Evaluation of Employees' Exposures to Welding Fumes and Powder Paint Dust During Metal Furniture Manufacturing

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The employer shall post a copy of this report for a period of 30 calendar days at or near the workplace(s) of affected employees. The employer shall take steps to insure that the posted determinations are not altered, defaced, or covered by other material during such period. [37 FR 23640, November 7, 1972, as amended at 45 FR 2653, January 14, 1980].

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Abbreviations

μg/m^3	Micrograms per cubic meter
μm	Micrometer
ACGIH®	American Conference of Governmental Industrial Hygienists
AL	Action level
CBT	Core body temperature
CFR	Code of Federal Regulations
CO	Carbon monoxide
DB	Dry bulb
dB	Decibels
dBA	Decibels, A-scale
fpm	Feet per minute
°F	Degrees Fahrenheit
GA	General area
GT	Globe temperature
HHE	Health hazard evaluation
HL	Hearing loss
Hz	Hertz
IgE	Immunoglobulin E
Kcal	Kilocalorie
Lpm	Liters per minute
MDC	Minimum detectable concentration
mg/m^3	Milligrams per cubic meter
MIG	Metal inert gas
mL	Milliliter
mm	Millimeter
MSDS	Material safety data sheet
NAICS	North American Industry Classification System
NIOSH	National Institute for Occupational Safety and Health
NO_2	Nitrogen dioxide
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PBZ	Personal breathing-zone
PEF	Peak expiratory flow
PEL	Permissible exposure limit
PEL-C	Permissible exposure limit as a ceiling limit
PPE	Personal protective equipment
ppm	Parts per million
psi	Pounds per square inch
REL	Recommended exposure limit

Abbreviations (continued)

REL-C	Recommended exposure limit as a ceiling limit
RH	Relative humidity
SEM	Scanning electron microscopy
SEIU	Service Employees International Union
STEL	Short-term exposure limit
STS	Standard threshold shift
TiO_2	Titanium dioxide
TEM	Transmission electron microscopy
TGIC	1,3,5-triglycidyl isocyanurate
TLV®	Threshold limit value
TWA	Time-weighted average
WB	Wet bulb temperature
WBGT	Wet bulb globe temperature
WEEL	Workplace environmental exposure level
WHO	World Health Organization

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a confidential employee request for a health hazard evaluation (HHE) at Dehler Manufacturing, Inc., Chicago, Illinois. The requestors submitted the HHE request because they were concerned about workplace exposures to welding fumes and powder paint dust. NIOSH investigators conducted an evaluation during June 28–29, and September 17–21, 2007.

What NIOSH Did

- We sampled welders' exposures to metals, carbon monoxide, and nitrogen dioxide.
- We sampled painters' exposures to 1,3,5-triglycidyl isocyanurate, titanium dioxide, and respirable and total dust.
- We interviewed nine painters and gave them peak flow meters to determine whether their breathing was affected before and after painting.
- We measured heat stress in the paint room.
- We measured noise levels throughout the plant.
- We took bulk samples of powder paint and sent them to a laboratory to determine the size of the paint particles. We did this to see if the particles were small enough to be inhaled into the lungs. The laboratory also checked the samples for asbestos, silica, and talc content.
- We checked airflow on the paint booth and a fume extractor.
- We watched employees' work practices and use of personal protective equipment.

What NIOSH Found

- Some welders were exposed to manganese and carbon monoxide above recommended levels.
- Some painters were exposed to 1,3,5-triglycidyl isocyanurate, and respirable and total dust above recommended limits.
- Two painters had changes in their breathing tests which may suggest asthma due to exposure to paints.
- Painters did not wear protective clothing because it was too hot.
- Some employees had not been fit tested for respirators and were not wearing them properly.
- Bulk samples of powder paint did not contain silica or asbestos.
- Powder paint had small particles which could reach deep into the lungs.
- Noise levels sometimes exceeded the recommended limit.
- Some employees did not wear hearing protection properly or did not wear it at all.
- Some employees do heavy lifting while in awkward postures. This increases their risk for musculoskeletal injury.
- Muscle strains and cuts were common injuries.

What Managers Can Do

- Use powder paints that do not contain 1,3,5-triglycidyl isocyanurate.
- Use welding wire that does not contain manganese.
- Install doors on the powder paint booth openings to improve dust capture.
- Install exhaust fans in the paint room to remove hot air, and in the welding area to remove fumes.
- Provide painters with powered air purifying respirators with loose fitting hoods.
- Start a respiratory protection program that meets the requirements of the Occupational Safety and Health Administration.
- Provide training on the use of hearing protection. Make sure it is worn correctly after training.
- Offer training about the symptoms of respiratory and skin sensitization caused by 1,3,5-triglycidyl isocyanurate.
- Provide prompt medical follow-up to those who report respiratory symptoms.
- Look at how employees lift parts from the conveyor at the end of the welding process to see how to make it easier.
- Provide supervisors and employees' training so they can identify unsafe work practices, and early warning signs of musculoskeletal disorders.

What Employees Can Do

- Do not place your head in the smoke plume when welding.
- Keep your helmet visor down until workers nearby finish welding.
- Wear respirators properly.
- Wear hearing protection properly.
- Cover your skin and hands when painting.
- Tell your supervisor about any work-related health problems.
- Follow up with your doctor about any work-related health problems.
- Avoid heavy lifting. Where possible, use mechanical lifts or two person lift teams.
- Use a vacuum to remove powder paint from clothes instead of compressed air.

Summary

NIOSH investigators were asked to evaluate welding, powder painting, and grinding operations. We found that some MIG welders were overexposed to manganese and carbon monoxide, and some painters were overexposed to TGIC, respirable dust, and total dust. Although no painter reported work-related respiratory diseases or symptoms, two painters had screening peak flow readings that may suggest asthma; further evaluation was recommended. We recommend using powder paint without TGIC and welding wire without manganese, providing painters with respirators with a higher protection factor, adding additional ventilation in the welding area, sealing unused doorways on the paint booth, and further evaluating noise exposures and muscle strain injuries.

On April 6, 2007, NIOSH received a confidential employee request for an HHE at Dehler Manufacturing, Inc., (Dehler) in Chicago, Illinois. Employees were concerned about exposure to welding fumes and dust from powder painting and grinding operations. During our initial site visit on June 28–29, 2007, we met with management and employee representatives; toured the facility; observed work processes, use of PPE, and existing engineering controls; and interviewed 10 employees. We collected bulk samples of powder paint for particle sizing and to check for silica and asbestos content.

Two of the 10 employees we interviewed reported symptoms we determined were not related to exposures in the workplace. They described episodic transient shortness of breath that lasted a few minutes and also affected members of their families who were not Dehler employees. Their condition did not improve when they were away from work. Two other employees reported eye and throat irritation. The remaining six employees reported no symptoms. Although the bulk powder paint samples did not contain silica or asbestos, we decided a return survey was needed to evaluate exposures to welding fumes, powder paint, noise, and heat stress.

During the follow-up evaluation on September 18–20, 2007, we collected PBZ air samples for carbon monoxide and nitrogen dioxide on welders, and for elements (metals) on welders and grinders. We also collected PBZ samples for carbon monoxide on two grinders. For the painters, we collected PBZ air samples for TGIC, respirable dust, and total dust. We measured the face velocity on door openings to the paint booth, the capture velocity on a welding fume extractor, and noise levels throughout the facility. We also evaluated heat stress in the paint room. We interviewed the nine painters who were available and provided them with self-recording PEF meters. We were interested in knowing if the painters' breathing was affected by TGIC in powder paint. These meters provide an indication of airway obstruction.

Of the 38 PBZ samples for elements collected on MIG welders, seven exceeded the ACGIH TLV of 200 μg/m^3 for manganese, and an additional eight samples were at least at half of the TLV. Concentrations of the remaining elements in the welding fumes were below applicable OELs. Of the 16 PBZ air samples for carbon monoxide collected on welders, four exceeded the NIOSH ceiling limit of 200 ppm. Despite painting for only 80 to 300 minutes, four of eight painters were exposed to TGIC above the ACGIH 8-hour TLV-TWA of 0.05 mg/m^3. One painter's exposure to TGIC exceeded the protection factor of the filtering facepiece respirator he was wearing. Had employees applied paint containing TGIC for 8 hours or longer at the same application rate (as is commonly done for a larger work order), at least six of the eight painters would have been overexposed to TGIC. Two of 15 PBZ air samples for respirable dust collected on painters exceeded the OSHA 8-hour PEL-TWA of 5 mg/m^3, and 7 of 13 PBZ air samples for total dust exceeded the OSHA 8-hour PEL-TWA of 15 mg/m^3. Talc was not detected in the respirable dust air samples collected on painters. The WBGT in the paint room did not exceed NIOSH recommended heat stress exposure limits, but at times the dry bulb temperature in the paint room exceeded 100°F. On the day of our evaluation, the outdoor temperature was 77°F, so it is possible that on warmer days the NIOSH RELs may be exceeded because the production area is not air-conditioned. Noise levels exceeded 85 dBA during grinding, welding, and painting, and at most presses occasionally exceeded 90 dBA. Hearing protection was required in the press area, but some employees were observed not wearing it, or wearing ear plugs that were not properly inserted.

Two of the nine painters interviewed had PEF readings with a variability of 20% or more, which may suggest asthma. One of the two painters reported having symptoms of shortness of breath, which predated employment at Dehler, and had reportedly not worsened since employment. Because these employees only had Sundays off during the period of the PEF recordings, we are unable to determine if the PEF rates would have improved while away from work. A single day away from work is not sufficient to observe such changes if present. We are therefore unable to make a determination on work-relatedness of this finding.

Our evaluation did not identify any painter who had definitive work-related respiratory disease or symptoms. However, we recommended to the two painters with increased variability of their daily peak flow readings that they consult their physician for further evaluation to determine if their bronchial hyperresponsiveness was related to workplace exposures. We also recommend that management take steps to prevent employee sensitization to TGIC. We recommend using powder paints that do not contain TGIC and welding wire that does not contain manganese. The paint booth should be further enclosed to better contain the powder paint, and the painters should be provided with a higher level of respiratory protection until exposures can be reduced through engineering or administrative controls. Painters should avoid skin contact with powder paint that contains TGIC because it is also a skin sensitizer and can cause allergic contact dermatitis and asthma. Management should inform employees about the risks of working with TGIC.

We recommend installing spot cooling fans and exhaust fans in the paint booth room to control heat stress, and exhaust fans in the welding area to remove welding fumes. We recommend that management conduct noise monitoring to determine employees' full-shift TWA noise exposures, and ensure employees wear hearing protection properly while in designated hazardous noise areas. We also recommend that an ergonomics consultant be hired to assess work tasks and provide recommendations for reducing the number of ergonomic injuries.

