Investigation of Dermal and Respiratory Exposures to Metalworking Fluids at an Automotive Parts Manufacturer

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Report No. 2013-0075-3264
December 2016

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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 a manager at an automotive part manufacturing plant. The request concerned respiratory, skin, and gastrointestinal symptoms among employees exposed to metalworking fluids. We visited the plant four times in 2013 and 2014.

What We Did

- We interviewed employees about their medical and work histories, examined employees' rashes, and reviewed employee medical records.
- We asked employees to fill out a questionnaire about work exposures and symptoms.
- We took air samples for metalworking fluid mist, formaldehyde, and endotoxin.
- We measured machine operators' metalworking fluid mist exposures while videotaping them do machining tasks.

We evaluated medical concerns and employee exposures at an automotive part manufacturer. Some employees reported skin and respiratory symptoms related to work. The company lowered metalworking fluid mist levels below the recommended exposure limit by improving local exhaust ventilation and adding a splash shield to each compressed air gun.

What We Found

- Some machine operators had skin rashes from metalworking fluid exposure.
- Some machine operators reported breathing problems.
- Most machine operators were exposed to formaldehyde above the NIOSH limit.
- Before the company made changes, most machine operators were overexposed to metalworking fluid mist.
- No employees were overexposed to metalworking fluid mist after the company improved ventilation and added splash shields to the compressed air guns.
- Machine operators had brief, high exposures to metalworking fluid mist when they blew parts off with compressed air.

What the Employer Can Do

- Reduce the number of times machine operators use compressed air for each part.
- Continue improving metalworking fluid management practices.
- Train employees about the health hazards of metalworking fluids and ways to reduce or prevent exposure.
- Periodically measure employee exposures to metalworking fluid mist, formaldehyde, and noise.

What Employees Can Do

- Report skin and breathing problems that may be related to work to your supervisor.
- Use compressed air on each part as few times as possible.
- Machine operators should cover their arms and legs to prevent metalworking fluid from splashing on them.

Abbreviations

CFR	Code of Federal Regulations
CFU	Colony forming unit
EU	Endotoxin unit
EU/m^3	Endotoxin units per cubic meter of air
LAL	Limulus amebocyte lysate
MWF	Metalworking fluid
mg/m^3	Milligrams per cubic meter
mL	Milliliter
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PPE	Personal protective equipment
ppm	Parts per million
REL	Recommended exposure limit

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Introduction

The Health Hazard Evaluation Program received a request from a manager at an automotive engine water pump manufacturer. The manager submitted the request because of employee health concerns including respiratory problems, dermatitis, and gastrointestinal problems that may be related to metalworking fluid (MWF) exposure. We conducted on-site evaluations in March and May 2013. We returned in April 2014 after the company improved engineering controls for MWF mists. We provided exposure monitoring result summaries in September 2013 and June 2014.

Process Description

The plant produced diesel engine water pumps by machining cast iron with a soluble oil MWF. The plant had an employee census that fluctuated from 20–40 employees. Production employees worked in either the assembly department or the machining department. The plant operated two shifts per day during our 2013 visits and three shifts per day during our 2014 visits, typically with 4–5 machine operators per shift. Four machining lines (body line 1, body line 2, cover line 1, cover line 2) each had a minimum of four fully enclosed computer numerical controlled machining centers, each with its own MWF sump, and a parts washer. Machine operators manually moved each part through each machining center and the parts washer sequentially, also performing quality control measurements on the parts and stacking finished parts on pallets at the end of the line. A fifth machining line (pulley line) automatically transferred parts among machines, but it required a machine operator (usually from cover line 2, adjacent to the pulley line) to stock parts into the beginning of the line and take them off at the end of the line.

All production employees were required to wear safety glasses and steel toe boots. Those entering the machining department were also required to wear hearing protection devices. Production employees were allowed to wear street clothes. When handling parts, machine operators were required to wear breathable fabric gloves coated in polyurethane on the palm and fingers. When they handled metal parts coated with MWFs, they also donned extended mid-forearm length, cuffed, heavy nitrile gloves.

To maintain the proper concentration of MWF in their machines, machine operators took refractometer readings at the start of their shift and added concentrated MWF or water to bring the sump mixture to the desired concentration. A chemical supply company representative maintained the proper concentration of triazine-containing biocide (Grotan®) in all machining center sumps. Assembly operators moved parts manually through a series of machines until the finished cover or body part was assembled. Their final step before placing the part on a pallet for shipment was to coat the part with a petroleum-based rust inhibitor, either by applying it with a brush or by spraying it with a small hand-pumped sprayer.

Methods

The objectives of our evaluation were to:

1. Assess whether any current employees had dermatitis, respiratory problems, or gastrointestinal problems associated with their exposures to MWFs.
2. Characterize employee exposures to MWF mist (measured as thoracic particulate) and select components of MWF mist.

2013 Site Visits

Medical Interviews and Review Review

We invited all 25 production employees to participate in confidential medical interviews. We examined their skin if they reported having a current rash. We requested employee medical records if an employee reported being medically evaluated for a skin or respiratory problem. We also reviewed the company's Occupational Safety and Health Administration (OSHA) Logs for years 2006 through 2013.

Environmental Assessment

MWF environments contain numerous potential exposure hazards for employees. We collected bulk fluid samples for amines (monoethanolamine, diethanolamine, and triethanolamine), fungi and bacteria, and endotoxin. Amines are common corrosion-inhibiting MWF additives, some of which may contribute to developing occupational asthma [NIOSH 1998a]. Fungi and bacteria can flourish in water-miscible MWFs. Endotoxin, a component of the cell wall in Gram negative bacteria common in water-miscible MWF, can cause acute and chronic respiratory health effects [NIOSH 1998a]. We also collected air samples for MWF mist, formaldehyde (released from triazine-containing biocides like the one used at this plant), and endotoxin; looked at the local exhaust ventilation system; observed employee work practices and workplace conditions; and reviewed the chemical storage, labeling, and safety data sheet management plan. Table 1 shows the numbers and types of environmental samples we collected. Machine operators, assembly workers, forklift drivers, and production team leads participated in the air sampling exposure assessment. More detailed information about some of these sampling and analytical methods is in Appendix A. Appendix B contains additional information on the health effects and occupational exposure limits (OELs) for substances we evaluated.

Table 1. Environmental samples collected during 2013 site visits

Date collected	Sample type	Number of samples	Analyte (analytical method)
3/28/2013	Bulk fluids	10	Solubility testing for future air sampling (NIOSH Method 5524*); triazine and amines (GC-FID)
5/29–30/2013	Personal air samples	30	MWF (NIOSH Method 5524*)
		16	Formaldehyde (NIOSH Method 2016*)
	Area air samples	16	Endotoxin (LAL)
	Bulk fluids	8	Bacteria and fungi (culture)
		10	Triazine, monoethanolamine, diethanolamine, triethanolamine (GC-FID)
		10	Endotoxin (LAL)

GC-FID = gas chromatograph with flame ionization detector

LAL = limulus amebocyte lysate assay

*National Institute for Occupational Safety and Health [NIOSH 2016]

Other Observations

We looked at the local exhaust ventilation associated with each machining center and at the building's general ventilation exhaust fan. We used ventilation smoke tubes to qualitatively test several machining centers to see whether the local exhaust ventilation drew air into the machine cabinet, out of the machine operator's breathing zone. To learn about the company's plans for working with hazardous chemicals, we evaluated the company's chemical and safety data sheet management policy. We focused on whether there was a complete written chemical inventory (including safety data sheets), what the company's plans were for informing employees of potential chemical exposure risks and how to protect themselves, and how to respond safely to small chemical spills. This plan included a description of the company's yet to be fully implemented MWF management practices.

2014 Site Visit

After our 2013 site visits, the company made engineering control improvements (described more fully in the Results section of this report) to reduce MWF mist exposures. Anticipating that MWF mist exposures may have decreased as a result of those changes, we returned in 2014 for medical and environmental assessments.

Questionnaires

We asked all 19 permanent nonsupervisory production employees and 4 temporary production employees who were available at the time to complete a written questionnaire. The questionnaire asked about demographic information, work and medical history, personal protective equipment (PPE) use, hygiene habits, and personal exposures. We used four questions from the European Community Respiratory Health Survey which have been validated for asthma symptoms [Grassi et al. 2003]. The dermatologic questions included standardized questions modified from the Nordic Occupational Skin Questionnaire [Susitaival et al. 2003], which is widely used in studies of dermatitis. We also asked about skin, nasal, and respiratory symptoms in the month prior and in the 12 months prior to the questionnaire and whether these symptoms changed on days away from work. Self-reported symptoms that improved on days away from work were defined as work-related symptoms.

In addition to analyzing the data for individual respiratory symptoms and physician-diagnosed asthma, we also looked at prevalence of "asthma-like symptoms" defined as answering "yes" to any of the following questions [Grassi et al. 2003]:

- Are you currently taking any medicine for breathing problems or asthma?
- Have you had wheezing or whistling in your chest in the past 12 months?
- Have you woken up with a feeling of tightness in your chest in the past 12 months?
- Have you had an attack of asthma in the past 12 months?

These questions were intended to identify employees who had asthma-like symptoms but had not been diagnosed as having asthma.

Environmental Assessment

We collected 29 personal air samples and two area air samples for MWF mist and had them analyzed by NIOSH Method 5524. We did video exposure monitoring of machine operators on two machining lines (cover line 1, body line 2) using a TSI Sidepak™ real-time personal air monitor (model AM510) to record moment by moment breathing zone thoracic particulate concentrations while videotaping those tasks. Thoracic particulate refers to inhaled particles that can penetrate beyond the larynx into the respiratory system. The time-stamped air monitoring data were combined with the video footage using NIOSH-developed freeware (Enhanced Video Analysis of Dust Exposures, http://www.cdc.gov/niosh/mining/Works/coversheet1867.html) to produce video files showing real-time exposure concentrations for all tasks recorded on the video. Additional details about the video exposure monitoring done during this survey are in Appendix A.

