each process, and the bottom panel shows other air samples collected during the sampling event. Samples that were below the LOD are displayed as “<value” with the value indicating the LOD for that method and sampling time. N/A indicates not applicable.

Vest Air Samples	No. of Samples	Avg. Passive Badge Sampling Time (min)	[Xylene] (ppm)	[EpiChl] (ppm)	Avg. IsoChek Sampling Time (min)	HMDI Monomer ($\mu\text{g}/\text{m}^3$)	HMDI Oligomer ($\mu\text{g}/\text{m}^3$)
Priming	1	152	0.41	<0.4	147	<0.2	<0.2
Topcoat	1	128	<0.4	<0.4	125	<0.2	<0.2
Booth Air Samples	No. of Samples	Avg. Passive Badge Sampling Time (min)	[Xylene] (ppm)	[EpiChl] (ppm)	Avg. IsoChek Sampling Time (min)	HMDI Monomer ($\mu\text{g}/\text{m}^3$)	HMDI Oligomer ($\mu\text{g}/\text{m}^3$)
Priming	1	274	<0.2	<0.2	257	<0.1	<0.1
Topcoat	1	205	<0.3	<0.3	200	<0.1	<0.1
Other Air Samples	No. of Samples	Avg. Passive Badge Sampling Time (min)	[Xylene] (ppm)	[EpiChl] (ppm)	Avg. IsoChek Sampling Time (min)	HMDI Monomer ($\mu\text{g}/\text{m}^3$)	HMDI Oligomer ($\mu\text{g}/\text{m}^3$)
PPE Removal Area	2	238	<0.2 to <0.3	<0.2 to <0.3	232	<0.1	<0.1
Locker Room	2	234	<0.2 to <0.3	<0.2 to <0.3	222	<0.1 to <0.2	<0.1 to <0.2
Field Blanks	2	N/A (Based on 4 hours)	<0.2	<0.2	N/A	<0.03 (μg)	<0.03 (μg)
Media Blanks	2	N/A (Based on 8 hours)	<0.1	<0.1	N/A	<0.03 (μg)	<0.03 (μg)

5.0 DISCUSSION/CONCLUSIONS

The Air Force currently adheres to the OSHA Permissible Exposure Limit (PEL) of $5 \mu\text{g}/\text{m}^3$ and action level of $2.5 \mu\text{g}/\text{m}^3$ for airborne Cr(VI) exposures as a time-weighted average (TWA) during eight-hour work shifts (OSHA, 2022). The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended lower exposure guidelines of $0.2 \mu\text{g}/\text{m}^3$ as a TWA during an eight-hour work shift and $0.5 \mu\text{g}/\text{m}^3$ as a 15-minute short-term exposure limit for inhalable Cr(VI) (ACGIH, 2023). Although the study was unable to measure PPE-attenuated personal exposures during maintenance processes, the assessment was performed to determine potential exposure levels that would be expected in the absence of PPE. On-body inhalable Cr(VI) levels of $1.6 \mu\text{g}/\text{m}^3$ and an area sample concentration of $4.7 \mu\text{g}/\text{m}^3$ inhalable Cr(VI) were measured during priming at the WPAFB maintenance shop. At the Hill LOASM shop, concentrations of inhalable Cr(VI) were $10\text{-}30 \mu\text{g}/\text{m}^3$ during media blasting and $0.5 \mu\text{g}/\text{m}^3$ during sanding activities. While the Cr(VI) levels measured during blasting exceeded the OSHA PEL-TWA, and the levels of Cr(VI) approached or exceed the action level, the actual personal exposure during all processes should have been significantly diminished by the full-face respirators worn during each process.

Cr(VI) was not a component of the topcoat paint being applied at the WPAFB maintenance shop, but a Cr(VI) concentration of $\sim 0.2 \mu\text{g}/\text{m}^3$ was measured from an area sample collected during topcoat painting. Although PPE was worn during topcoat painting, which occurred approximately 24 hours after priming, if this level was a result material being re-aerosolized in the paint booth, then there would have been potential for inhalable Cr(VI) exposure at times other than when priming was occurring. Inhalable Cr(VI) was not present at measurable levels during priming or topcoat painting at the Hill LOASM shop, which used a primer that did not contain Cr(VI).

While the initial study plan called for mostly on-body and area samples during work processes to evaluate exposure during those processes, the number of personnel involved each day being lower than initially anticipated necessitated a shift in the design of the field assessment to collect alternative samples. Samples were collected in the transition area associated with PPE doffing where exposures could still be present. Samples were also collected in the locker/laundry room areas, which were outside of the PPE-recommended areas. The air sampling performed during the WPAFB maintenance shop field assessment found inhalable Cr(VI) concentrations in those areas on the day of the priming process, indicating that airborne contamination of those locations from the active work areas occurred during that process. Inhalable Cr(VI) was measured in the PPE removal area at a level of $0.59 \mu\text{g}/\text{m}^3$, and in the locker room at $0.18 \mu\text{g}/\text{m}^3$. Although the levels were well below the OSHA PEL-TWA, they are at or above the ACGIH exposure guidelines. However, these measurements were not representative of personal exposures because they did not account for time spent by personnel in these areas. The on-body exposure samples collected during the present study were mostly representative of exposures that occurred in the paint booth while the worker was protected by PPE, and the fraction of the personal exposure in the transition area with PPE doffed is unknown. Personal exposure monitoring targeted on just transition area activities would better characterize potential exposure risk in these areas.