Keywords: NAICS 337124 (Metal Household Furniture Manufacturing), welding, manganese, powder paint, total dust, respirable dust, TGIC, TiO_2, smoke, paint, noise

Introduction

On April 6, 2007, NIOSH received a confidential employee request for an HHE at Dehler Manufacturing, Inc., (Dehler) in Chicago, Illinois. The requestors were concerned about exposure to welding fumes and dust from powder painting and grinding operations. Reported symptoms included respiratory problems, excessive tiredness, and accumulation of dust in the nasal passages by the end of the work shift. During June 28–29, 2007, we visited the Dehler facility to become more familiar with the operation and to look at areas of concern. On September 18, 2007, we returned to the facility to collect air samples and evaluate existing engineering controls and use of PPE. On October 22, 2007, we sent Dehler a letter summarizing our activities during our second site visit and provided some preliminary recommendations. The letter was translated into Spanish and the requestors were provided a copy of the letter.

Dehler has approximately 146 employees manufacturing metal furniture in a 110,000 square foot facility. The facility has 133 employees on first shift, 10 on second shift, and 3 on third shift. Most were members of SEIU Local 1 and the primary language for 138 employees was Spanish. Dehler has a safety committee that meets every 3 months; the meetings are attended by representatives of the local union.

Process Description

Dehler manufactures metal furniture by cutting, bending, and welding sheet metal in an assembly line fashion to form end tables, lockers, and beds. Most of the punch presses were enclosed by guards and had safeguard controls so the machines could not be activated while the operators' hands were in the pinch point. After the parts were bent to the desired shape, the corners were spot welded. Parts that could not be joined using a spot welder were MIG welded by tacking the corners so total welding time per part was minimal. Some parts, such as bed frames, were made by cutting metal tubing with a saw and welding the pieces together. With the exception of one fume extractor used while welding bed frames, general dilution ventilation was used to reduce exposures to welding fumes.

Once the parts were welded, other employees used hand-held grinders to smooth the welds and remove sharp edges. The parts were then hung on an overhead conveyor, which traveled through a degreasing booth where the parts were rinsed with phosphoric acid. As the parts exited the booth, an employee manually cleaned missed areas with a rag dipped in toluene. The parts continued on the conveyor through the powder paint spray booth, a curing oven, and then to the packing area.

At the time of this evaluation 14 MIG welders and 13 spot welders worked at Dehler. The MIG welders were using Millermatic

212 or 250 welders with ER 70S-6 welding wire that contained 1.4%–1.8% manganese by weight. We were provided with an MSDS for aluminum welding wires and rods which listed the manganese content as 0.01%–5.50% by weight depending on the specific product. The welders were wearing EQC Jackson welding hoods with a #10 shade lens. They wore leather gloves, a cloth apron, cloth sleeves, and safety shoes. Some welders also wore N95 filtering facepiece respirators on a voluntary basis.

The powder paint booth had permanently mounted spray guns that sprayed the parts as they passed by on the conveyor. The rectangular paint booth had three openings on the front and three on the back where painters could stand to spray areas that the spray guns missed (see Figure 1).

Figure 1. Powder paint spray booth

Painters were applying Sherwin-Williams Powdura® or Americoat Corp. powder paint to the furniture parts. According to the MSDSs, most of the paints contained talc, calcium carbonate, and TiO_2, while the dark color paints also contained TGIC. Powder paint does not contain a solvent. Instead, it is applied by imparting an electrostatic charge to the paint particles while grounding the part being painted, so that the paint particles are attracted to the part. According to several powder paint manufacturers, this requires that the paint particle diameters fall within a range of 10 to 100 µm for effective application. The powder paint is placed in a fluidized bed feed hopper where the particles are agitated so that they remain continuously suspended to prevent bonding and clogging of the spray gun. A pump pulls the powder from the feed hopper through a hose and delivers it to the paint gun. At Dehler, painters use Wagner PEM-C2 Airmatic sprayguns for applying the powder paint. A charge is applied to the part being painted and to an electrode on the gun tip [Wagner 1996]. The electrode generates an electric field that applies a negative charge to the paint particles causing the particles to repel each other as they deposit on the grounded surface. Some particles that miss the parts

Introduction (continued)

remain trapped in the electric field and deposit on the back side of the parts, but a great deal of paint overspray settles on the paint booth floor and on the walls. Painters enter the paint booth and remove the paint from the walls and the floor with a squeegee. The painted parts continue on the conveyor to a gas oven for curing at an approximate temperature of 400°F. From the oven, the parts move on the conveyor to the packing and shipping department.

Dehler had 15 painters at the time of this evaluation. The painters were wearing Safety Zone RS-900-N95 filtering facepiece respirators (NIOSH approval TC 84A-3323). One painter wore a bandanna over his mouth and nose instead of a respirator. Some painters wore removable sleeves while others only wore T-shirts with no sleeves.

Assessment

During our initial site evaluation on June 28–29, 2007, we reviewed the OSHA 300 Log of Work Related Injuries and Illnesses and MSDSs. We toured the Dehler facility and observed work processes, PPE use, and existing engineering controls. We collected bulk samples of powder paint and submitted them for laboratory analysis to determine if talc, listed as an ingredient in the MSDSs, contained silica or asbestos. We also requested particle sizing of the powdered paint. We randomly selected 10 employees from a list of employees provided by management and interviewed them in a private setting.

During September 18–20, 2007, we collected 38 PBZ air samples for elements on MIG welders, 9 on spot welders, and 13 on grinders. We placed Biosystems Toxi Ultra (Biosystems Inc., Middletown, Connecticut) data logging instruments on welders in their PBZ to measure CO from the welding fumes. We also measured the air concentration of NO_2 in the welders' PBZ using direct reading Drager Safety (Drager Safety, Luebeck, Germany) NO_2 colorimetric detector tubes and a Drager Accuro® bellows pump. We collected 12 PBZ air samples for TGIC on painters, 17 for respirable dust, and 14 for total dust. Sampling methods are discussed in Appendix A.

We used an air velocity meter to measure the face velocity at door openings to the paint booth and the capture velocity on a fume extractor. We used an integrating sound level meter to measure noise levels throughout the facility. We also placed an instrument in the paint room to record the WBGT. The WBGT provides an indication of the major environmental factors that contribute to heat stress: air temperature, air movement, humidity, and radiated heat [NIOSH 1986]. Other factors contributing to an employee's heat load include work rate and the type of clothing. Information on the methods for determining the WBGT is provided in

Appendix A, while Appendix B provides more information on heat stress.

On September 20, 2007, we interviewed all nine painters who were available during the period of our site visit. After coaching and demonstrating to them how to use PEF meters (a device that provides an indication of airway obstruction), we provided them with self-recording PEF meters to measure their peak flows pre- and post-shift for 14 consecutive days. We requested that they take three measurements for each attempt. The PEF meters were programmed to record only the highest reading for each attempt.

RESULTS

Detailed sample results for elements, CO, TGIC, respirable dust and TiO_2, total dust, and noise are provided in Tables C1–C6 in Appendix C.

Welding

With the exception of manganese, the concentrations of elements in air samples collected in the welders' PBZ were below applicable OELs. Manganese concentrations for 7 of the 38 samples collected on MIG welders exceeded the ACGIH TLV and an additional 8 samples were at least at one half the TLV. None of the spot welders' exposures exceeded the TLV for manganese. The results for PBZ samples collected on spot welders were approximately 20 times lower than the ACGIH TLV for manganese. A summary of the air sampling results for manganese, copper, and iron, which were the more prevalent elements detected, is provided in Table 1.

Table 1. Air sampling results for metals in welding fumes

Job Title	Sample Date	# Samples	Mean (Min-Max) Concentration (µg/m³)		
			Copper	Iron	Manganese
MIG Welder	9/18/2007	12	6.7 (2.1−15)	890 (350-1830)	66 (2.8−230)*
	9/19/2007	13	9.8 (1.8−24)	660 (170−1400)	100 (16−250)†
	9/20/2007	13	10.8 (2.7−26)	722 (180−1370	116 (22−270)‡
Spot Welder	9/18/2007	4	ND§	39 (34−46)	1.6 (0.81−2.2)
	9/19/2007	2	1.6 (1.3−1.8)	115 (110−120)	4.3 (4.2−4.4)
	9/20/2007	3	1.6 (0.91−1.8)	135 (129−140)	8.5 (8.3−8.7)
OSHA PEL-TWA			100	10000	5000
NIOSH REL-TWA			100	5000	1000
ACGIH TLV-TWA			200	5000	200

* Levels for two of the 12 MIG welders exceeded the TLV for manganese on this day.
† Levels for three of the 13 MIG welders exceeded the TLV for manganese on this day.
‡ Levels for two of the 13 MIG welders exceeded the TLV for manganese on this day.
§ ND = less than the MDC of 0.36 µg/m³.

NO_2 was not detected in air samples collected in welders' PBZ using Draeger colorimetric detector tubes. Carbon monoxide concentrations exceeded the NIOSH ceiling limit of 200 ppm for 4 of the 16 samples collected on welders. The CO concentration for one of the MIG welders was more than 2.5 times greater than the NIOSH ceiling limit. Eight- to 10-hour TWA concentrations for CO did not exceed applicable OELs.

Painting

A summary of the air sampling results for samples collected on painters is provided in Table 2. On the date employees used paint containing TGIC, three out of eight painters were exposed to airborne concentrations of TGIC above the ACGIH 8-hour TLV-TWA during a 5-hour period, and one employee was exposed above the 8-hour TLV-TWA during an 80-minute period. Had these employees applied paint containing TGIC for eight hours or longer using the same technique, TGIC exposures for six of the eight employees would have exceeded the TLV. Of the 17 PBZ air samples for respirable dust, 2 were above the OSHA 8-hour PEL-TWA of 5 mg/m^3. Seven of the fourteen PBZ air samples for total dust exceeded the OSHA 8-hour PEL-TWA of 15 mg/m^3. All talc measurements fell below the MDC of 26 $\mu g/m^3$ in the respirable dust air samples collected on painters. We collected 7 PBZ and 2 GA samples for TiO_2 on painters. The sample results for TiO_2 did not exceed the OSHA 8-hour PEL-TWA of 5 mg/m^3. Some sample results may have exceeded the NIOSH proposed RELs of 0.1 mg/m^3 for ultrafine TiO_2 and 1.5 mg/m^3 for fine TiO_2; however, we cannot ascertain from the sample results what mass of particulates was fine or ultrafine. NIOSH currently does not have an REL for TiO_2 but classifies it as a potential occupational carcinogen based on observation of lung tumors in a chronic inhalation study of rats exposed to 250 mg/m^3 of fine TiO_2 [NIOSH 2005].