Results

2013 Site Visits

Medical Interviews

We interviewed 23 of 25 production employees; 2 declined. The 23 participants included 14 first shift and 9 second shift employees and consisted of 10 machine operators, 5 assembly operators, and 8 who worked in other jobs including floaters, forklift drivers, quality assurance lab personnel, planning, and maintenance. Among the 23 interviewed employees, the average age was 42 years (range: 19–62 years), the average time worked for this company was 3 years (range: 3 weeks to 7 years), and the average time in their current job was 2 years (range: 3 weeks to 7 years).

Ten of the 23 employees reported current or past medical problems they related to working at this plant: five assembly employees, three machinists, and two other production employees. Reported health problems included rash (five employees), upper respiratory symptoms including nasal congestion, runny nose, throat irritation (three employees with sinus symptoms and one employee with throat symptoms), and lower respiratory symptoms including cough, wheeze, chest tightness, and shortness of breath (two employees). No employees reported gastrointestinal symptoms.

Four of the five assembly employees had worked as machinists at this plant previously; three reported developing a rash when working as machinists and eventually transferring to assembly because of their rash. Two of the three reported being medically diagnosed with work-related contact dermatitis. Among these three employees with a history of rash, two reported the rash cleared after transferring away from MWF, and one reported improvement but not complete clearing. Skin examination of this employee revealed signs of chronic contact dermatitis (dry, flaking, reddened skin on the hands and wrists). Three of the assembly employees also reported sinus and eye symptoms they thought were from the rust inhibitor that was sprayed onto the finished parts. One assembly employee also reported hand and wrist pain and numbness that was worse because of increased use of their hand at work. Two assembly employees reported the presence of more than one medical problem.

Among the three machinists reporting work-related medical problems, two reported shortness of breath, coughing, and labored breathing at work particularly when the large shipping/receiving bay doors of the plant were closed; one reported developing a rash when heavily splashed with coolant.

Of the two other production employees reporting health problems, one reported developing a sore throat and raspy voice only when fresh coolant was added to the MWF. The other reported a rash that had improved but not resolved. Upon examination, this employee had skin discoloration on the lower extremities that did not appear to be related to work exposures.

When asked if they had any concerns about their work environment or exposures, most machine operators reported they were concerned about the lack of ventilation and the accumulation of MWF mist in the air over the workday in the machining area. Some reported that the air felt "too thick to breathe" at times. Others reported that the MWF was not maintained as it should be. Heat and lack of air movement were common concerns.

Medical Record Review

We reviewed medical records of three employees who reported seeing a medical provider for possible work-related illnesses. Two of the employees were diagnosed with work-related conditions linked to chemical exposure. One was diagnosed with atypical chest pain after an acute chemical exposure, and the second employee was diagnosed with contact dermatitis. The employee with chest pain had also reported being diagnosed with work-related contact dermatitis, but this evaluation and diagnosis was not included in the medical records. The second employee was also diagnosed with carpal tunnel syndrome, which the record states may have been aggravated by work. The third employee was diagnosed with conjunctivitis (irritation of the membranes in the eye), but the record did not indicate work-relatedness.

OSHA Log Review

The type and number of entries from the OSHA recordable injury and illness logs from 2006–2013 are shown in Table 2. The number of entries ranged from 1–8 per year during this time period. The most common entries were musculoskeletal disorders and eye injuries.

Table 2. Review of entries from the plant's OSHA Logs, years 2006–2013

Number of:	Year							
	2006	2007	2008	2009	2010	2011	2012	2013
Total employees in the plant	4	19	19	20	33	36	36	40
Total work hours	5520	33,395	38,453	43,315	52,315	69,703	*	85,000
Entries:								
Skin	—	—	—	3	—	1	—	1
Respiratory	—	—	—	2	—	1	—	—
MSD†	—	3	3	—	1	3	1	2
Eye	—	3	—	—	1	—	2	3
Slip/trip/fall	—	1	—	—	—	—	1	1
Cuts, etc.‡	—	—	1	3	2	—	—	—
Other	1	—	1	—	—	—	—	—
Total entries:	1	7	5	8	4	5	4	7

*Not included on the OSHA 300A summary for 2012

†Musculoskeletal disorder

‡Lacerations, contusions, abrasions

Environmental Sampling

Metalworking Fluid Mist

Table 3 contains the summary air sampling results for MWF mist in 2013; detailed results are in Appendix C, Tables C1 and C2. We compared personal MWF mist sample results to the NIOSH recommended exposure limit (REL) of 0.4 milligrams per cubic meter (mg/m^3) for thoracic particulate mass.

Table 3. Summary of full-shift MWF personal air sampling results

Job/location	Number of samples	MWF mist concentration range, (mg/m^3)
Machine operator – cover line 1	4	0.37–0.55
Machine operator – cover line 2 (and pulley line)	4	0.26–0.37
Machine operator – body line 1	5	0.29–0.76
Machine operator – body line 2	5	0.45–0.68
Forklift driving	4	0.24–0.33
Assembly operator	8	0.19–0.25
NIOSH REL	—	0.4
% above the NIOSH REL	33	—
% at/above half the NIOSH REL	97	—

Forty-four percent of machine operators' MWF mist exposures exceeded the NIOSH REL. At least one machine operator from all lines but cover line 2 were exposed to MWF mist above the REL. The average percentage of extractable material on the air samples was 68%, (range: 47%–86%) (Tables C1 and C2 in Appendix C). Machine operators on all machining lines frequently used compressed air guns to blow off parts and machine dies. Machining centers on cover line 1 and body line 1 were connected to a single large Donaldson Torit® WSO model 25-2 mist collector, but none of the others were. When we used ventilation smoke tubes to qualitatively assess the direction of airflow at breathing zone height at each machining center on body line 1 and cover line 1, we found very few that consistently drew the smoke into the machine and into the exhaust ventilation system. Several roll-top garage doors in the shipping and receiving department, adjacent to the machining department, provided passive natural ventilation when they were open. However, no outdoor air was mechanically supplied to the production areas of the plant.

Formaldehyde

We assessed formaldehyde exposures only for the machine operators. We took 16 personal air samples, one on each of four machine operators on both shifts for 2 days. The detailed results are in Table C3, Appendix C. Formaldehyde concentrations ranged from 0.041 parts per million (ppm) to 0.19 ppm. These results were below the OSHA permissible exposure limit of 0.75 ppm and the OSHA action level of 0.5 ppm. One short-term sample (89-minute sample time on the pulley line machine operator) indicated the potential for exposures to exceed 0.1 ppm, the level at which the OSHA formaldehyde standard (29 CFR 1910.1048[n]) requires additional employee safety training. All personal air sample results exceeded the NIOSH REL of 0.016 ppm.

Endotoxin

We took 16 full-shift area air samples for endotoxin in the machining department, placing the sampling trains atop machining centers. The sampling filters hung at approximately breathing zone height and close to the opening machining center enclosure doors wherever possible. The results, shown in Table C4, Appendix C, ranged from not detected to 10 endotoxin units per cubic meter of air (EU/m^3). Because these were area samples, the results are not directly comparable to OELs. However, it is helpful to note these concentrations would have been well below the 90 EU/m^3 exposure limit recommended by the Dutch Expert Committee on Occupational Safety [DECOS 2010] had they been collected as personal air samples.

Bulk Fluid Samples

Results from chemical analysis of bulk fluid samples are shown in Tables C5 and C6, Appendix C. There are no occupational health limits for triazine or amines in MWF. We sought to verify the presence or absence of these chemicals because of the potential health effects they can cause and to show their relative abundance compared to each other. Though not listed as an ingredient on the safety data sheet, we suspected the soluble oil MWF used at this plant (SYN-SOL 7000, Metalloid Corporation) had triethanolamine in it. We found that it had triethanolamine and diethanolamine in it. The fresh water used to dilute SYN-SOL 7000 for use in the machining centers also had a low concentration of triethanolamine but it was below the lab's quantifiable limit. All used MWF samples had triethanolamine in them. More than half of the used MWF samples had monoethanolamine; less than half had diethanolamine. No triazine was detected in any sample.

Bacteria and fungi results are shown in Table C7, Appendix C. The Health and Safety Executive in the United Kingdom states that well-maintained MWFs have bacterial concentrations below 10^3 colony forming units per milliliter (CFU/mL) of fluid [HSE 2006]. Concentrations between 10^3 and 10^6 CFU/mL indicate reasonable control, and concentrations greater than 10^6 CFU/mL indicate poor control [HSE 2006]. The sample concentrations we measured (none exceeding 500 CFU/mL) were in the category of "good control" (below 10^3 CFU/mL) of bacterial contamination. This indicated no further action required to control bacterial contamination was needed at that time. The primary organisms (Bacillus spp.) found in the used MWF were mostly of the same genera found in the fresh water sample from the source used to dilute concentrated MWF for use in machining centers. *Aerococcus viridans*, *Pseudomonas alcaligenes*, *Staphylococcus spp*., and *Streptomyces spp*. were also present. *Mycobacterium gordonae* was isolated only from the fresh water sample. Only one sample contained culturable fungi (*Cladosporium spp*).

Endotoxin concentrations in the bulk MWF samples, shown in Table B8, Appendix B ranged between not detected and 160 EU/mL. There are no limits for endotoxin in MWF.

Metalworking Fluid Management

In 2013, the primary elements of the company's MWF management program consisted of the following:

1. MWF concentration measurements and fluid additions made by each machine operator

each shift for each machining center

2. Periodic triazine biocide additions made by the MWF supplier
3. Periodic sump cleanouts (the most recent was 7 months before our testing)

The company was in the process of implementing a more robust MWF management system, to include monthly testing of used MWF for bacteria and fungi, conductivity, and oil sediment.