At the Hill LOASM shop and Wright-Patterson 445th MXS maintenance shop, inhalable Mn was not detected above levels of $0.3\text{-}0.4 \mu\text{g}/\text{m}^3$, which was well below the ACGIH 8-hour TWA exposure guideline of $100 \mu\text{g}/\text{m}^3$ for inhalable Mn particulate matter and PEL-Ceiling of 5 milligrams per cubic meter for Mn (ACGIH, 2023; OSHA, 2023). Similarly, EpiChl were not present above its LOD of $0.2\text{-}0.3 \text{ ppm}$, which was below its ACGIH 8-hour TWA exposure guideline of 0.5 ppm (ACGIH, 2023). The EpiChl level was also well below the OSHA PEL-TWA of 5 ppm (OSHA, 2020). At the Hill LOASM shop, no xylene was detected at levels above $0.2\text{-}0.3 \text{ ppm}$, but a maximum level of xylene was 0.41 ppm during priming at the Wright-Patterson 445th MXS maintenance shop. This level was well below the ACGIH 8-hour TWA exposure guideline of 20 ppm and the OSHA PEL-TWA of 100 ppm for xylene (ACGIH, 2023; OSHA, 2021). At the Wright-Patterson 445th MXS maintenance shop, no HMDI was detected at a level above $0.1 \mu\text{g}/\text{m}^3$. At the Hill LOASM shop, the maximum level of HMDI was $8 \mu\text{g}/\text{m}^3$, which corresponded to $\sim 0.001 \text{ ppm}$, and was lower than the ACGIH 8-hour TWA exposure guideline of 0.005 ppm (ACGIH, 2023).

Average Cr(VI) and total Cr surface levels in the paint booth at the Wright-Patterson 445th MXS maintenance shop were at least an order of magnitude higher than the surface levels of Cr(VI) measured in work areas at the Hill LOASM corrosion control shop (Cr(VI): 0.017 ± 0.029 vs. $1.29 \pm 1.74 \mu\text{g}/\text{cm}^2$; total Cr: 0.837 ± 0.937 vs. $20.37 \pm 33.45 \mu\text{g}/\text{cm}^2$). Despite these differences, the Cr surface levels in transition areas were comparable between the two facilities. Additionally, there was presence of surface Mn at one location in the Wright-Patterson 445th MXS maintenance shop, whereas there was no surface Mn detected at the Hill LOASM corrosion control shop. It is possible that the differences were a result of differences in Cr-generating processes at the two facilities. The Hill AFB shop used non-chromated primer, so the only Cr-generating process performed in

the paint booth during sampling was sanding to remove old surface coatings. The Wright-Patterson shop used a primer containing Cr(VI) that was applied with a paint sprayer to aircraft components.

Current occupational guidance does not provide a specific threshold for Cr(VI) surface levels, with OSHA's guidelines only stating that Cr(VI) levels should be reduced "as free as practicable," (OSHA, 2019) so a comparison of the sufficiency of the surface concentrations measured during this field assessment levels to a specific occupational standard cannot be made. ACGIH also notes that Cr(VI) is a dermal sensitizer, although it does not have any specific guidelines for surface exposure limits (ACGIH, 2023). Similarly, there are no occupational standards for surface levels of Mn. However, this does highlight the gap in knowledge about protective surface limits for dermal sensitizers present in Air Force maintenance shops. Attempts to address this gap are being made using existing information and new approach toxicology methods to derive preliminary candidate surface guidelines that can be used to compare to measured levels of chemicals and materials on work surfaces and better understand dermal sensitization risk (Keebaugh *et al.*, 2023).

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APPENDIX: PROCESSES OCCURRING IN LOASM SHOP

Processes listed that were potentially associated with dermal sensitizer exposure. Colors indicated likelihood of process occurrence during sampling event. Green: High likelihood, Yellow: Moderate likelihood, Red/Pink: Low likelihood. X indicates potential exposure to chemical listed in column header during process

Database	Process Name	Cr(VI)	EpiChl	FA	MnO2	HMDI	Xylene	Ni	Acr	Co
DOEHRS	Post-Painting Spray Gun Cleaning	x								
DOEHRS	Bead Blasting using the Glove Box	x								
DOEHRS	Sanding with Orbital Sanders, Large Paint Booth	x								
DOEHRS	Sanding with Orbital Sanders, Small Paint Booth	x								
DOEHRS	Priming Equipment, Large Paint Booth	x				x	x			
DOEHRS	Priming Equipment, Small Paint Booth	x				x	x			
DOEHRS	Painting Equipment, Large Paint Booth	x				x	x			
DOEHRS	Painting Equipment, Small Paint Booth	x				x	x			
DOEHRS	Cutting/Drilling Metal for Structural Repair	x								
DOEHRS	Fastener/Nut Plate Installation				x					
DOEHRS	Sealant Application, Eddie Bolt					x	x			
EESOH-MIS	4835A1 - PRIMING		x							
EESOH-MIS	4835A1 - PRIMING					x				
DOEHRS	Confined Space Inspecting F-35 Intake									
DOEHRS	Bead Blasting Aircraft Parts and Equipment	x								
DOEHRS	Rain Erosion Coating Brush Method					x				
DOEHRS	Tape & Boot/Moderate Temperature Boot Repairs/Applications									
EESOH-MIS	4835A1 - SEALING & BONDING		x							
EESOH-MIS	4835A1 - SEALING & BONDING	x								
EESOH-MIS	4835A1 - SEALING & BONDING				x					