Table 2. Summary of PBZ air samples collected on painters

Analyte	# of Samples	Concentration (mg/m^3) Min	Max	Mean	OEL (mg/m^3) 8-hour TWA	# > OEL
TGIC*	8	0.002	0.89	0.19	TLV = 0.05	4
Respirable Dust	17	ND†	8.4	2.3	PEL = 5	2
Total Dust	14	0.80	130	26	PEL = 15	7
TiO_2‡	9	0.01	1.0	0.30	PEL = 5§	0
Talc¶	8	ND	ND	ND	REL = 2	0

* Sample times ranged from 67−161 minutes. The concentration reflects zero TGIC exposure for the remainder of the employee's shift averaged into the 8-hour TWA.
† ND = Not detected.
‡ Nine of the 17 respirable dust samples were also analyzed for TiO_2.
§ OSHA PEL is for respirable dust. The NIOSH REL is the lowest feasible concentration.
¶ Eight of the 17 respirable dust samples were also analyzed for talc.

Respirators

Painters, the only employees at Dehler required to wear respirators, wore N95 filtering facepiece respirators during this evaluation.

One painter's 8-hour TWA exposure to TGIC exceeded the protection factor of the filtering facepiece respirator he was wearing. Grinders and some welders were wearing N95 respirators on a voluntary basis. None of the employees had been fit tested. Most of the employees were not wearing the respirators properly. NIOSH investigators observed employees with facial hair and respirator straps not properly placed over the crown of the head, missing straps, and nose clips not molded around the nose. Additionally, respirators were not always stored properly after use. Dehler did not have a written respiratory protection program.

Bulk Samples

Neither silica nor asbestos was found in the four bulk samples of Sherwin-Williams Powdura paint we submitted for analysis. The MSDSs for the powder paints listed the main ingredients as talc, calcium carbonate, and TiO_2. Other ingredients in some paints included chromium oxide, barium sulfate, carbon black, nitrolotriacetic acid, and inorganic cobalt, and the percentages of these compounds varied by paint type. Dark color paints (green, blue, black) contained TGIC, a potential sensitizer. One of the four bulk samples did not contain TiO_2 but did contain 85% barium by weight.

We were informed by the Sherwin-Williams technical department that the median paint particle diameter was 50 μm. Our analysis of the bulk samples revealed that more than 90% of the paint particles in the four bulk samples were in the 0.1 to 2.5 μm diameter size range. This apparent particle size difference is likely the result of how the powder paint was analyzed. In this evaluation we used TEM, but we subsequently learned that this analysis is biased towards smaller particles because fewer of the larger particles are seen on a TEM grid (see Figure 2). According to Sherwin-Williams, powder paint particle sizing is generally done by light scattering to avoid the small particle sizing bias. We did use a handheld light-scattering ART Instruments, Inc., Met One HHPC-6 air particle counter to characterize particles in the painters' breathing zone which indicated that approximately 90% of the particles were less than 1.0 μm in diameter. This may be attributed to the fact that the painters were standing outside the paint booth, and the larger particles settled before they reached their breathing zone. The instrument counts particles in six size ranges (0.3, 0.5, 1.0, 3.0, 5.0, and >10 μm). When the particle counter was placed in the paint cloud inside the paint booth a larger number of particles >10 μm in size were detected because the particles were suspended by the inertia provided by the spray gun and the electrostatic forces. Additionally, 2 of the 17 respirable dust samples exceeded the OSHA PEL-TWA and 6 of 17 exceeded the ACGIH TLV-TWA, suggesting that the powder paint contained a large fraction of respirable particulates.

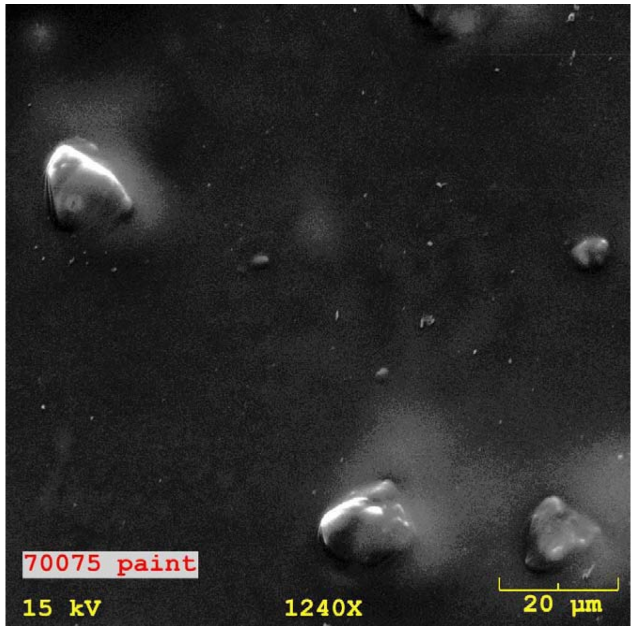

Figure 2. Paint particles under electron microscope

Employee Interviews

During our initial site visit on June 28–29, 2007, we privately interviewed 10 employees whom we randomly selected from a list of employees provided by management. These employees had worked for the company an average of 7 years (range 6 months to 20 years). Two of the employees reported episodic shortness of breath that lasted a few minutes and also affected members of their families who were not Dehler employees. Their symptoms did not improve while away from work. Two other employees reported eye and throat irritation.

All nine of the painters interviewed on September 20, 2007, were men. They had been working at Dehler for an average of 1 year and 9 months (range 2 months to 7 years). The average time they had worked as painters at Dehler was 9 months (range 2 months to 3 years). Three of the employees reported eye irritation. Other symptoms reported were excessive sneezing due to paint dust and shortness of breath that predated work at the plant and was not worsened by employment at the plant. None of the employees interviewed had been diagnosed with asthma.

Two of the nine painters had PEF readings with variability of 20% or more, which may suggest asthma. Only one of these two employees reported being symptomatic with shortness of breath that predated his employment at Dehler and had reportedly not worsened since then. We were not able to determine if the PEF rates would have improved while employees were away from work, because the employees only had Sundays off during the period of the recordings, and one day away from work was not sufficient time to observe such changes.

Ventilation

We measured the capture velocity of a Sentry Air fume extraction hood (see Figure 3) using a TSI VelociCalc® air velocity meter (TSI Incorporated, Shoreview, Minnesota). The fume extractor had a 6-inch diameter flexible duct that was 64 inches long. Smoke released 12 inches in front of the hood was captured with the fume extractor air flow set at high and at 6 inches on the low setting. At 12 inches in front of the hood the air velocity ranged from 24 to 34 fpm. At 6 inches the air velocity ranged from 137 to 170 fpm. The fume extractor can be effective at capturing welding fumes if placed within 6–12 inches from the point of contaminant generation. When more than one spot was welded, as with the bed frames, the fume extractor was ineffective because the areas previously welded were still releasing smoke as a result of heating of the oil coating.

Figure 3. Welder using fume extractor.

The rectangular paint booth had three doorways on each of the longer sides and openings on each end for the conveyor to transport parts (see Figure 4). The doorways were 3 feet wide and 5.5–6 feet high. Painters stood on platforms at the doorways (see Figure 1) and used paint spray guns to touch up parts as they passed by on a conveyor using paint spray guns. Generally two or three painters performed this task. Table 3 lists the average airflow across each doorway of the paint booth. Airflow through the doorways ranged from 20–106 fpm. While not illustrated in Figure 4, the area above door 8 was not enclosed resulting in lower airflow. Only 3 painters were painting parts as they passed by on the conveyor so 3 doorways could be closed to increase airflow though the remaining doorways.

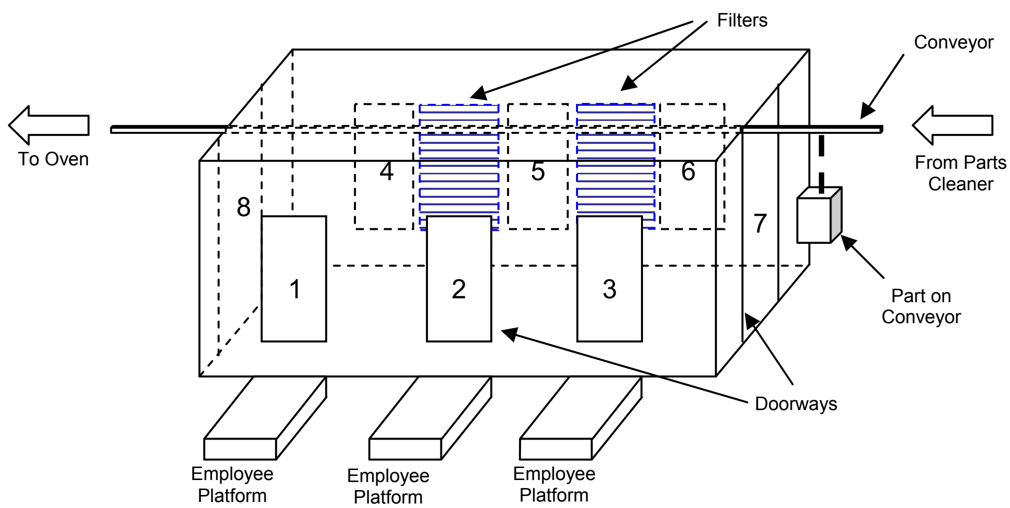

Figure 4. Paint booth

Table 3. Paint booth doorways airflow

Doorway	Average Air Flow (fpm)	Doorway	Average Air Flow (fpm)
1	81	5	91
2	59	6	78
3	62	7	106
4	65	8	20*

* This doorway was open on top resulting in an increase in entry loss and lower airflow.

In its book, *Industrial Ventilation: A Manual of Recommended Practice* [ACGIH 2007], ACGIH recommends a capture velocity range of 200–500 fpm for spray painting in shallow booths.

Heat Stress

The paint booth room was hot due to lack of ventilation, the heat generated by mechanical equipment, and its proximity to the oven. Temperature measurements with a TSI Q-Trak™ Indoor Air Quality Monitor (TSI Incorporated, Shoreview, Minnesota) ranged from 94°F to 103°F during the evaluation. On September 20, 2007, the outdoor temperature was 77°F while the temperature in the paint booth was 95°F. Although the paint room lacked exhaust fans, abandoned ducts in the ceiling of the paint room could be used to exhaust hot air if fans were installed.

Applying NIOSH criteria for heat stress, the metabolic heat rate for an employee standing doing light work with one arm would be 156 Kcal/hour. The average WBGT would need to exceed 88°F for the employees to require additional rest time during each one hour period worked. The average WBGT on the days of this evaluation exceeded neither the NIOSH RELs (see Table 4) nor ACGIH TLVs for acclimatized employees. If the employees were to wear a protective suit such as Tyvek®, a clothing adjustment factor would have to be added to the WBGT reading that would reduce the allowable exposure time.