Other Observations

We evaluated the company's chemical and safety data sheet management policy to learn about safety plans for working with hazardous chemicals. We observed that staff followed the policy's requirements for safe chemical storage, handling, and labeling of bulk quantities of chemicals. We also observed that safety data sheet books were available to staff as described in the policy. This policy did not specify plans to effectively inform and train staff about hazardous chemicals they may become exposed to or how to work safely during chemical spills. It also did not contain a complete list of hazardous chemicals at the plant. We observed that production employees consistently wore safety glasses and gloves when handling parts, but often wore short sleeves and shorts, with fully exposed arms and legs. Machine operators consistently were able to accurately tell us what PPE they had to wear when transferring bulk MWF into a smaller container used to add fluid to their machining centers.

On the basis of a recommendation made by a state occupational safety professional, the company treated the machining department as a hearing conservation area. As a result, the company required people working in the area to wear hearing protection devices. Employees had access to earmuffs and several types of Moldex® disposable ear plugs, all of which had a noise reduction rating of at least 27 decibels. We observed that some employees did not use hearing protection devices when working in the machining department, which increased their exposure to potentially hazardous noise. The company informed us of plans to increase the number of machines in the machining department, which could increase noise exposures.

2014 Site Visit

Results from our initial environmental assessment led us to focus our attention on MWF mist exposures in our follow-up assessment. Before our surveys in April 2014, the company made several engineering control improvements to reduce MWF mist exposures. They disconnected body line 1 from the large mist collector, thus increasing the amount of exhaust ventilation for cover line 1. The company installed Amano® Mistria model MZ-15 mist collectors for all other machining centers and Amano Mistria model MZ-10 mist collectors on the parts washers. As well, the company installed a general building air-conditioning system that they stated brought outdoor air into the work environment. Information about the amount of outdoor air brought in by this system was not available. The company also added small (approximately 6 inches in diameter) shields to the handheld compressed air guns each machine operator used. The shields reduced the amount of MWF mist blowing back towards machine operators when they blew metal shavings and MWF out of each part when transferring parts between machining centers.

Questionnaire

Twenty-one production employees participated in the questionnaire including all 17 permanent nonsupervisory employees who were at the plant during our visit and four of nine temporary employees who were available. Ten of the 21 employees had been hired within the past year; 5 machinists, 3 assembly, 1 quality assurance, and 1 forklift driver. Nonmachinist production jobs included assembly operator (n = 5), quality assurance inspectors (n = 3), forklift drivers (n = 2), and planner (n = 1). Employee characteristics are shown in Table 4.

Table 4. Employee characteristics by machining and nonmachining production jobs

	Machine operators (n = 10)	Nonmachinist production employees (n = 11)
Average age in years (range)	39 (23–53)	40 (20–54)
Average no. of months since hired [median] (range)	24 [11] (1.5–84)	35 [18] (1–84)
Number of female employees	2	0
Number handling coolant or parts wet with coolant	10	5
Number of employees reporting current smoking	7	4
History of atopy (atopic eczema, asthma, or hay fever)	7	5

When asked about medical history, four employees reported a history of childhood asthma. All were current smokers, and three were machine operators. Eleven had a history of allergic rhinitis/hay fever; seven were machine operators. Two machine operators and two nonmachinist production employees reported a history of skin disease. Other than childhood asthma, no employees reported a history of a respiratory condition.

Fifteen of the 21 employees reported handling used MWF, called "coolant," or parts wet with MWF in the previous month. Of these 15 employees, 12 reported always wearing gloves when doing these tasks, and 3 reported usually wearing gloves. Of those reporting any glove use, the black fabric gloves, the green extended cuff nitrile gloves, or both were worn. Over half reported wearing one pair of gloves over their entire shift. One employee reported always wearing protective sleeves ("yellow plastic") and three employees reported sometimes wearing protective aprons. The employer provided the sleeves and aprons for optional use.

Information Regarding Symptoms in the Month prior to the Questionnaire

Among the 21 employees, 17 (including all 10 machine operators) reported experiencing one or more of the symptoms listed in Table 5 in the month prior to our visit; 13 (including 8 machine operators) reported work-related symptoms, as defined by questionnaire responses. No employees reported seeking medical care or taking time off from work because of work-related symptoms.

Table 5. Number of employees reporting work-related symptoms in the month prior to the NIOSH visit, by job category

Work-related symptom in the month prior to NIOSH visit	No. of machine operators reporting (n = 10)	No. of nonmachinist production employees reporting (n = 11)
Irritated eyes	3	3
Cough	3	0
Shortness of breath	2	0
Chest tightness	2	0
Wheezing	0	0
Skin redness	3	0
Dry, cracking skin	2	1
Runny nose	2	2
Sinus problems	1	0

All three employees reporting work-related respiratory symptoms (cough, shortness of breath, or chest tightness) were machine operators. Machine operators and nonmachinist production employees reported work-related eye irritation and runny nose. All employees reporting respiratory or nasal symptoms had a history of current or past smoking.

All but one employee reported having the same job during the 12 months prior to the survey as they did in the month prior. The one employee remained in a job with similar MWF exposure, so the number of machine operators (n = 10) and nonmachinist production employees (n = 11) remained the same. Among the 21 employees, nine reported dermatitis in the 12 months prior to the survey. Of these, seven were machine operators, and two were nonmachinist production employees. When asked if the dermatitis improved away from work when away for more than 5 days, five of the seven machine operators and both nonmachinist production employees reported improvement. Two machine operators reported they had not been away from work more than 5 days. Six machine operators reported that they thought MWF caused their rash, and one reported wearing gloves caused a rash. The two nonmachinist production employees thought gloves caused their rash. One machine operator reported changing jobs to one without MWF exposure because of dermatitis and that the change improved the dermatitis. One machine operator reported seeing a doctor for dermatitis who said it was related to work. When asked if they had dermatitis at the time of the survey, four machine operators and two nonmachinist production employees reported yes. All four machinists reported skin changes on wrists and forearms; three also reported changes on hands and fingers. The two nonmachinist production employees reported skin changes only on their hands and fingers. These findings suggest that MWF exposure to skin above the gloved hands of machinists likely caused their dermatitis.

We asked certain standardized questions that have been shown to predict asthma [Grassi et al. 2003; Susitaival et al. 2003]. When asked these questions, no employees reported asthma attacks, episodes of chest tightness, or episodes of illness with two or more respiratory symptoms during the 12 months prior to the questionnaire, suggesting that no employees had asthma. Two nonmachinist production employees reported wheezing that did not improve away from work for 5 days or more in the prior 12 months, suggesting that the symptom was likely not related to work. Both had a smoking history.

Environmental Assessment

Summary results for MWF in personal air samples are below in Table 6; detailed results are in Appendix C, Tables C9 and C10. None of the machine operators' MWF mist samples exceeded the NIOSH REL, and fewer than 30% of them were above half the NIOSH REL. In contrast, one third of all personal air samples collected during our initial survey were above the NIOSH REL, and nearly all (97%) were above half the NIOSH REL. Overall exposures were lower in 2014 compared to 2013. However, the average percentage of each air sample that was extractable increased from 68% in 2013 to 91% in 2014 (Tables C9 and C10, Appendix C), indicating that on average a greater proportion of each sample collected in 2014 was liquid aerosol, and not aerosolized particulate, compared to the ones collected in 2013. The role of extractable MWF on the respiratory health of exposed employees has not been thoroughly differentiated from that of unextractable MWF. NIOSH considers MWF mist to consist of the MWF mist itself and all the contaminants in the mist generated during machining operations [NIOSH 1998a].

Table 6. Summary of full-shift MWF personal air sampling results

Job/location	Number of samples	MWF mist concentration range, (mg/m³)
Machine operator – cover line 1	1	[0.044]
Machine operator – cover line 2 (and pulley line)	6	[0.064]–0.31
Machine operator – body line 1	4	0.13–0.34
Machine operator – body line 2	4	0.13–0.31
Forklift driver	4	[0.083]–0.15
Team lead	2	[0.028, 0.11]
Assembly operator	8	[0.061]–0.26
NIOSH REL	0.4	—
% samples above the NIOSH REL	0	—
% samples at/above half the NIOSH REL	28	—

[ ] = Concentrations in brackets are between the minimum detectable and minimum quantifiable concentrations and have more uncertainty associated with them.

Video Exposure Monitoring

When we compared the thoracic particulate mass concentrations collected by the two area air samples to the measurements recorded by the real-time air monitors, we found two results that are important for properly interpreting the data. First, the thoracic particulate concentrations measured by our area air samples were between the minimum detectable concentration and the minimum quantifiable concentration, meaning there is more uncertainty associated with them. As a result, accurate calibration of the real-time monitor results was not possible. The results we report here are considered estimated thoracic particulate concentrations, which are best used to assess relative particulate concentrations during different tasks and not for direct comparison to OELs. Second, the two area air sample results were 10%–40% lower than the real-time concentrations measured at the same time in the same location by the real-time air monitors. Therefore, the real-time personal air monitoring results measured during video exposure monitoring likely overestimate the true concentration. As such, we refer to these results as "estimated thoracic particulate concentration(s)."

We observed brief peaks (ranging 1–12 seconds in duration) in MWF mist concentrations that were associated with certain work practices. Machine operators often used compressed air to clean metal shavings and excess MWF off machine dies before placing a part inside a machine for processing. They also used compressed air (1) to blow metal shavings and MWF out of parts' holes, channels, and recesses before moving the part further in the machining process (Figure 1), and (2) to perform one final blow-off of each finished part before stacking it on a pallet with other parts (Figure 2). We saw that sometimes, depending on the orientation of the part and the compressed air gun, MWF mist sprayed onto the machine operators and into their breathing zone.