Database	Process Name	Cr(VI)	EpiChl	FA	MnO2	HMDI	Xylene	Ni	Acr	Co
EESOH-MIS	4835A1 - SEALING & BONDING			x						
EESOH-MIS	4835A1 - RAM PASTE APPLICATION	x								
EESOH-MIS	4835A1 - GAP FILLER APPLICATION							x		
EESOH-MIS	4835A1 - PAINTING/COATING TOPCOAT		x							
EESOH-MIS	4835A1 - PAINTING/COATING TOPCOAT			x						
EESOH-MIS	4835A1 - COMPOSITE REPAIR ON AIRCRAFT - MECHANICAL		x							
DOEHRS	Apply Chromate Conversion Coating	x								
DOEHRS	Confined Space Aircraft Fuel Tank Maintenance									
DOEHRS	Transfer Blast Booth Media - Non-Routine	x								
DOEHRS	Chemical Stripping Aircraft Coatings									
DOEHRS	Confined Space Sanding									
DOEHRS	Confined Space Surface Wipe Down Exposure									
DOEHRS	Confined Space Priming/Painting/Coating Topcoat Brush/Roll Method									
DOEHRS	Confined Space Removing RAM									
DOEHRS	Confined Space Applying RAM									
DOEHRS	Confined Space Gap Filler Application		x	x						
DOEHRS	LO Material Removal From Panels									
DOEHRS	Sealing & Bonding						x			
DOEHRS	Composite Repair on Aircraft - Manual									
DOEHRS	Shop Equipment Maintenance									
EESOH-MIS	4835A1- NON-INDUSTRIAL MATERIALS IN SHOP				x					
EESOH-MIS	4835A1 - SEALING & BONDING								x	

Database	Process Name	Cr(VI)	EpiChl	FA	MnO2	HMDI	Xylene	Ni	Acr	Co
EESOH-MIS	4835A1 - SEALING & BONDING						x			
EESOH-MIS	4835A1 - SEALING & BONDING					x				
EESOH-MIS	4835A1 - SEALING & BONDING							x		
EESOH-MIS	4835A1 - SEALING & BONDING									x
EESOH-MIS	4835A1 - GAP FILLER APPLICATION		x							
EESOH-MIS	62A1 - SEALANT/ADHESIVE APPLICATION		x							
EESOH-MIS	4835A1 - PAINTING/COATING TOPCOAT						x			
EESOH-MIS	4835A1 - PAINTING/COATING TOPCOAT				x					
EESOH-MIS	4835A1 - PAINTING/COATING TOPCOAT									x
EESOH-MIS	4835A1 - PRIMING				x					
EESOH-MIS	4835A1 - CORROSION RESISTANT TOPCOAT				x					
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3649		x							
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3649	x								
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3649						x			
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3649					x				
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3649									x

Database	Process Name	Cr(VI)	EpiChl	FA	MnO2	HMDI	Xylene	Ni	Acr	Co
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3650		x							
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3650	x								
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3650						x			
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3650					x				
EESOH-MIS	4835A1 - APPLY COATINGS IN BOOTH 3650									x
EESOH-MIS	4835A1 - PAINTING/COATING TOPCOAT					x				

Acr = acrylonitrile; Co = cobalt; Cr(VI) = hexavalent chromium; EpiChl = epichlorohydrin; FA = formaldehyde; HMDI = hexamethylene diisocyanate; MnO₂ = manganese dioxide; Ni = nickel

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AFB	Air Force Base
cm ²	Square centimeters
Cr(VI)	Hexavalent Chromium
Cr(III)	Trivalent Chromium
DIS	Disposable Inhalable Sampler
DOEHRS	Defense Occupational and Environmental Health Readiness System
EESOH-MIS	Enterprise Environmental Safety and Occupational Health Management Information System
EpiChl	Epichlorohydrin
HMDI	Hexamethylene Diisocyanate
LOASM	Low Observable Aircraft Structural Maintenance
LOD	Limit of Detection
LPM	Liters Per Minute
µg	Micrograms
µg/cm ²	Micrograms per square centimeter
µg/m ³	Micrograms per cubic meter
mm	millimeter
Mn	Manganese
MnO ₂	Manganese Dioxide
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PBZ	Personal Breathing Zone
PPE	Personal Protective Equipment
ppm	Parts Per Million
PVC	Polyvinyl Chloride
Total Cr	Total Chromium
TWA	Time-Weighted Average