Table 4. WBGT levels		
Date	Time	WBGT (Min−Max) °F
9/18/07	2:00 p.m.−5:30 p.m.	79.1−86.9
9/19/07	12:00 p.m.−4:00 p.m.	81.5−85.8
NIOSH REL for acclimatized employees doing light work 60 minutes/hour.		88
NIOSH REL for unacclimatized employees doing light work 60 minutes/hour.		84
ACGIH TLV-TWA for moderate work, 60 minutes/hour.		88.7
ACGIH TLV-AL for moderate work, 60 minutes/hour.		84.2

Noise

A summary of noise level measurement results for each work area is provided in Table 5. During production, noise levels exceeded 85 dBA for most of the presses, the MIG welders, the grinding areas, and the powder paint booth. Additionally, noise levels were sometimes greater than 90 dBA in the press and grinding areas. The highest noise level was measured at the KMT chop saw (96.5 dBA). Noise levels were less than 85 dBA at the spot welding and assembly areas and were less than 80 dBA at the spot cleaning and part loading workstations along the monorail conveyor.

Table 5. Summary of noise level measurements

Location	Noise Levels (dBA)	Location	Noise Levels (dBA)
CNC and shear presses	83.5 – 93.4	Spot welding	79.2 – 83.5
Press area	81.0 - 90.8	Powder paint booth	83.8 – 86.5
KMT chop saw	96.5	Monorail conveyor	72.4 – 75.1
Grinding	88.2 – 90.6	Final assembly	72.9 – 80.5
MIG welding	84.6 – 87.6		

Peak noise levels greater than 120 dBA occurred in the press areas as a result of metal-to-metal impacts, such as dropping parts into a bin or metal parts striking against press surfaces. During powder painting, peak levels up to 114.2 dBA occurred when the automated booth filter cleaning system periodically shook excess dust off the filters. This process produced a loud "bang" noise approximately every 10 to 60 seconds, depending on the filter location.

Musculoskeletal Disorders/Muscle Strain

A review of the OSHA 300 Log of Work-Related Injuries and Illnesses revealed that most recorded injuries were strains and sprains. During 2006, 14 of 37 recordable injuries were due to muscle strain. Of those 14 injuries, 7 were due to lower back strain.

Grinders reported three of the lower back strain cases. There were 26 recordable injuries in 2005 and 24 in 2004 with eight cases of muscle strain in 2005 and seven in 2004. These numbers reflect that 29% of recordable cases in 2004 were due to muscle strains, 31% in 2005, and 38% in 2006. There appears to be an upward trend over time in these types of musculoskeletal disorders. Grinders, assembly, and press brake employees were more likely to have musculoskeletal disorders. The OSHA Logs showed four cases of a foreign body in the eye in 2006, three in 2005, and four in 2004. Most of these cases were reported by grinders. Three cases of hand lacerations occurred in 2004, eight in 2005, and three in 2006.

Most stations, tables, and carts for the press brake and CNC machine employees were not adjustable. In most cases the height was too low requiring the employee to maintain awkward postures to hold material in the machines. For example, employees at the station shown in Figure 5 sat on a cooler to retrieve/straighten the material as it came out of the machine. This required employees to maintain bent postures while performing their work. Employees in these areas also expressed concerns about the carts not rolling well, especially when full of material.

Figure 5. Employees sit on a cooler to retrieve/straighten material.

Specially designed jigs were observed in different areas of the plant, especially in the assembly area. Some were at appropriate heights and some had the capability to allow the employee to move the piece (welding) and eliminate awkward postures. Some of the welders, however, did not use the maneuverability function of the tables.

At the end of the assembly line, grinders worked on the pieces before sending them to the paint department. One assembly line had a ramp that the employees could use to slide the piece down to the grinding table. The other assembly line did not have a ramp, requiring employees to lift large pieces from one table to another. After grinding, pieces were placed on pallets for transfer to the paint department. We observed some of the larger pieces stacked three high, requiring the employee to lift a heavy piece at or above shoulder level.

Other Observations

Safety hazards that we observed during our evaluation included the following:

- A fire extinguisher was covered by cardboard boxes. In the event of a fire employees may be delayed in responding if they are not aware the extinguisher is behind the boxes (see Figure 6).

Figure 6. Fire extinguisher blocked and hidden by boxes.

- An extension cord with exposed wiring posed an electrocution hazard (see Figure 7).

Figure 7. Damaged extension cord

Results (continued)

- Improperly adjusted hand restraints allowed employees to place their hands in the pinch points of powered presses while working (see Figure 8).

Figure 8. Wrist restraints with too much slack

- Compressed gas cylinders were not properly secured. These cylinders could fall and damage the valve, resulting in the rapid release of compressed air and the cylinder becoming an unguided projectile (see Figure 9).

Figure 9. Unsecured gas cylinders

- Employees used an uncovered 5-gallon bucket of solvent (toluene) for cleaning parts with a rag prior to painting (see Figure 10). Employees performing this task have a greater potential for solvent inhalation and skin exposure. A less hazardous cleaning chemical such as Stoddard solvent dispensed from a plunger can should be used (see Figure 11).

Figure 10. Open container of toluene

- Employees at the powder paint booth were using compressed air to clean excess powder paint dust off their clothing prior to breaks. This practice increases dust in the air and also increases the risk of eye injuries from particulates blown toward the face or skin injuries from compressed air injection.

Figure 11. A better solution for dispensing solvent is a plunger can

- Compressed air nozzles in the powder paint area were not equipped with diffuser nozzles that would reduce the air pressure to no more than 30 psi in case the nozzle tip became blocked or dead-ended [29 CFR 1910.242(b)].
- Many employees did not know who the safety manager was, what MSDSs were, or how to report a safety/health concern.
- Spray bottles that contained WD-40® did not have a label indicating the contents.
- Employees were wearing cotton gloves that may not prevent lacerations when handling sheet metal.

Discussion

Employees welding tubing were exposed to higher concentrations of welding fumes than employees welding sheet metal because the tubing was of a higher gauge and therefore required more time to weld. Total welding time on other parts was minimal because the task consisted of MIG welding corners or joining corners with a spot welder. With the exception of manganese, welders' exposures to elements were well below their respective OELs. Seven of the air sampling results for MIG welders exceeded the ACGIH 8-hour TLV-TWA for manganese of 0.2 mg/m^3. High exposure to manganese has been associated with Parkinson-like health effects such as poor hand-eye coordination, motor slowing, increased tremor, reduced response speed, mood disturbance, and possible memory and intellectual loss [Welch et al. 2004; Bowler et al. 2006; Antonini et al. 2006]. Until manganese exposures can be reduced, all MIG welders should wear respiratory protection. The N95 filtering facepiece respirators currently worn by some employees would provide adequate protection if properly fitted and worn. We observed an employee welding a rectangular bed frame who was not turning the rotary table but instead leaning over the bed frame to weld an opposite corner. In doing this he placed his breathing zone over a previously welded area that was still smoking. Had he rotated the table, the recently welded corner would have been at least 2 feet from his breathing zone (see Figure 12). Additionally, placing the fume extraction hood closer to the welding plume will improve the fume capture efficiency.

Figure 12. MIG welder leaning over previously welded area.

Some welders were concerned that the yellow transparent welding curtains provided inadequate eye protection. These curtains, if installed and used properly, provide adequate eye protection from potentially dangerous optical radiation. They also maximize the welder's visibility of work while allowing supervisors and coworkers to observe employees in the event of an accident or other medical emergency. An orange curtain is ideal for removing ultraviolet and blue light while maximizing visibility [Sliney et al. 1981, 1982]. Information on the performance of welding curtains is provided in Appendix B.

We observed two employees welding the same part with no welding curtain between them. If one welder removed his welding hood before the other welder finished welding his corner, he could be exposed to the welding flash (see Figure 13). Some of the parts welded were boxlike cabinets that required the welder to place his head inside the cabinet to weld. During this evaluation the high bay door and skylights were fully opened (a typical configuration during warm weather) providing additional dilution air in the building. However, during cold weather doors and skylights are kept closed, which may result in higher welding fume exposure. Although welders were wearing flame retardant cloth aprons and sleeves, some said they were injured by sparks that burned through the aprons and sleeves.

Figure 13. Two welders working on the same table without a welding curtain between them.

The corrosion-inhibiting coating on the sheet metal and other metal stock contained a chlorinated paraffin that can decompose at temperatures above 840°F, releasing hydrochloric acid [Strack

1986]. Temperatures for welding processes range from about 842°F for brazing to well above 27,000°F for plasma arc cutting [NIOSH 1988]. At these temperatures the chlorinated paraffins could release other degradation products, such as polychlorinated biphenyls, aliphatic and aromatic naphthalenes, and benzene [Bergman et al. 1984; WHO 1996]. Some employees mentioned that the welding fumes were irritating, which could be due to the breakdown of the chlorinated paraffins because NO_2 was not detected in the PBZ samples.

Of the 16 CO samples collected on welders, four had ceiling concentrations that were above the NIOSH REL-C of 200 ppm; for one, the concentration of CO was greater than 500 ppm. The REL-C is a value that should not be exceeded at any time. One spot welder was exposed above the REL-C on September 18, 2007, at 1:34 p.m., one MIG welder was overexposed on September 19, 2007, at 10:16 a.m., and two other MIG welders at 1:22 p.m. and 1:26 p.m. One possible explanation for the high CO levels is that employees were sitting outdoors during their lunch period or break and were exposed to engine exhaust from automobiles passing or idling nearby.

Painters were reluctant to wear additional skin protection because of the elevated temperatures in the paint room (see Figure 14). The paint room was about 20 feet from the oven. While the average WBGT measured during this evaluation indicated that acclimatized employees may be able to work 100% of the time without additional breaks, these measurements were obtained when the outdoor temperature was 77°F. On hotter days painters may be at greater risk of heat stress. In its documentation of TLVs [ACGIH 2008], ACGIH recommends using protective clothing to prevent skin contact with TGIC; however, the temperature in the paint room must be lowered through air conditioning or other means before employees can safely wear protective clothing.

We observed some painters stepping inside the paint booth to touch up areas of the parts that the mounted spray guns missed because they did not have enough time to do it as the parts passed their work station. It is possible that the conveyor was moving too fast for the employees, or the permanently mounted spray guns were not at the proper angle to properly cover the parts. If the guns had the capability to oscillate vertically and horizontally they may provide better coverage.