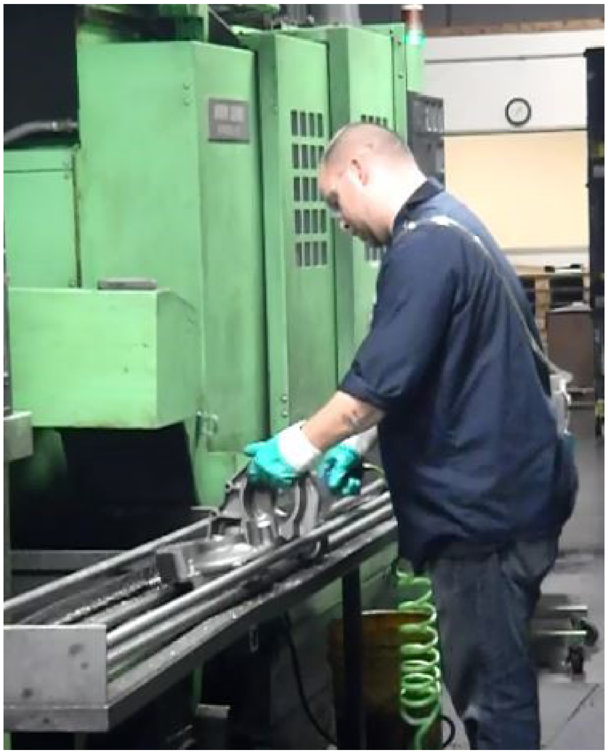

Figure 1. Machine operator holds a part in his gloved left hand, while blowing it off with the compressed air gun held in his gloved right hand. Photo by NIOSH.

The final blow-off step on each machining line was supposed to occur within a roughly waist-height enclosure (Figure 2), but these blow-off boxes were rarely used during our evaluations. Instead, we observed that machine operators tended to allow each part to partly drip dry in the blow-off box, then remove the part, hold it up with their hand or place it on a nearby shelf or table out in the open, and blow it off using compressed air. During this task, the body line 2 machine operator was exposed briefly to as high as 11 mg/m^3 estimated thoracic particulate (Figure 3). This task was the only one that caused peak exposures for the body line 2 machine operator during the time we monitored his exposures. In contrast, the cover line 1 machine operator's peak exposures came from more than just one task but did not exceed 2 mg/m^3 during the time we monitored.

Figure 2. Machine operator standing in front of blow-off box, blowing off finished part before placing it on pallet to his left. Photo by NIOSH.

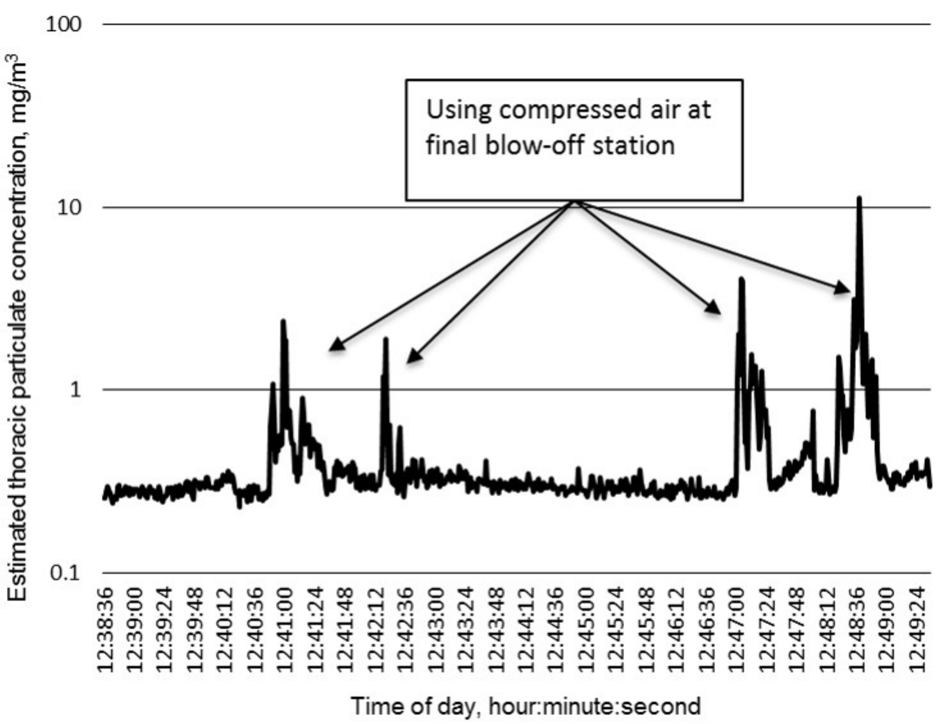

Figure 3. Estimated thoracic particulate concentration measured in breathing zone of body line 2 machinist.

The timing of certain work practices sometimes affected peak exposures. In some cases, a machine finished its machining cycle, the machine cabinet doors opened, but some time passed before the machine operator removed the part and advanced it to the next machine. In these cases, MWF mist exposures when the machine operator stood between the open machine cabinet doors tended to be nearly indistinguishable from those encountered when the machine operator was far from a machine, for example at their quality control bench (Figure 4). Other times, a machine operator waited by the machining center's door to transfer the part just as soon as the doors opened. In these cases, the machine operator sometimes received a brief increase in exposure (Figure 4). The OP30 machine in cover line 1 demonstrated these effects the most consistently. Most peak exposures, however, were not caused by this timing issue but by using compressed air.

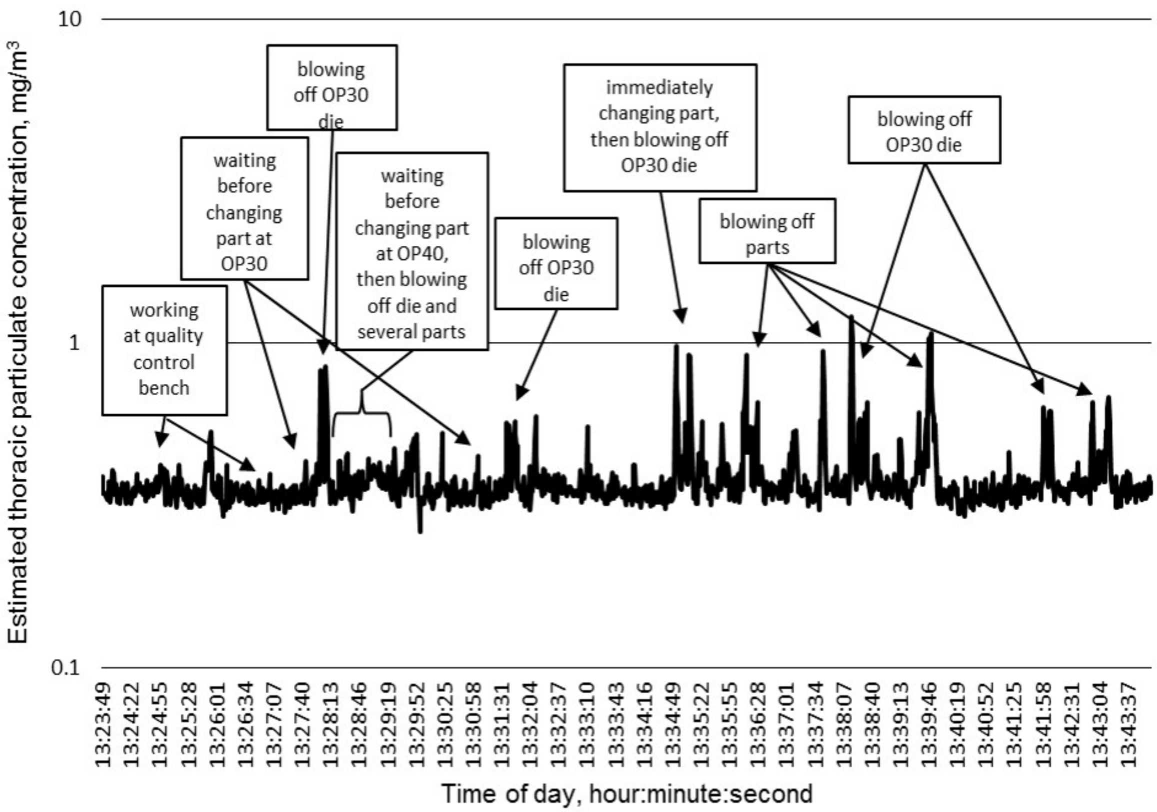

Figure 4. MWF mist concentrations measured in breathing zone of machine operator on cover line 1.

Other Observations

We observed work practices similar to what we had initially seen at this plant. Machine operators consistently wore safety glasses and gloves, made frequent use of compressed air, and commonly had exposed skin on legs and arms. They also occasionally neglected to wear hearing protection devices in the area where it is required. Also, at the final blow-off station, they commonly removed parts from the blow-off box and blew them down on a nearby railing or when holding the part aloft in their other hand.

Discussion

During our Spring 2013 site visit, machine operators were exposed to MWF mist and formaldehyde above the NIOSH REL. The personal air sampling results and airflow patterns observed around the machines confirmed that the local exhaust ventilation (mist collectors) was not effective in controlling exposures. Additionally, local exhaust ventilation was present on only a few machining centers. Interviews found that most machine operators were concerned about poor ventilation and inhaling MWF mist.

Some current and former machine operators reported upper and lower respiratory symptoms and skin symptoms consistent with coolant exposure. No employees reported gastrointestinal symptoms. Three former machine operators transferred to other work located away from MWF exposure because they had developed skin rashes. Two of these employees had complete clearing of their rash and one had improvement, but some skin symptoms persisted. Skin contact with MWFs is known to cause allergic contact dermatitis or irritant contact dermatitis depending on the chemical composition, additives and contaminants, type of metal being machined, and the exposed individual's tendency for developing allergies [WISHA 2001]. The widespread use of compressed air by machine operators, who often had much exposed skin on their arms and legs, presented a plausible route of skin exposure despite consistent use of gloves. Inhalation of MWF aerosols may irritate the throat, nose, and lung and has been associated with chronic bronchitis, asthma, hypersensitivity pneumonitis, and worsening of pre-existing respiratory problems [Burton et al. 2012]. Machine operators' symptoms were consistent with MWF exposure. These findings suggest that, at the time of our initial assessment, control of dermal and respiratory MWF exposure was inadequate.

Between our 2013 and 2014 site visits, the employer made sure all machining centers were connected to mist collectors and reduced the "splash back" effect of blowing off parts with compressed air guns by installing plastic shields on each air gun in front of the handle. When we returned in April 2014, the MWF mist personal air sampling results were all below the REL; however, some exceeded half the REL. This means that daily variability in workplace conditions could result in some personal exposures exceeding the REL and that continued exposure reduction efforts and medical surveillance are warranted. NIOSH recommends more frequent air sampling when airborne MWF exposures are more than half the REL. Machine operators continued to report work-related respiratory and skin symptoms; nonmachinist production employees did not report work-related respiratory symptoms. This suggests that MWF exposure was a likely cause of machinists' symptoms. Formaldehyde is also associated with upper and lower respiratory and skin symptoms. No employees reported asthma-like symptoms on the questionnaires.

Some employees can develop respiratory symptoms at MWF levels below OELs like the REL [NIOSH 1998a]. One study found significantly more upper and lower respiratory symptoms among employees exposed to a mean value of total MWF aerosols of 0.4 mg/m^3, which is below the NIOSH REL for total MWF aerosols of 0.5 mg/m^3, compared to unexposed employees [Lillienberg et al. 2010]. Park et al. studied an auto parts manufacturing employee population; 61% of MWF-exposed employees reported rhinitis-related symptoms. Air sampling found that 82% of employees at this plant were exposed to total MWF levels at or below 0.5 mg/m^3 [Park et al. 2008]. Looking at the general population, Guerra et al. found rhinitis (defined as runny or stuffy nose or episodes of sneezing apart from a cold) to be a significant risk factor for adult-onset asthma in those with and without history of allergies [Guerra et al. 2002]. Overall, the best way to prevent upper and lower respiratory symptoms and diseases among MWF-exposed employees is to keep MWF mist levels as low as feasible. Additionally, all employees exposed to MWF mist should be medically monitored annually, and those who report wheezing, asthma-like symptoms, and work-related asthma-like symptoms need to be referred to a health practitioner for medical evaluation.

Limiting skin exposure is critical to preventing allergic and irritant skin disorders related to MWF exposure. Studies have shown that about one in four employees diagnosed with occupational contact dermatitis will have persistent symptoms despite treatment or job change [Jungbauer et al. 2004]. Limiting exposure to MWF aerosols is also prudent because previous exposures to some MWFs have been associated with increased risk of some types of cancer [NIOSH 2013]. Although actions taken in the last several decades have reduced that risk, it is not known if these actions have totally eliminated the risk [NIOSH 2013]. Additional information about contact dermatitis and tips to reduce or prevent work-related contact dermatitis are given in Appendix D.

The role of short-term peak MWF mist concentrations in affecting the respiratory and dermal health of employees is uncertain. Nonetheless, reducing these short-term exposures is prudent. Video exposure monitoring showed that using compressed air to blow off parts and machine dies caused the vast majority of peak exposures measured during this evaluation. Peak exposures also occurred when a machine operator stood in front of opening machining center cabinet doors before the mist collector had time to sufficiently reduce MWF aerosol concentrations. This information may provide a starting point for future exposure control efforts. Because all the machining centers now have mist collectors on them, there may be benefit in delaying the cabinet doors' opening until the mist collector has adequate time to filter the air within the machining center cabinet. Using compressed air the way machine operators did at this plant can also contribute to employees' dermal exposure by blowing MWF mist onto unprotected skin [HSE 2011]. Minimizing the use of compressed air, and allowing enough time for mist collectors to lower airborne concentrations within the machining centers before the cabinet doors open, could lower the risk for respiratory and dermal routes of exposure.

The design of some features within the machining lines contributed to respiratory and dermal exposure of employees to MWF mist. The blow-off box at the end of each machining line seemed too low (and, on the cover lines, too small) for most of the machine operators to use comfortably, providing incentive for them to remove parts before blowing them off. As well, because the blow-off boxes were not connected to local exhaust ventilation, and open only on the side facing the machine operator, they were not optimized for MWF mist exposure prevention. A second feature that likely contributed to MWF mist exposure, as documented by video exposure monitoring on cover line 1, was the lack of a splash guard where machine operators blew off parts along the parts conveyor between machining centers. The small splash shields the company installed were effective a great deal of the time. However, MWF mist escaped to the surrounding area depending on the angle of compressed air applied to the part and the depth the air gun nozzle was inserted into the holes and recesses of the part. The complexities inherent with solving these exposure challenges underscore the importance of first seeking ways to reduce or eliminate the need for machine operators to use compressed air on things covered with MWF and metal shavings.

We analyzed bulk MWF for biological and chemical constituents. The culturable analyses of bulk MWF indicated well controlled MWF, having virtually no fungal growth and bacteria not exceeding 500 CFU/mL of sample [HSE 2006]. However, the samples we collected contained no detectable triazine, possibly indicating the eventual need to add biocide to maintain low culturable counts of microbes in the future. The endotoxin concentrations in bulk MWF were generally lower than those reported in the scientific literature for other facilities using similar types of MWF. Simpson and associates found endotoxin ranging from the limit of detection to 1,870,000 EU/mL in 154 water-based MWF samples [Simpson et al. 2003]. The median endotoxin concentration for these samples was 8,039 EU/mL [Simpson et al. 2003]. In a study of three facilities, Cyprowski and associates [2007] found that the average concentration of bacterial endotoxins in the used MWFs was 773 EU/mL. Endotoxin concentrations ranged from 220 to 1,700 EU/mL in a manufacturing plant for steel roller bearings [NIOSH 2006], but were below 75 EU/mL in an aluminum can manufacturing plant [NIOSH 2012]. The health relevance of the low endotoxin concentrations in bulk MWF at the plant we visited remains unclear, however. Detecting ethanolamines, particularly diethanolamine and triethanolamine, in the process MWF samples was not surprising because (1) they are relatively common additives in water miscible MWF [NIOSH 1998a] and (2) the unused concentrated MWF (SYN-SOL 7000) contained both these ethanolamines.

The results from the formaldehyde in air testing indicated a potential health risk. One sample indicated the potential for exposures to exceed 0.1 ppm, the level at which the OSHA formaldehyde standard (29 CFR 1910.1048[n]) requires additional employee safety training. The personal air samples for formaldehyde all exceeded the NIOSH REL. The NIOSH REL was established in 1981 when NIOSH recognized formaldehyde as a potential occupational carcinogen. On the basis of the carcinogen policy in existence at the time, NIOSH set the REL to the "lowest feasible concentration." For formaldehyde, this was defined as the analytical limit of quantification of 0.016 ppm for up to a 10-hour TWA and a ceiling limit of 0.10 ppm that should not be exceeded [NIOSH 1981]. However, research has shown that concentrations of formaldehyde in ambient air can approach or exceed this level [Lemen 1987]. Additionally, the subsequent revision of the NIOSH carcinogen policy [NIOSH 1995], combined with better exposure characterization and advances in risk assessment and management strategies, support the need for NIOSH to reassess the formaldehyde REL. In the meantime, minimizing formaldehyde exposures seems prudent.

The company treated the machining department as a hearing conservation area, requiring employees and visitors to wear hearing protection devices. Evaluating potentially hazardous noise levels was outside the scope of this health hazard evaluation, but we observed some employees neglecting to wear hearing protection devices when in the machining department. Adhering to company requirements for using PPE like hearing protection devices is an important element of employee health and safety. So is periodically assessing noise exposures after making changes in the workplace that could potentially change noise levels.

Conclusions

Current and former machine operators reported respiratory and skin symptoms consistent with work-related exposure to MWF, both before and after ventilation improvements were made at this plant. Exposures to MWF mist and formaldehyde were above the REL in 2013 before the ventilation improvements, but microbial contaminants in bulk MWF were low. Local exhaust ventilation improvements were effective at reducing employees' MWF mist exposure to below the REL. However, workers can develop respiratory illness from MWF exposures below the REL. Short-term peak exposures to MWF mist were associated primarily with two work practices: using compressed air to blow off machine dies and parts, especially at the last station in each machining line, and removing a part from a machining center immediately after the cabinet doors open. The company needed to improve several elements of their chemical and safety data sheet management program and may need to update their noise exposure risk assessment if new machines are added to the machining department.

Recommendations

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

Our recommendations are based on an approach known as the hierarchy of controls (Appendix B). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and PPE may be needed.

Elimination and Substitution

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

1. Eliminate the need for machine operators to use compressed air, perhaps by developing machining centers that can blow off the part and die as part of each machining cycle, inside the enclosed and ventilated machining cabinet.
2. Substitute biocides with less irritating and sensitizing components if proper fluid maintenance and PPE use does not alleviate employee contact dermatitis. Be aware that formaldehyde releasing agents such as triazines are known sensitizers, but other, less studied chemicals in MWF may also cause contact dermatitis.
3. Switch to a less irritating rust inhibitor spray in the assembly department.

Engineering Controls

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

1. Adjust machining center operating software settings to allow the cabinet doors to remain closed long enough for the mist collectors to adequately lower MWF mist concentrations inside. This will minimize machine operators receiving short-term peak MWF exposures when the cabinet doors open.
2. Ensure compressed air line pressure used to clean parts and machines stays below 30 pounds per square inch and that all air guns have splash guards.
3. Actively ventilate and optimize the height of the blow-off station at the end of each machining line.
4. Add a splash shield to conveyor lines between machining centers so machine operators who blow off parts have a barrier between themselves and the MWF mist coming off the part they are cleaning.
5. Partially enclose assembly department rust inhibitor spray stations and connect exhaust ventilation if switching to a less irritating rust inhibitor is not feasible.