Although two of the painters we interviewed had respiratory symptoms, it did not appear that these symptoms were work related because they predated the painters' employment at Dehler. Their symptoms did not seem to be influenced by being at or away from work; other family members who did not work at Dehler had similar symptoms. In addition, one of the two employees reported

Figure 14. Painter with exposed arms

worsening of the shortness of breath when lying down. While the aforementioned reasons suggest that these symptoms may not be related to work at Dehler, they do not completely preclude contributions from workplace exposures. The PEF recordings identified two employees with increased variability, which may suggest bronchial hyperresponsiveness, a feature of asthma. The limitations of the PEF readings included inadequate number of trials by the employees and the lack of sufficient time away from exposure during recordings. These limitations preclude our ability to interpret the PEF findings as bronchial hyperresponsiveness, or the work relatedness of the observed variability in these two individuals. Because TGIC is a known sensitizer that has been reported to cause occupational asthma [Piirila et al. 1997], we strongly recommend that these two individuals follow up with their healthcare provider for appropriate diagnosis and treatment. These individuals have been notified of the results of their PEF and have been provided a copy of the readings.

The NIOSH REL and the OSHA AL for noise is 85 dBA, as an 8-hour TWA. OSHA also has a PEL for noise of 90 dBA. Noise measurements taken during this evaluation were of short duration and do not represent 8-hour TWAs. Because many of the noise levels we measured were greater than 85 dBA, employees who work in these areas could have TWA exposures that exceed the NIOSH REL. At the time of our site visit, only the employees in the press area were included in a hearing conservation program. However, employees grinding and MIG welding may also need to be in a hearing conservation program. Full-shift noise monitoring should be conducted to determine TWA exposures.

Several of the noise measurements indicated peak noise levels greater than 120 dBA. These high peaks were associated with metal-to-metal impact, such as dropping parts into a metal bin or metal striking against press surfaces as sheet metal parts were moved. Because of noise monitoring equipment limitations, the measured peak levels may underestimate the true peak noise [Kardous 2004]. Dehler may be able to reduce noise levels by using parts bins with thicker metal sides. Additionally, using two employees to move and carefully place sheet metal at presses could reduce impact noise.

Although Dehler requires hearing protection for employees in the press areas, we observed some employees in these areas wearing no hearing protection. We also observed some employees wearing ear plugs that were not inserted correctly.

Conclusions

We found that some MIG welders were exposed to airborne concentrations of manganese fumes above the ACGIH TLV-TWA and to concentrations of CO above the NIOSH REL-C. Some painters were exposed to airborne respirable and total dust concentrations above their respective OSHA PEL-TWAs and ACGIH TLV-TWAs. Of eight painters, four were exposed to TGIC concentrations above the ACGIH 8-hour TLV-TWA during a 5-hour period. Painters may also be at risk for heat stress. Although our evaluation identified no painters with work-related respiratory disease or symptoms, PEF readings identified two painters with hyperresponsive airways that may suggest asthma.

Area noise levels in the press, grinding, MIG welding, and powder paint areas were greater than 85 dBA and were sometimes greater than 90 dBA in the press and grinding areas. In addition, the number of recordable musculoskeletal disorders at Dehler has steadily increased over the past 3 years. Although we did not do a comprehensive evaluation of noise and ergonomics, our findings suggest the need for assessment of these potential hazards.

Recommendations

1. Ventilation

- Install sliding doors that can be closed over the paint booth openings when no painters are working at the openings. This will improve the capture efficiency of the paint booth. Consult with a ventilation engineer about how many openings may be closed while still providing adequate makeup air and ensuring efficient performance of the paint booth. The American Industrial Hygiene Association has a list of consultants from which you can select a ventilation systems expert [www.aiha.org/Content/AccessInfo/consult/consultlisting.htm]. Conduct additional PBZ air sampling for TGIC, respirable dust, and total dust on painters after modifying the paint booth to determine if employees' exposures have been reduced.
- If modifications to the paint booth do not reduce the painters' exposures to dust and TGIC below applicable OELs, then a paint booth that is designed for worker protection as well as paint recovery should be installed.
- Install exhaust fans above the welding area to remove welding fumes, and in the paint booth room to remove hot air. During the summer it may be necessary to air-condition the paint room. If that is not feasible then spot coolers at painters' work stations may be employed. Install supply fans in each area to provide outdoor air. Conduct a heat stress evaluation in the paint room during warmer days. If you cannot employ controls to lower the temperature in the paint room during summer months, implement a heat stress

control program that includes medical monitoring. Refer to the NIOSH criteria document for guidance in implementing a heat stress program [www.cdc.gov/niosh/86-113.html].

2. Safety

- Properly secure gas cylinders with a chain or metal strap.
- Do not obstruct fire extinguishers.
- Adjust wristlets so employees cannot place their hands in pinch points.
- Use an appropriate safety plunger container for dispensing solvents onto cleaning rags. Polyvinyl alcohol gloves are recommended for protecting the hands from contact with toluene. A less hazardous solvent such as Stoddard solvent should be used to clean parts.
- Do not use compressed air to blow off paint dust. Employees should use a vacuum to clean dust off clothing.
- Install a diffuser nozzle on the compressed air line that reduces air pressure to no more than 30 psi in case the nozzle tip becomes blocked or dead-ended.

3. Hazard Communication

- Inform employees about the hazardous compounds present at this facility and how to handle them appropriately; follow OSHA's Hazard Communication Standard [29 CFR 1910.1200].
- Label all containers with the identity of the contents and with appropriate hazard warning information [29 CFR 1910.1200(f)(5)]. If Spanish-speaking employees do not understand the label, add the Spanish product/chemical name to the label. Provide employees who do not understand English with MSDSs in Spanish.
- Tell employees who the Safety Manager is, his or her responsibilities pertaining to health and safety, and how employees may report an occupational safety and health concern. This should be done in Spanish for employees who do not understand English.

4. Personal Protective Equipment

- Until engineering controls are installed, provide painters exposed to TGIC with a higher level of respiratory protection, such as a powered air-purifying respirator with a high efficiency particulate air filter and a loose-fitting hood. This type of PPE has a level of protection higher than a filtering facepiece, does not require that painters be clean shaven, can provide better skin protection, and the air blowing into the hood provides a cooling effect. This respirator has a NIOSH-assigned protection factor of 25.

- Implement a formal respiratory protection program that meets the requirements of OSHA standard 29 CFR 1910.134. The OSHA *Small Entity Compliance Guide* provides guidance for a respiratory protection program [www.osha.gov/Publications/secgrev-current.pdf].
- Train employees on how to properly don respirators and insert ear plugs.
- Provide employees with protective clothing for skin protection while applying paint that contains TGIC.
- Provide employees handling sheet metal with cut-resistant gloves (e.g., Kevlar®) to prevent lacerations.

5. Medical

- Instruct employees with respiratory symptoms to contact their healthcare provider for proper diagnosis and appropriate management modalities.

6. Work practices

- Reduce the speed of the conveyor, if feasible, so that painters do not have to step into the paint booth to touch up parts. Investigate the repositioning of the mounted paint spray guns to provide better coverage or purchase self-adjusting spray guns.
- Make sure the air pressure, charge, and nozzle controls on the paint spray guns are properly set to minimize overspray. Proper grounding of the workpiece is also important for optimal powder coating and to prevent back spray onto the spraygun and the painter [Wagner 1996].

7. Ergonomics

- Avoid lifting heavy objects, particularly when placing items onto the conveyor line and when stacking finished items at the end of the welding process. Reduce the risk of employee injury by assessing the task. Where possible, provide mechanical assistance, such as a hoist. Where practical, look for ways to change the task, the weight, or involve two-person lift teams.
- Design all work areas within a working height range of 28 inches to 56 inches [Kroemer 1989]. This will eliminate

Recommendations (continued)

the need for employees to maintain bent postures while performing their work. Areas where this should be implemented include the CNC machines, press brake areas, and welding and assembly stations.

- Rotate the welding tables to avoid leaning over a previously welded area and inhaling welding fumes. This should also result in less back strain.
- Hire an ergonomics consultant to evaluate the worksite and provide recommendations for reducing the number of ergonomic injuries. The Board of Certification in Professional Ergonomics lists 18 certified ergonomics professionals in the state of Illinois [http://bcpe.org/certificants/default.asp].

8. Noise

- Retrain employees on how to use their hearing protection properly. Supervisors should be responsible and held accountable for ensuring the proper use of hearing protection in designated hazardous noise areas.
- Conduct full-shift noise monitoring to determine employees' TWA noise exposures.
- Refer to the NIOSH document *Preventing Occupational Hearing Loss: A practical guide* [www.cdc.gov/niosh/96-110.html] and to the NIOSH hearing conservation program evaluation checklist [www.cdc.gov/niosh/topics/noise/workplacesolutions/hearingchecklist.html] for more detailed information on noise and hearing loss.

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Elements

NIOSH investigators collected 60 PBZ full-shift air samples for elements on 37-mm diameter cassettes with 0.8-µm pore size mixed cellulose ester filters at a flow rate of 2.0 Lpm. The samples were analyzed using inductively coupled argon plasma-atomic emission spectroscopy per NIOSH Method 7303 with modifications [NIOSH 2008]. Instead of adding 1.25 mL of concentrated hydrochloric acid and 1.25 mL of concentrated nitric acid, the laboratory added 2.5 mL of hydrochloric acid to each sample. After heating the samples on a hot block the method calls for adding 1.25 mL of nitric acid, however with the modification, 2.5 mL of nitric acid was added.

TGIC

TGIC samples were collected on 37-mm glass fiber filters treated with hydrobromic acid in closed face cassettes at a nominal sampling flow rate of one Lpm. To avoid overloading, the filters were replaced after about 2 hours of painting. The samples were analyzed by gas chromatography using an electron capture detector per OSHA Method PV2055 [OSHA 2008].

Respirable and Total Dust

Samples were collected on tared 37-mm polyvinyl chloride filters at flow rates of 2.2 for respirable dust and 2.0 Lpm for total dust. The samples were analyzed per NIOSH Method 0600 for respirable dust and NIOSH Method 0500 for total dust [NIOSH 2008]. BGI cyclones were used as preselectors for the respirable dust samples because they match the 4-µm, 50% cut, respirable curve and are not sensitive to charge effects, which was a concern when sampling charged paint particles.

Titanium dioxide

Respirable dust samples were analyzed for TiO_2 per a method titled "Determination of Titanium Dioxide in Foods Using Inductively Coupled Plasma Optical Emission Spectometry" [Lomer et al. 2000]. The results for TiO_2 are based on the titanium result, calculated using the formula for TiO_2 and assuming all titanium detected is in the form of TiO_2.

Temperature

Air temperature in the paint room was measured using a TSI Q-TRAK™ Indoor Air Quality Monitor (TSI Incorporated, Shoreview, Minnesota). The WBGT was measured with a QUESTemp°36 data logging Thermal Environment Monitor. The QUESTemp°36 data logging heat stress monitor measures four parameters: ambient or DB temperature, WB temperature, GT, and RH. The ambient or DB temperature is the air temperature we normally measure with a thermometer; the WB sensor takes into account evaporative cooling, giving an indication of the effects of humidity on an individual. To determine the WB temperature a cotton wick is placed over a thermometer and a sensor measures the change in temperature as water evaporates from the wick. The GT sensor provides an indication of the radiant heat exposure on an individual due to either direct light or hot objects in an environment. It is simulated by placing a thermometer inside a black copper sphere. The RH is measured by a sensor located inside the sensor housing [Quest 2006]. The following formula was used to calculate the WBGT:

$$\text{WBGT (indoors)} = 0.7\text{WB} + 0.3\text{GT}$$

Appendix A: Methods (continued)

Noise

Real-time noise levels were measured at several work areas or near production equipment using a Quest® Technologies SoundPro® Model SE/DL sound level meter. A-weighted noise measurements were collected by taking a short duration (approximately 30 seconds) integrated measurement in the work area where an employee was working. Unweighted peak noise measurements were simultaneously collected during the integrated measurements. The instrument was equipped with a ½-inch free-field Type 2 electret microphone. The microphone has a frequency response range (± 2 dB) from 20 to 17 kilohertz. During measurements a foam windscreen was placed over the microphone to eliminate effects from air blowing across the microphone. The sound level meter was calibrated before and after use according to the manufacturer's instructions.

Powder Paint Particles Analysis

Four bulk samples of powder paint were submitted to Bureau Veritas North America laboratory for analysis of particle size and asbestos content. The presence of asbestos was determined using the Environmental Protection Agency Method EPA 600/R-93/116 [EPA 1993] for polarized light microscopy and transmission electron microscopy. Scanning electron microscopy, energy dispersive spectroscopy, and an integrated x-ray fluorescence digital image system were utilized for particle sizing of the paint and titanium particles during examination of pre-ashed and ashed residues, respectively. Paint particles were ashed to separate the TiO_2 particles for sizing.

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Appendix B: Occupational Exposure Limits & Health Effects

In evaluating the hazards posed by workplace exposures, NIOSH investigators use both mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents as a guide for making recommendations. OELs have been developed by Federal agencies and safety and health organizations to prevent the occurrence of adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure to which most employees may be exposed 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 from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the employee to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Also, some substances can be absorbed by direct contact with the skin and mucous membranes in addition to being inhaled, which contributes to the individual's overall exposure.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8–10-hour workday. Some chemical substances and physical agents have recommended STEL or ceiling values where health effects are caused by exposures over a short period. Unless otherwise noted, the STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits, while others are recommendations. The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits enforceable in workplaces covered under the Occupational Safety and Health Act. NIOSH RELs are recommendations based on a critical review of the scientific and technical information available on a given hazard and the adequacy of methods to identify and control the hazard. NIOSH RELs can be found in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2005a]. NIOSH also recommends different types of risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects from these hazards. Other OELs that are commonly used and cited in the U.S. include the TLVs recommended by ACGIH, a professional organization, and the WEELs recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and WEELs are developed by committee members of these associations from a review of the published, peer-reviewed literature. They are not consensus standards. ACGIH TLVs 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 2008a]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2008].

Outside the U.S., OELs have been established by various agencies and organizations and include both legal and recommended limits. Since 2006, the Berufsgenossenschaftliches Institut für Arbeitsschutz (German Institute for Occupational Safety and Health) has maintained a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the U.S. [http://www.hvbg.de/e/bia/gestis/limit_values/index.html]. The database contains international limits for over 1250 hazardous substances and is updated annually.

Employers should understand that not all hazardous chemicals have specific OSHA PELs, and for some agents the legally enforceable and recommended limits may not reflect current health-based information.

However, an employer is still required by OSHA to protect its employees from hazards even in the absence of a specific OSHA PEL. 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))]. Thus, NIOSH investigators encourage employers to make use of other OELs when making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminate or minimize identified 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) personal protective equipment (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 that focuses resources on exposure controls by describing how a risk needs to be managed [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 the OELs, when available.

Elements/Welding Fumes

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

The content of welding fumes depends on the base metal being welded, the welding process and parameters (such as voltage and amperage), the composition of the consumable welding electrode or wire, the shielding gas, and any surface coatings or contaminants on the base metal. The flux coating (or core) of the electrode/wire may contain up to 30 organic and inorganic compounds. In general, welding fume constituents may include minerals, such as silica and fluorides, and metals, such as arsenic, beryllium, cadmium, chromium, cobalt, nickel, copper, iron, lead, magnesium, manganese, molybdenum, tin, vanadium, and zinc [Welding Institute 1976; NIOSH 1988]. A PEL for total welding fumes has not been established by OSHA; however, PELs have been set for individual welding fume constituents (e.g., iron, manganese) [29 CFR 1910.1000]. NIOSH has concluded that it is not possible to establish an exposure limit for total welding emissions because the composition of welding fumes and gases varies greatly, and the welding constituents may interact to produce adverse health effects. Therefore, NIOSH recommends controlling total welding fume to the lowest feasible concentration and meeting the exposure limit for each welding fume constituent [NIOSH 2005a]. In addition to welding fume, many other potential health hazards exist for welders. Welding operations can produce gaseous emissions such as CO, ozone, nitrogen dioxide, and phosgene (formed from chlorinated solvent decomposition) [Welding Institute 1976; NIOSH 1988]. Welders can also be exposed to hazardous levels of ultraviolet radiation from the welding arc if welding curtains or other precautions are not used.

Powder Paint

Powder paints contain various chemical ingredients but the most common are talc, calcium carbonate, titanium dioxide, barium sulfate, carbon black, and TGIC. Some powder paints may also contain small percentages of metal pigments such as cobalt. In their guide to powder coatings, a multinational paint manufacturer AkzoNobel, reports that most commercial powders have a particle size between 10 and 100 µm [AkzoNobel 1999]. When the individual paint ingredients have applicable OELs, the OELs should be applied when considering employee exposures. If no ingredients in the paint have specific OELs, and the ingredients are of low toxicity, then the OSHA PELs for respirable dust and total dust of 5 mg/m^3 and 15 mg/m^3 respectively may be applied.

TGIC

TGIC, molecular formula $C_{12}H_{15}N_3O_6$, is an ingredient in some powder paints, primarily the darker colors such as blue, green, and black. It is also used in solder inks in the printed circuit board industry. TGIC synonyms include; s-triazine-2,4,6(1H,3H,5H)-trione; triglycidyl isocyanurate; 1,3,5-triglycidyl-s-triazinetrione; tris(epoxypropyl)isocyanurate; and 1,3,5-tris(2,3-epoxypropyl)-s-triazine-2,4,6(1H,3H,5H)-trione. TGIC does not occur naturally and is produced by reacting cyanuric acid with excess epichlorohydrin. The WHO reports that TGIC is partially cross-linked to the resin in powder coatings and only the unbound TGIC is bioavailable. In their chemical assessment of TGIC, the WHO recommended maintaining workplace exposures to TGIC at the lowest practicable level due to its genotoxic and sensitization effects. Previous animal studies of TGIC inhalation revealed chromosomal aberrations in mouse spermatogonia indicating a potential for reproductive effects. TGIC was also found to cause DNA damage raising concerns about potential heritable genetic damage in humans. Direct contact with TGIC may also cause serious eye damage [WHO 1998].

In 2000, Swedish scientists conducted a study to determine the prevalence of respiratory symptoms and immunogical response among powder painters and to describe the exposure to organic acid anhydrides [Blomqvist et al. 2005]. The scientists used a study group of 205 subjects from 32 workplaces comprised of 93 exposed employees, 26 formerly exposed, and 86 unexposed. The scientists had employees complete a questionnaire about working conditions and symptoms and administered each employee a medical examination which included a lung function test, urine samples for the determination of two organic acid anhydrides, and blood samples for specific antibodies against the organic acid anhydrides. The results indicated that powder painters reported more work-related respiratory symptoms than the unexposed subjects. Respiratory symptoms reported included rhinitis, sore throat, cough, and rhonchi. According to the physicians examining the employees, asthma symptoms were considerably higher for the high-exposure group (40%) than for the low-exposure (7%) and unexposed (2%) groups. High exposure was defined by one or more of the following criteria: visible dust in the shop; no paint booth or a booth with insufficient ventilation; PPE seldom used, manual spraying often; or exposure to paint powder at least 10 hours per week. Defining criteria for the low exposure group was use of a modern spray booth, use of PPE while cleaning the booth, and only occasional manual spraying. Out of 119 subjects who were exposed, 50 were classified as highly exposed [Blomqvist et al. 2005]. No association between lung function and exposure was observed. According to the authors, a lack of correlation between exposure and lung function has been seen in previous studies, even when subjects had an increased prevalence of airway symptoms. The authors concluded that work-related symptoms were probably caused by irritative properties of high levels of powder paint dusts.

In 1993, physicians from the Finnish Institute of Occupational Health examined a painter diagnosed with allergic contact dermatitis due to TGIC exposure during powder painting. They performed a challenge test with a mixture of 4% TGIC and 96% lactose according to the European Academy of Allergology and Immunology protocol. The challenge test induced a dual reaction in peak expiratory flow and a late 23% fall in the forced expiratory volume in 1 second. Spirometry showed slight obstruction and the blood eosinophils and serum IgE value were elevated. The physicians concluded that the employee had occupational asthma caused by TGIC and recommended that both the skin and the respiratory tract be protected from type IV allergens which may also be type I allergens. To their knowledge that was the first diagnosed case of occupational asthma caused by TGIC [Piirila et al. 1997].

To minimize the potential for adverse hematopoietic, spermatogonial, and fertility effects, and because it may be a sensitizer, ACGIH recommends that exposure to TGIC not exceed 0.05 mg/m^3. In addition to the ACGIH exposure criterion, several countries (Canada, Spain, Ireland, and Malaysia) have set a TLV of 0.05 mg/m^3 for TGIC.