Administrative Controls

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

1. Implement fully a comprehensive MWF management program as specified in the 1998 NIOSH document, "Criteria for a Recommended Standard: Occupational Exposure to Metalworking Fluids" [NIOSH 1998a].
2. Periodically monitor full-shift employee exposures to MWF mist, noise, and formaldehyde, particularly when process changes are made that could affect those exposures. MWF mist should be monitored every 6 months until exposures are reduced to below half the REL, and then annually thereafter [NIOSH 1998a]. Noise should be monitored at least once every 2 years until exposures are consistently below the REL [NIOSH 1998b].
3. Develop a training program on the proper handling and use of MWF, the hazards and potential health effects associated with MWF exposure, and ways to prevent or reduce MWF exposure. Include information on moisturizers, soaps, and skin cleaners because some components, such as lanolin and fragrances, are known allergens and may cause allergic contact dermatitis in sensitive individuals. Guidelines for MWF training are included in the NIOSH MWF criteria document [NIOSH 1998a].
4. Include formaldehyde in the hazard communication program for employees working in machining areas. If follow-up air monitoring shows employees' exposures meet or

exceed 0.1 ppm, additional formaldehyde-specific safety training will be required at least annually, per 29 CFR 1910.1048(n).

5. Look for health problem or injury trends in company injury and illness logs that may be related to particular job duties, work materials, machines, or areas of the plant. Evaluate areas or jobs that show an increase in injuries or health problems and develop an intervention to reduce exposures. For more information, refer to Chapter 9 in the NIOSH MWF criteria document [NIOSH 1998a].
6. Encourage employees to take prompt action when their skin or clothing contacts MWFs. For example, exposed skin should be flushed with large amounts of running water or washed with soap and water as soon as possible. Residual soap should be washed off the skin surface. Clothing contaminated with MWFs should be removed and laundered prior to reuse.
7. Start a medical monitoring program for employees who are exposed to MWFs. Periodic use of a medical questionnaire that focuses on skin and respiratory symptoms may be helpful. The questionnaire should be given before placement in a job with MWF exposure and periodically thereafter. Questionnaire responses can help identify work areas and tasks that need additional evaluation and employees who need additional medical follow-up. A medical monitoring program helps prevent, identify, and manage skin and respiratory disease among participants. It includes preplacement or initial examination, periodic examination, detailed examination for a subset of employees, physician's reports, and follow-up evaluations. More information about medical monitoring and its implementation can be found in Chapter 9 of the NIOSH MWF criteria document [NIOSH 1998a].
8. Encourage employees to discuss their work exposures with their primary healthcare provider and share any exposure sampling records and any health concerns with him or her.

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.

1. Encourage the use of protective sleeves and aprons when working with MWFs to prevent splash exposures. Exactly which PPE and when it should be used should be determined by a hazard assessment with employer and employee involvement. Written procedures should define the necessary PPE and include guidance on proper selection and use. The PPE should also be inspected, cleaned, or replaced as needed, and properly stored according to OSHA requirements [29 CFR 1910.132].
2. Enforce hearing protection device use in hearing conservation areas.

Appendix A: Methods

Endotoxin

Bulk samples and air samples were analyzed for endotoxin using the Endpoint Chromogenic LAL assay, a quantitative test used to detect Gram negative bacterial endotoxin. Samples were incubated with the LAL reagent and then a chromogenic substrate reagent causing the sample to turn yellow in the presence of endotoxin. After the reaction stopped, the plate was read at 405 nm by a plate reader. Sample results were quantified using an endotoxin standard curve. Because the polycarbonate air filters used to collect air samples contained endotoxin, field sample results were blank corrected using the average endotoxin concentration of the filter blanks submitted for analysis with the field samples.

Bulk Sampling for Microbial Analysis

We collected bulk MWF samples using sterile pipettes and 50 mL conical centrifuge tubes. The samples were immediately cooled and shipped overnight to the laboratory for analysis. The laboratory reported total CFUs plus the top three most prevalent species for each sample.

Bulk Sampling for Chemical Analysis

We collected bulk MWF samples using sterile pipettes and 50 mL conical centrifuge tubes. The samples were immediately cooled, and shipped overnight to the laboratory for analysis. These samples were analyzed by preparing dilutions of the MWF in acetone, and directly injecting an aliquot into a gas chromatograph with flame ionization detection.

Video Exposure Monitoring

The TSI Sidepak™ Personal Air Monitor (model AM510) was factory calibrated with Arizona road dust which may have different light-scattering and aerodynamic properties than the MWF mist in this plant. To help us understand whether this difference affected our results, we compared the thoracic particulate mass concentrations collected by the two area air samples (which collected MWF mist on filters and were analyzed by NIOSH Method 5524) to the results recorded by the real-time air monitors. We collected these two pairs of samples at separate machining centers' operator stations at approximately breathing zone height.

Appendix B: Occupational Exposure Limits and Health Effects

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

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

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

- The U.S. Department of Labor OSHA permissible exposure limits (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 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.
- Other OELs commonly used and cited in the United States include the threshold limit values, which are recommended by the American Conference of Governmental Industrial Hygienists, a professional organization, and the workplace environmental exposure levels, which are recommended by the American Industrial Hygiene Association, another professional organization. The threshold limit values and workplace environmental exposure level are developed by committee members of these associations from a review of the published, peer-reviewed literature. These OELs are

not consensus standards. Threshold limit values 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 2016]. Workplace environmental exposure level have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2016].

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.

Metalworking Fluid

MWFs are complex mixtures used to cool, lubricate, and remove metal chips from tools and parts during machining of metal stock. MWFs often contain other substances including biocides, corrosion inhibitors, metal fines, tramp oils, and biological contaminants [Burton et al. 2012; NIOSH 1998a]. Inhalation of MWF aerosols may irritate the throat, nose, and lungs and has been associated with chronic bronchitis, asthma, hypersensitivity pneumonitis, and worsening of pre-existing respiratory problems [Burton et al. 2012]. Additionally, skin contact with MWFs may cause allergic contact dermatitis or irritant contact dermatitis depending on the chemical composition, additives and contaminants, type of metal being machined, and the exposed individual's tendency for developing allergies [WISHA 2001].

NIOSH recommends limiting exposures to MWF aerosols to 0.4 mg/m^3 for the thoracic particulate mass, as a time-weighted average concentration for up to 10 hours per day during a 40-hour workweek [NIOSH 1998a]. The NIOSH REL is intended to prevent or greatly reduce respiratory disorders associated with MWF exposure. In addition, limiting dermal (skin) exposure is critical to preventing allergic and irritant disorders related to MWF exposure. NIOSH recommends that all employees exposed to MWFs at over half the REL, or who work in areas where one or more employees have recently developed asthma, hypersensitivity pneumonitis, or other serious conditions related to MWF exposure, receive medical monitoring, and all employees with exposure to MWF may benefit from medical monitoring [NIOSH 1998a]. Medical monitoring is needed for the early identification of employees who develop symptoms of MWF-related conditions such as hypersensitivity pneumonitis, asthma, and dermatitis. Supervision of the medical monitoring program should be done by a physician or other health professional with expertise in the identification and management of MWF-related respiratory conditions and skin diseases.

Contaminated water in MWFs may also contain fungi. Some fungi may infect susceptible hosts, such as immune compromised persons, and exposure to some fungi may result in adverse health effects such as hypersensitivity pneumonitis, allergic sensitization, and asthma. At this time, health data are insufficient to recommend a specific limit for fungal contamination in MWFs.

Triazine

Triazine is the major component of the biocide used at the plant, and exposure to triazine may also be a factor in employees' symptoms. Triethanol triazine (i.e., 1,3,5-triazine-1,3,5-triethanol) is a formaldehyde-releasing biocide/preservative that is often added to MWF. Formaldehyde is a known corrosive and may cause irritant contact dermatitis, in addition to eye irritation [EPA 1997]. Although animal studies have not found triethanol triazine to be sensitizing (causing an allergic reaction), medical case studies have reported that it has caused allergic contact dermatitis in humans [Dahl 1981; Keczkes and Brown 1976; Veronesi et al. 1987]. Pre-existing eczematous dermatitis may increase the likelihood of sensitization in some individuals. Schnuch et al. found that a 1% concentration of triazine (as Grotan BK) produced positive sensitization reactions in 1% of 1,772 patients with suspected allergic contact dermatitis [Schnuch et al. 1998].

Formaldehyde

Formaldehyde is a microbiocidal breakdown product of triazine, the active ingredient in the biocide (Grotan®) added to the MWF at this company. Formaldehyde is also a potential dermal sensitizer and respiratory sensitizer [ACGIH 2016]. The NIOSH REL for formaldehyde initially was set as low as possible (at the analytical limit of detection at the time, [NIOSH 1981]) because formaldehyde is a potential human carcinogen. Additional research has shown, however, that sometimes ambient air can have formaldehyde levels as high or higher than the NIOSH limit, even with no obvious source nearby. As a result, NIOSH is revising its formaldehyde limit and, in the meantime, recommends that employers and employees minimize formaldehyde exposures to the extent feasible. The most commonly reported and best documented health complaints due to exposure to low concentrations of formaldehyde include irritation of the eyes, nose, and throat; nasal congestion; headaches; skin rash; and asthma. Following the NIOSH carcinogen policy in existence at the time, NIOSH set the REL to the “lowest feasible concentration.” For formaldehyde, this was defined as the analytical limit of quantification of 0.016 ppm for up to a 10-hour time-weighted average and a ceiling limit of 0.10 ppm that should not be exceeded [NIOSH 1981, 2010]. Since then, experience has shown that this REL is actually not the “lowest feasible concentration” because formaldehyde in the ambient air can exceed 0.016 ppm, a fact later acknowledged by NIOSH [Lemen 1987]. Additionally, the subsequent revision of the NIOSH carcinogen policy [NIOSH 1995], combined with better exposure characterization and advances in risk assessment and management strategies, support the need for NIOSH to reassess the formaldehyde REL that is in progress.

Appendix C: Tables

Table C1. Personal air sample results for metalworking fluid mist (thoracic particulate), May 29, 2013

Job/Activity	Shift	Sample time (minutes)	Total volume (liters)	Concentration (mg/m^3)	Percent that was extractable
Machine operator – Cover line 1	1	581	930	0.52	79
Machine operator – Pulley line	1	618	983	0.26	62
Machine operator – Body line 2	1	591	946	0.63	72
Machine operator – Body line 1 (trainee)	1	586	938	0.29	85
Machine operator – Body line 1 (trainer)	1	257	409	0.76	68
Forklift driver	1	607	959	0.24	70
Assembly operator – Cummins line	1	551	882	0.26	70
Assembly operator – Navistar line	1	549	878	0.23	70
Machine operator – Cover line 1	2	641	1,026	0.40	76
Machine operator – Cover line 2 & Pulley line	2	629	1,006	0.32	72
Machine operator – Body line 1	2	628	1,005	0.54	65
Machine operator – Body line 2	2	596	954	0.45	86
Forklift driver	2	557	891	0.24	76
Assembly operator	2	594	950	0.24	78
Assembly operator	2	592	947	0.19	47
NIOSH REL				0.4	—

Table C2. Personal air sample results for metalworking fluid mist (thoracic particulate), May 30, 2013

Job/Activity	Shift	Sample time (minutes)	Total volume (liters)	Concentration (mg/m³)	Percent that was extractable
Machine operator – Cover line 2	1	615	984	0.37	83
Machine operator – Body line 1 (trainee)	1	613	980	0.30	79
Machine operator – Body line 1 (trainer)	1	572	915	0.62	72
Machine operator – Cover line 1	1	612	979	0.55	69
Machine operator – Body line 2	1	598	957	0.68	62
Forklift driver	1	590	944	0.33	52
Assembly operator – Navistar line	1	573	917	0.24	55
Assembly operator – Cummins line	1	576	922	0.20	67
Machine operator – Body line 1	2	626	1,002	0.34	74
Machine operator – Cover line 1	2	627	1,003	0.37	68
Machine operator – Body line 2	2	627	1,003	0.47	67
Machine operator – Cover line 2	2	615	984	0.37	68
Forklift driver	2	557	891	0.24	76
Assembly operator	2	608	973	0.25	46
Assembly operator	2	553	885	0.23	70
NIOSH REL				0.4	—

Table C3. Machine operator personal air sample results for formaldehyde, May 29–30, 2013

Employee work location	Day	Shift	Sample duration (minutes)	Sample volume (liters)	Concentration (ppm)
Cover line 1	1	1	584	29.8	0.043
Pulley line	1	1	89	4.5	0.19
Body line 2	1	1	405	20.3	0.055
Body line 1	1	1	*	*	*
Cover line 1	1	2	645	32.4	0.044
Cover line 2 & Pulley line	1	2	634	31.7	0.050
Body line 1	1	2	405	20.3	0.043
Body line 2	1	2	599	29.9	0.053
Body line 2	2	1	601	30.1	0.045
Cover line 1	2	1	617	30.9	0.041
Body line 1	2	1	510	25.5	0.043
Cover line 2	2	1	616	30.8	0.041
Body line 1	2	2	521	26.1	0.052
Cover line 1	2	2	630	31.5	0.043
Body line 2	2	2	588	29.4	0.052
Cover line 2	2	2	*	*	*
NIOSH REL					0.016
OSHA permissible exposure limit					0.75

*Result censored due to pump failure

Table C4. Area air sample results for endotoxin in May 29–30, 2013

Area	Day	Shift	Sample duration (minutes)	Sample volume (liters)	Concentration (EU/m³)
Cover line 1 – OP210	1	1	553	1,099	3
Body line 1 – OP120	1	1	550	1,084	ND
Body line 2 – OP120	1	1	547	1,084	4.6
Pulley line – above tool door	1	1	545	1,089	3.6
Body line 2	1	2	606	1,212	ND
Body line 1	1	2	*	*	*
Cover line 1	1	2	607	1,214	3.4
Cover line 2 & Pulley line	1	2	606	1,212	5.2
Cover line 1 – parts washer	2	1	591	1,182	ND
Body line 1 – OP10A	2	1	590	1,180	7.3
Body line 1 – between 220 & 230	2	1	589	1,178	4.3
Body line 2 – OP110C	2	1	582	1,164	ND
Cover line 1	2	2	609	664	7.8
Body line 1	2	2	609	1,218	8.3
Body line 2	2	2	609	1,218	10
Cover line 2	2	2	332	664	3.7

ND = Not detected; the minimum detectable concentration was 2.3 EU/m³ based on a sample volume of 1.1 m³.

*Result censored due to pump failure.

Table C5. Chemical analysis of bulk metalworking fluid samples, µg/mL, collected March 28, 2013

Sample location	Triazine	Monoethanolamine	Diethanolamine	Triethanolamine
Fresh water (used for mixing MWF)	ND	ND	ND	[46]
Cover line 1, OP-10A	ND	[340]	ND	2,600
Cover line 1, OP-10B	ND	ND	ND	2,200
Body line 1, OP-10B	ND	[400]	ND	3,000
Body line 1, OP-10B	ND	ND	ND	2,100
Cover line 2, OP-20	ND	[430]	ND	3,100
Pulley line	ND	ND	ND	2,100
Cover line 1 – parts washer	ND	ND	ND	780
Unused SYN-SOL 7000	ND*	ND*	9700*	31,000*
Body line 2 – parts washer	ND	ND	[530]	2,700
Minimum detectable concentration†	40, 400	30, 300	30, 300, 500, 600, 700, 800	30, 300
Minimum quantifiable concentration†	120, 1,300	83, 910	83, 910, 1700, 2,000, 2,300, 2,600	83, 910

ND = Not detected

[ ] = Concentrations in brackets are between the minimum detectable concentration and minimum quantifiable concentration for that particular sample, and have more uncertainty associated with them.

*Sample was too viscous to be analyzed by volume and had to be weighed; units are in milligrams per kilogram.

†Some samples required various amounts of dilution prior to analysis, and as a result these table values may vary from sample to sample.

Table C6. Chemical analysis of bulk metalworking fluid samples, µg/mL, collected May 30, 2013

Sample location	Triazine	Monoethanolamine	Diethanolamine	Triethanolamine
Cover line 1, OP-10A	ND	[350]	ND	3,000
Cover line 1, OP-40	ND	[550]	[500]	4,900
Cover line 1, parts washer	ND	ND	ND	1,600
Body line 1, OP-10A	ND	[510]	[550]	4,100
Body line 1, parts washer	ND	ND	[660]	1,800
Body line 1, OP-30	ND	[550]	[670]	4,300
Body line 2, OP-10C	ND	[500]	[450]	3,800
Body line 2, OP-40	ND	[640]	1100	5,700
Cover line 2, OP-230C	ND	ND	ND	1,900
Cover line 2, OP-210C	ND	[410]	ND	2,900
Minimum detectable concentration	400	300	300	300
Minimum quantifiable concentration	1,300	910	910	910

ND = Not detected

[ ] = Concentrations in brackets are between the minimum detectable concentration and minimum quantifiable concentration, and have more uncertainty associated with them.

Table C7. Microbial analysis of bulk fluids collected March 28, 2013

Fluid type and source	Predominant organisms	Fungal content	Mycobacterial content
Used MWF, cover line 1 OP220	28 CFU/mL *Aerococcus viridans*	None	None
Used MWF, cover line 1 OP230	500 CFU/mL *Pseudomonas alcaligenes*	100 CFU/mL *Cladosporium spp.*	None
Used MWF, body line 1, OP110A	1 CFU/mL *Bacillus spp*., morphotype 1 1 CFU/mL *Bacillus spp*., morphotype 2 1 CFU/mL *Bacillus spp*., morphotype 3 1 CFU/mL *Streptomyces spp.*	None	None
Used MWF, body line 1, OP130	100 CFU/mL *Bacillus spp.* 100 CFU/mL *Staphylococcus spp.* coagulase negative	None	None
Used MWF, body line 2 OP110B	100 CFU/mL *Bacillus spp.*	None	None
Used MWF body line 2 robodrill	1 CFU/mL likely *Bacillus pumilus*	None	None
Used MWF, cover 2 body mount surface finish	None	None	None
Fresh water for MWF mixing	100 CFU/mL *Bacillus spp.,* morphotype 1 100 CFU/mL *Bacillus spp*., morphotype 2 100 CFU/mL *Staphylococcus spp.*, coagulase negative	None	*Mycobacterium gordonae**

*Isolated from the broth only, and unable to be counted.

Table C8. Endotoxin concentration in bulk fluid samples collected May 30, 2013

Sample location	Endotoxin, EU/mL
Cover line 1, OP-10A	42
Cover line 1, OP-40	98
Cover line 1, parts washer	2.8
Body line 1, OP-10A	5.7
Body line 1, parts washer	13
Body line 1, OP-30	3.4
Body line 2, OP-10C	160
Body line 2, OP-40	4
Cover line 2, OP-230C	ND
Cover line 2, OP-210C	1.7

ND = Not detected; the limit of detection was 1.25 EU/mL.

Table C9. Personal air sample results for metalworking fluid mist (thoracic particulate), April 8, 2014

Title – location	Shift	Sample time (minutes)	Total volume (liters)	Concentration (mg/m³)	Percent that was extractable
Machine operator – Cover line 2	1	503	798	0.16	94
Machine operator – Pulley line (plus trainee on cover line 2)	1	500	795	0.15	100
Machine operator – Body line 1	1	435	690	0.13	86
Machine operator – Body line 2	1	505	804	0.20	95
Forklift driver	1	470	746	[0.083]	100
Assembly operator – Cummins line	1	542	858	0.24	87
Assembly operator – Navistar line	1	543	859	[0.061]	100
Machine operator – Body line 2	2	502	801	0.21	95
Machine operator – Cover line 2	2	501	796	0.31	93
Machine operator – Body line 1	2	456	729	0.13	32
Forklift driver	2	551	876	0.15	94
Assembly operator – Cummins line	2	529	843	[0.074]	100
Assembly operator – Cummins line	2	527	838	0.13	100
NIOSH REL				0.4	—

[ ] = Result fell between the minimum detectable concentration and the minimum quantifiable concentration (0.09 mg/m³ based on an average sample volume of 816L), and has more uncertainty associated with it.