Titanium Dioxide

In addition to powder paint, TiO_2 is used in many commercial products including cosmetics, plastics, paper, and food. TiO_2 is a poorly soluble, low-toxicity dust, produced in varying particles sizes including fine (approximately <2.5 µm in diameter) and ultrafine (<0.1 µm in diameter). During a chronic inhalation study of rats exposed to 250 mg/m^3 of fine TiO_2, research scientists observed nonmalignant tumors in the rats. Based on the results of that study, NIOSH classified TiO_2 as a potential occupational carcinogen and recommended that exposures be limited to the lowest feasible concentration. Subsequently a 2-year inhalation study of rats exposed to ultrafine TiO_2 showed a statistically significant increase in lung cancer. A similar relationship was not found with exposure to total and respirable TiO_2. After reviewing previous animal and human studies of TiO_2 exposure [NIOSH 2005b], NIOSH concluded that the tumorigenic effects observed in rats were not chemical specific or a direct action of the chemical itself. NIOSH believes that these effects were a function of particle size and surface area acting through a secondary genotoxic mechanism associated with persistent inflammation. In addition, NIOSH concluded that current evidence indicates that occupational exposures to low concentrations of TiO_2 produce a negligible risk of lung cancer in employees [NIOSH 2005b]. Based on these conclusions, NIOSH has published a draft Current Intelligence Bulletin for occupational exposure to TiO_2 in which it recommends that exposure to TiO_2 particles be limited to 1.5 mg/m^3 for fine and 0.1 mg/m^3 for ultrafine particulates, as TWA concentrations for up to 10-hours per day during a 40-hour workweek. These are preliminary proposed RELs to minimize any risks that may be associated with the development of pulmonary inflammation and cancer [NIOSH 2005b]. These criteria may be revised once NIOSH has a more complete understanding of the possible health risks associated with TiO_2 exposure. The draft NIOSH TiO_2 document includes an exposure assessment protocol for TiO_2. The OSHA PELs for TiO_2 are 15 mg/m^3 and 5 mg/m^3 for total and respirable particles not otherwise regulated, respectively, as an 8-hour TWA [29 CFR 1910.1000]. The OSHA limits are based on the risk of physical irritation associated with exposure to TiO_2.

Respirable and Total Dust

Respirable particulates are those particles that when inhaled can be deposited in the gas exchange region [ACGIH 2008a]. Total dust refers to particulates that may be deposited anywhere in the respiratory tract. Total dust includes respirable particulates. OSHA has 8-hour PEL-TWAs for respirable particulates of 5 mg/m^3 and 15 mg/m^3 for total particulates (particulates not otherwise regulated). ACGIH believes that all particles, even if they are biologically inert or insoluble, may have adverse health effects and therefore recommends that exposure to respirable particles not exceed 3 mg/m^3 and that exposures to inhalable particles not exceed 10 mg/m^3. These recommendations are for particles that do not have a specific TLV, are of low toxicity, and are referred to by ACGIH as particles (insoluble or poorly soluble) not otherwise specified [ACGIH 2008a].

Carbon Monoxide

CO is a colorless, odorless, tasteless gas that can be a product of the incomplete combustion of organic compounds. It is classified as a chemical asphyxiant because it combines with hemoglobin and interferes with the oxygen-carrying capacity of blood. Symptoms include headache, drowsiness, dizziness, nausea, vomiting, collapse, myocardial ischemia, and death [Becker et al. 1990]. The NIOSH REL for CO is 35 ppm for an 8-hour TWA. NIOSH also recommends a ceiling limit of 200 ppm that should not be exceeded at any time during the workday [NIOSH 2005a]. The OSHA PEL for CO is 50 ppm for an 8-hour TWA. The ACGIH TLV for CO is 25 ppm as an 8-hour TWA. This value is intended to maintain blood carboxyhemoglobin levels below 3.5% to minimize the potential for adverse neurologic behavioral changes and to maintain cardiovascular work and exercise capacities. The time to reach a carboxyhemoglobin level of 3.5% at a given CO concentration decreases as the workload increases [ACGIH 2008b].

Nitrogen Dioxide

NO_2 is a yellowish-brown liquid or reddish-brown gas (above 70°F) with a pungent, acrid odor [NIOSH 1981; 2005a]. NO_2 reacts with water to form nitric acid, hence its irritant property when in contact with the mucous membranes and the respiratory tract. It is irritating to the eyes, respiratory tract, and skin; pulmonary edema may be induced at concentrations above the TLV. Animals chronically exposed to concentrations of NO_2 ranging up to 25 ppm did not exhibit ill health effects [ACGIH 2008b]. Where the air concentration is above the OELs, a supplied air respirator or self-contained breathing apparatus should be used as protection against NO_2 [NIOSH 2005a]. NIOSH has an REL-STEL of 1 ppm for NO_2. OSHA has a PEL-C of 5 ppm for NO_2. ACGIH recommends an 8-hour TLV-TWA of 3 ppm and a TLV-STEL of 5 ppm for occupational exposure to NO_2 to minimize the potential for ocular, mucous membrane, and respiratory tract irritation.

Heat Stress

NIOSH defines heat stress exposure as the sum of the heat generated in the body (metabolic heat) plus the heat gained from the environment (environmental heat) minus the heat lost from the body to the environment, primarily through evaporation. Many bodily responses to heat stress are desirable and beneficial because they help regulate internal temperature and, in situations of appropriate repeated exposure, help the body adapt (acclimatize) to the work environment. However, at some stage of heat stress, the body's compensatory measures cannot maintain internal body temperature at the level required for normal functioning. As a result, the risk of heat-induced illnesses, disorders, and accidents substantially increases. Increases in unsafe behavior, behavior that may lead to accidents, are also seen as the level of physical work of the job increases [NIOSH 1986].

ACGIH guidelines require the use of a decision-making process that provides step-by-step situation-dependent instructions that factor in clothing insulation values and physiological evaluation of heat strain [ACGIH 2008a]. ACGIH WBGT screening criteria factor in the ability of the body to cool itself (clothing insulation value, humidity, and wind) and, like the NIOSH criteria, can be used to develop work/

rest regimens for acclimatized and unacclimatized employees. The ACGIH WBGT-based heat exposure assessment was developed for a traditional work uniform of long-sleeved shirt and pants, and represents conditions under which it is believed that nearly all adequately hydrated, unmedicated, healthy employees may be repeatedly exposed without adverse health effects.

NIOSH and ACGIH criteria can only be used when WBGT data for the immediate work area are available and must not be used when employees wear encapsulating suits or garments that are impermeable or highly resistant to water vapor or air movement. Further assumptions regarding work demands include an 8-hour work day, 5-day workweek, two 15-minute breaks, and a 30-minute lunch break, with rest area temperatures the same as, or less than, those in work areas, and at least some air movement. It must be stressed that while NIOSH and ACGIH guidelines distinguish between safe and dangerous levels, professional judgment must be used in administering a heat stress management program to ensure adequate protection. The OSHA technical manual's section on heat stress refers back to the ACGIH document for guidelines to evaluate employee heat stress and how to investigate the workplace [OSHA 1999].

Heat disorders and health effects of individuals exposed to hot working environments include (in increasing order of severity) skin disorders (heat rash, hives, etc.), heat syncope (fainting), heat cramps, heat exhaustion, and heat stroke. Heat syncope (fainting) results from blood flow being directed to the skin for cooling, resulting in decreased supply to the brain, and most often strikes employees who stand in place for extended periods in hot environments. Heat cramps, caused by sodium depletion due to sweating, typically occur in the muscles employed in strenuous work. Heat cramps and syncope often accompany heat exhaustion, or weakness, fatigue, confusion, nausea, and other symptoms. The dehydration, sodium loss, and elevated CBT (above 100.4°F) are usually due to performing strenuous work in hot conditions with inadequate water and electrolyte intake. Heat exhaustion may lead to heat stroke if the individual is not quickly cooled and rehydrated.

While heat exhaustion victims continue to sweat as their bodies struggle to stay cool, heat stroke victims cease to sweat as their bodies fail to maintain an appropriate core temperature. Heat stroke occurs when hard work, hot environment, and dehydration overload the body's capacity to cool itself. This thermal regulatory failure (heat stroke) is a life-threatening emergency requiring immediate medical attention. Signs and symptoms include irritability, confusion, nausea, convulsions or unconsciousness, hot dry skin, and a CBT above 106°F. Death can result from damage to the brain, heart, liver, or kidneys [Cohen 1990].

The loss of acclimatization begins when the activity under those heat stress conditions is discontinued, and a noticeable loss occurs after 4 days. This loss is usually rapidly made up so that by Tuesday, employees who were off on the weekend are as well acclimatized as they were on the preceding Friday.

Palatability of any fluid replacement solution is important to ensure adequate rehydration. Evidence shows that adding sweeteners to drinks leads to increased consumption. Glucose-electrolyte solutions have been shown to facilitate sodium and water absorption. Also, the glucose in these solutions provides energy for muscular activity in endurance events that require vigorous exercise [Rolls et al. 1990]. However, employees should be cautioned to avoid drinking large amounts of sugar-laden beverages in hot climates as this causes an osmotic diuresis that increases fluid loss through urination. Caffeinated beverages and alcohol intake also increase urinary fluid loss and should be avoided. The temperature of the drink also influences consumption of fluids. Ideally, fluids should be ingested at temperatures of 50°F–60°F, in small quantities (5–7 ounces), and at frequent intervals (every 15–20 minutes).

Average Americans consume adequate, if not excessive, amounts of sodium in their usual diet such that for mild dehydration, only water replacement is needed. However, in moderate dehydration or when involved in events resulting in prolonged sweating, electrolyte (i.e., sodium) replacement is indicated. Many oral electrolyte replacement formulas such as Gatorade® are available. Salt tablets are not recommended as they can irritate the stomach, leading to vomiting, which can exacerbate fluid losses and do not address water replacement needs. Those with nausea and vomiting from heat stress may require intravenous saline administration to replace their water and sodium.

NOISE

Noise-induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically [Berger et al. 2003]. While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise-induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 Hz (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components [Suter 1978].

The dBA is the preferred unit for measuring sound levels to assess employee noise exposures. The dBA scale is weighted to approximate the sensory response of the human ear to sound frequencies near the threshold of hearing. The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels audible to the human ear. Because the dBA scale is logarithmic, increases of 3 dBA, 10 dBA, and 20 dBA represent a doubling, tenfold increase, and hundredfold increase of sound energy, respectively. Noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise [29 CFR 1910.95] specifies a maximum PEL of 90 dBA for a duration of 8 hours per day. The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship, or exchange rate. This means that a person may be exposed to noise levels of 95 dBA for no more than 4 hours, to 100 dBA for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dBA is allowed by this exchange rate. The duration and sound level intensities can be combined in order to calculate a employee's daily noise dose according to the formula

$$\text{Dose} = 100 \times (C1/T1 + C2/T2 + \ldots + Cn/Tn),$$

where Cn indicates the total time of exposure at a specific noise level and Tn indicates the reference duration for that level as given in Table G-16a of the OSHA noise regulation. Doses greater than 100% are in excess of the OSHA PEL.