Table C10. Personal air sample results for metalworking fluid mist (thoracic particulate), April 9, 2014

Title – location	Shift	Sample time (minutes)	Total volume (liters)	Concentration (mg/m³)	Percent that was extractable
Machine operator – Body line 2	1	492	784	0.31	100
Machine operator – Cover line 2	1	209	333	[0.13]	69
Machine operator – Pulley line	1	488	778	0.15	100
Machine operator – Body line 1	1	485	774	0.19	100
Machine operator – Cover line 1	1	754	1,195	[0.044]	56
Forklift driver	1	518	821	0.16	94
Assembly operator – Cummins line	1	524	830	0.24	100
Assembly operator – Navistar line	1	522	828	[0.075]	95
Team lead	1	501	796	[0.028]	100
Machine operator – Body line 2	2	513	817	0.13	100
Machine operator – Cover line 2	2	512	815	[0.064]	100
Machine operator – Body line 1	2	446	713	0.34	100
Forklift driver	2	586	924	0.10	64
Assembly operator – Cummins line	2	586	930	0.26	97
Assembly operator – Cummins line	2	583	928	[0.067]	95
Team lead	2	433	687	[0.11]	100
NIOSH REL				0.4	—

[ ] = Result fell between the minimum detectable concentration and the minimum quantifiable concentration (0.09 mg/m³ based on an average sample volume of 797 L), and has more uncertainty associated with it.

Appendix D: Contact Dermatitis

Contact dermatitis makes up 90% to 95% of all occupational skin diseases [Ingber and Merims 2004; Lushniak 2004]. Contact dermatitis, both irritant and allergic, is an inflammatory skin condition caused by skin contact with agents such as chemical irritants (irritant contact dermatitis) or allergens (allergic contact dermatitis). Irritant contact dermatitis is skin inflammation due to direct cell damage from a chemical or physical agent, while allergic contact dermatitis is a delayed immune reaction. Over 57,000 chemicals are reported to cause skin irritation, but only 3,700 chemicals are known skin allergens [Belsito 2005]. Usually, only a small percentage of people are susceptible to skin allergens.

In contact dermatitis, the skin initially turns red and can develop bumps and small, oozing blisters. After several days, crusts and scales form. Stinging, burning, and itching often occur. With no further contact with the agent, the dermatitis usually disappears in 1 to 3 weeks. With chronic exposure, deep fissures, scaling, and darkening of the skin can occur. Exposed areas of the skin, such as hands and forearms, have the greatest contact with irritants or allergens and are most commonly affected. Over 80% of occupational contact dermatitis involves the hands [Belsito 2005; Flyvholm et al. 2007; Warshaw et al. 2003]. If the agent gets on clothing, it can bring on dermatitis at areas of greatest contact, such as thighs, upper back, armpits, and feet. Dusts can produce dermatitis at areas where the dust accumulates and is held in contact with the skin, such as under the collar and belt line, at the tops of socks or shoes, and in skin creases, such as inside elbows and behind knees. Mists can produce dermatitis on the face and neck. Irritants and allergens can be transferred to distant areas of the body, such as the trunk or genitalia, by unwashed hands or from areas of accumulation, such as under rings or in finger webs.

It is often impossible to clinically distinguish irritant contact from allergic contact dermatitis, as both can have a similar appearance and both can result in an acute, subacute, or chronic condition. Irritant contact dermatitis can be caused by many factors. The most common skin irritant at work is wet work, defined as exposure of skin to liquid for more than 2 hours per day, use of occlusive gloves for more than 2 hours per day, or frequent hand washing [Chew and Maibach 2003; Slodownik et al. 2008]. Other common causes of irritant contact dermatitis include soaps and detergents, solvents, food products, cleaning agents, plastics and resins, petroleum products and lubricants, metals, and machine oils and coolants [Chew and Maibach 2003; Slodownik et al. 2008]. Frictional irritant contact dermatitis can be caused by low humidity, heat, paper, tools, metals, fabrics, plastics, fibrous glass and other particulate dusts, and cardboard, among other causes [McMullen and Gawkrodger 2006; Morris-Jones et al. 2002]. Causes of allergic contact dermatitis include plants (e.g., poison ivy), metallic salts, germicides, plastic resins, rubber additives, and fragrances [Mathias 1990]. In patients with occupational contact dermatitis who were skin-patch tested, the most common relevant allergens included thiuram mix, carba mix, bacitracin, methyldibromo glutaronitrile/phenoxyethanol, formaldehyde, glutaraldehyde, methylmethacrylate, nickel, cobalt, and chromium [Warshaw et al. 2007, 2008].

Studies on the prognosis of occupational contact dermatitis stress the importance of primary prevention. One study found that 32% of 124 surveyed patients had severe hand dermatitis 5 years after they were initially diagnosed with irritant hand dermatitis. Severity was measured by self-reported frequency of relapses, frequency of dermatologist visits, and use of topical corticosteroids [Jungbauer et al. 2004]. Another study found that 25% of 540 surveyed patients had persistently severe or aggravated symptoms 1 year after initial diagnosis of occupational hand dermatitis. Poor prognosis was associated with the presence of atopic dermatitis and being 25 years of age or older. Prognosis was not affected by whether the dermatitis was irritant or allergic. Those with severe occupational hand dermatitis at baseline had a higher risk of taking sick leave and job loss in the following year than those with mild cases. The study found no significant improvement in the disease after the change of job [Cvetkovski et al. 2006]. Widespread hand dermatitis on initial examination was found to be the greatest factor for a poor long-term prognosis in a third study [Meding et al. 2005]. In addition, many skin disorders, including contact dermatitis, have been shown to have a significant impact on quality of life [Cvetkovski et al. 2005; Fowler et al. 2006; Kadyk et al. 2003; Lan et al. 2008].

Prevention of Contact Dermatitis

Avoiding irritants and allergens, in addition to wet work, is the first step in dermatitis prevention. Liberal use of skin moisturizers helps to prevent contact dermatitis by maintaining a healthy skin barrier, and also helps to repair this barrier if it has been compromised [Chew and Maibach 2003]. The following list provides strategies in the prevention of occupational contact dermatitis:

- Identifying irritants and allergens
- Substituting chemicals that are less irritating or allergenic
- Establishing engineering controls to reduce exposure
- Emphasizing personal and occupational hygiene
- Establishing educational programs to increase awareness in the workplace
- Using PPE, such as gloves and special clothing [NIOSH 1988]

Chemical changes in industrial materials have been beneficial. For example, the addition of ferrous sulfate to cement to reduce the hexavalent chromium content has been effective in reducing occupational allergic contact dermatitis in Europe [Goh and Gan 1996]. Avoiding the use of formaldehyde-releasing biocides in MWF will likely reduce contact dermatitis among machinists [Aalto-Korte et al. 2008]. Protective gloves can reduce or eliminate skin exposure to hazardous substances if used correctly but may actually cause or worsen hand dermatitis (by permeation and penetration) if selected poorly and used improperly (by contamination) [Foo et al. 2006]. The use of PPE may occlude irritants or allergens next to the skin, and PPE components may directly irritate the skin. Therefore, the correct use of PPE is at least as important as the correct selection of materials [Kwon et al. 2006]. Similarly, the excessive pursuit of personal hygiene in the workplace may actually lead to misuse of soaps and detergents and cause irritant contact dermatitis. Proper hand washing methods and adequate moisturizing are valuable in preventing contact dermatitis [Warshaw 2003]. The effectiveness of barrier creams is controversial because data on the protective nature of these topical products during actual working conditions involving high-risk exposures are limited. Educating the workforce about skin care, exposures, and PPE use is an especially important measure in the prevention of occupational contact dermatitis [Loffler et al. 2006; Schwanitz et al. 2003; Weisshaar et al. 2006]. The following list provides tips on proper hand washing [Warshaw et al. 2003]:

- Avoid hot water; use lukewarm or cool water instead.
- Use mild cleansers without perfume, coloring, or antibacterial agents.
- Pat hands dry, especially between fingers.
- Apply skin moisturizer generously after hand washing and repeat throughout the day.
- Avoid rubbing, scrubbing, the use of washcloths, and the overuse of soap and water.

This additional list provides tips for the workplace [Warshaw et al. 2003]:

- Remove rings before work.
- Wear protective gloves in cold weather and for dusty work.
- Wear tight-fitting leather gloves for frictional exposures.
- When performing wet work, wear cotton gloves under vinyl or other nonlatex gloves.
- Avoid immersing hands; use running water if possible.

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Keywords: North American Industry Classification System 333618 (Other Engine Equipment Manufacturing), Indiana, Metalworking fluid, MWF, triazine, formaldehyde, endotoxin, respiratory, dermatitis, cast iron, video exposure monitoring

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Acknowledgments

Analytical Support: Bureau Veritas North America and Microbiology Specialists Inc.
Desktop Publisher: Shawna Watts
Editor: Ellen Galloway
Industrial Hygiene Field Assistance: Aalok Oza, Wei Gong, Alia El Burai Felix
Logistics: Donnie Booher, Kevin Moore

Availability of Report

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Recommended citation for this report:

NIOSH [2016]. Investigation of dermal and respiratory exposures to metalworking fluids at an automotive parts manufacturer. By Harney JM, Tapp L. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH Health Hazard Evaluation Report 2013-0075-3264, http://www.cdc.gov/niosh/hhe/reports/pdfs/2013-0075-3264.pdf.

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