The OSHA regulation has an additional AL of 85 dBA; an employer shall administer a continuing, effective hearing conservation program when the 8-hour TWA value exceeds the AL. The program must include monitoring, employee notification, observation, audiometric testing, hearing protectors, training, and record keeping. All of these requirements are included in 29 CFR 1910.95, paragraphs (c) through (o). Finally, the OSHA noise standard states that when employees are exposed to noise levels in excess of the OSHA PEL of 90 dBA, feasible engineering or administrative controls shall be implemented to reduce the employees' exposure levels.

NIOSH [NIOSH 1998] and ACGIH [ACGIH 2008a] recommend an exposure criteria of 85 dBA as a TWA for 8 hours, which is 5 dB less than the OSHA standard. The criteria also use a more conservative 3 dB time/intensity trading relationship in calculating exposure limits. The 3-dB exchange rate used by NIOSH assumes that equal amounts of sound energy will produce equal amounts of hearing impairment regardless of how the sound energy is distributed in time [Driscoll and Royster 2000]. Using NIOSH criteria, a employee can be exposed to 85 dBA for 8 hours, but to no more than 88 dBA for 4 hours or 91 dBA for 2 hours. Twelve-hour exposures have to be 83 dBA or less according to the NIOSH REL.

Audiometric evaluations of employees are conducted in quiet locations, preferably in a sound-attenuating chamber, by presenting pure tones of varying frequencies at threshold levels (i.e., the level of a sound that the person can just barely hear). Audiograms are displayed and stored as tables or charts of the HL at specified test frequencies [ANSI 1996]. Zero dB HL represents the hearing level of an average, young individual with normal hearing. In OSHA-mandated hearing conservation programs, thresholds must be measured for pure-tone signals at the test frequencies of 500, 1000, 2000, 3000, 4000, and 6000 Hz. Individual employee's annual audiograms are compared to their own baseline audiogram to determine the amount of STS that might have occurred between the two tests. Specifically, OSHA states that an STS has occurred if the average threshold values at 2000, 3000, and 4000 Hz have increased by 10 dB or more in either ear when comparing the annual audiogram to the baseline audiogram [29 CFR 1910.95]. The NIOSH-recommended threshold shift criterion is a 15-dB shift at any frequency in either ear from 500–6000 Hz measured twice in succession [NIOSH 1998]. Practically, the criterion is met by immediately retesting an employee who exhibits a 15-dB shift from baseline on an annual test. If the 15-dB shift persists on the second test, a confirmatory follow-up test should be given within 30 days of the initial annual examination. Both of these threshold shift criteria require at least two audiometric tests. In cases where only one audiogram is available, a criterion has been proposed for single-frequency impairment determinations [Eagles et al. 1968]. It employs a lower fence (the amount of hearing loss necessary before a hearing handicap is said to exist) of 25 dB HL. With this criterion, any person who has a hearing level of 26 dB HL or greater at any single frequency is classified as having some degree of hearing loss. The degree of loss can range from mild (26–40 dB HL) to profound (>90 dB HL).

The audiogram profile is a plot of the hearing test frequencies (x-axis) versus the hearing threshold levels (y-axis). For many employees, the audiogram profile tends to slope downward toward the high frequencies with an improvement at the audiogram's highest frequencies, forming a "notch" [Suter 2002]. A notch in an individual with normal hearing may indicate the early onset of hearing loss. Although no universal criterion defines what constitutes a "notch," several mathematical models that attempt to identify notches are presented in the scientific literature [Dobie and Rabinowitz 2002; Niskar et al. 2001; Cooper and Owen 1976]. The relative strengths and weaknesses of these models have also been reviewed [Rabinowitz and Dobie 2003]. For this evaluation, a notch is defined as the frequency where the hearing level is preceded by an improvement of at least 10 dB and followed by an improvement of at least 5 dB. The notch from occupational noise can occur between 3000 and 6000 Hz, depending on the frequency spectrum of the noise, and the anatomy of the individual's ear [ACOM 1989; Osguthorpe and Klein 2001]. It is generally accepted that a notch at 4000 Hz indicates occupational hearing loss [Prince et al. 1997]. On the other hand, some researchers have argued that the notch at 6000 Hz may not be a good marker for occupational hearing loss because it is widely seen in young adults and others with little documented occupational noise exposure [McBride and Williams 2001]. An individual may have notches at different frequencies in one or both ears [Suter 2002].

Eye Hazards from Welding

The main eye hazards associated with welding arcs are ultraviolet, visible, and infrared radiation, which together are known as optical radiation [Sliney et al. 1982]. Optical radiation is responsible for an inflammatory response of the cornea and conjunctiva following prolonged exposure to ultraviolet radiation without proper eye protection. This condition, which may affect welders or bystanders, is generally referred to as 'welder's flash" or "arc eye" [Sliney et al. 1982]. Welding curtains are used to protect bystanders from the optical radiation produced during welding. Transparent curtains allow supervisors to observe an employee's progress and to detect accidents (e.g., heart attacks, falls, and fires). Transparent welding curtains also improve ambient illumination in the welder's work area. Visible light can cause photochemical injury to the retina. Because this effect is most pronounced between 400 and 500 nanometers, it is termed blue light [Sliney et al. 1982]. The ideal welding curtain is transparent enough to allow viewing of the work area, filters out hazardous ultraviolet radiation and blue light, increases ambient illumination, and reduces glare [Sliney et al. 1981]. An orange curtain would maximize visibility while minimizing the blue light hazard [Sliney et al. 1982].

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Table C1. Air sampling results for elements from welding fumes							
Job Title	Sample Date	Sample Time (Minutes)	Concentration µg/m³				
			Cu	Fe	Mn	Ni	Ti
MIG Welders	09/18/2007	479	5.1	1,700	23	Trace*	0.81
		478	15	1,400	**220**	ND†	0.39
		479	7.9	500	77	ND	0.17
		478	13	790	2.8	Trace	0.28
		479	9.7	1,800	26	1.3	1.1
		475	5.1	1,800	**230**	Trace	0.76
		485	2.4	520	10	Trace	0.37
		483	2.1	500	8.7	Trace	0.34
		472	5.4	540	59	ND	0.39
		473	5.9	410	51	ND	0.26
		473	4.0	400	46	ND	0.17
		472	4.6	350	39	ND	0.17
	09/19/2007	488	7.5	750	95	ND	0.58
		490	6.5	500	71	ND	0.21
		487	4.7	330	52	ND	0.91
		485	9.8	730	100	Trace	0.20
		485	8.3	630	100	Trace	0.22
		483	5.1	410	59	ND	0.15
		486	1.8	170	16	Trace	Trace
		485	22	1,400	**240**	Trace	0.22
		483	24	1,200	**250**	ND	0.37
		479	19	1,100	**200**	Trace	0.38
		481	4.1	500	38	Trace	0.17
		483	4.4	410	46	Trace	0.16
		477	9.9	480	71	Trace	0.15
	09/20/2007	494	9.9	710	110	Trace	0.90
		494	4.7	390	54	ND	0.18
		494	24	1,400	**270**	Trace	0.18
		493	13	1,000	150	Trace	0.32
		495	8.6	770	110	Trace	0.18
		498	26	1,300	**240**	Trace	0.32
		498	10	760	110	Trace	0.16
		486	13	1,100	170	Trace	0.28
		486	15	780	140	Trace	0.25
		492	3.0	250	25	Trace	0.072
		492	2.7	180	22	Trace	Trace
		491	4.1	290	45	Trace	0.11
		495	6.9	500	66	Trace	0.16
Spot Welders	09/18/2007	449	ND	36	1.8	ND	0.086
		446	ND	34	0.81	ND	Trace
		456	ND	38	2.2	ND	0.079
		457	ND	46	1.4	ND	Trace
	09/19/2007	469	1.3	120	4.4	ND	0.041
		464	1.8	110	4.2	ND	0.058
	09/20/2007	490	2.0	140	8.3	ND	Trace
		487	0.91	180	8.7	Trace	Trace
		489	1.8	129	8.5	Trace	Trace

Table C1. Air sampling results for elements from welding fumes

Job Title	Sample Date	Sample Time (Minutes)	Concentration µg/m³				
			Cu	Fe	Mn	Ni	Ti
Grinders	09/18/2007	483	2.3	240	18	ND	0.18
		481	4.2	1,200	17	Trace	0.78
		471	17	1,100	150	ND	0.27
	09/19/2007	490	10	4,200	60	Trace	0.97
		487	2.7	620	18	Trace	0.57
		486	4.6	840	20	Trace	0.44
		481	9.1	3,900	54	0.91	0.86
		484	1.6	240	5.5	ND	0.11
	09/20/2007	500	1.4	100	6.9	Trace	Trace
		500	8.8	2,400	49	0.73	0.57
		495	8.1	1,100	32	0.96	0.49
		487	2.6	380	18	Trace	0.21
		499	8.9	3,100	52	0.80	0.81
REL-TWA			100	5000	1000	15	LFC‡
PEL-TWA			100	10,000	5,000§	1000	15,000
TLV-TWA			200	5000	200	1,500	10,000
MDC¶			0.36	0.90	.07	0.18	0.018
MQC**			1.8	4.5	0.25	0.61	0.061

Cu = copper, Fe = iron, Mn = manganese, Ni = nickel, Ti = titanium.
* Trace = Sample result was between the MDC and MQC.
† ND = not detected (below the MDC).
‡ LFC = Lowest feasible concentration.
§ Ceiling value.
¶ MDC = Minimum detectable concentration calculated by dividing the method limit of detection by the highest sample volume collected (1.1 m³).
** MQC = Minimum quantifiable concentration calculated by dividing the method limit of quantification by the highest sample volume collected (1.1 m³).
All sample results for antimony, arsenic, beryllium, lithium, molybdenum, phosphorus, potassium, selenium, silver, tellurium, vanadium, and yttrium were ND. Air concentrations of other metals not listed in this table were below applicable OELs.
Results in bold exceeded the ACGIH TLV-TWA for manganese.

Table C2. Air sampling results for CO						
Sample Date	Occupation	Unit ID	Sample Time (minutes)	Peak* (ppm) /Time	STEL (ppm)	TWA (ppm)
9/18/2007	MIG welder	4898/C01	554	28/10:23	16	8
		4559/C06	472	21/15:19	11	7
		6798/C02	479	83/11:59	23	9
	Spot Welder	6738/C05	409	**221**/13:34	60	10
		4899/C08	405	118/10:24	34	6
		721/C11	410	18/13:18	10	5
		766/C12	402	14/11:59	7	2
	Grinder	6990/C03	474	15/10:00	12	7
		6681/C09	476	120/10:38	25	8
9/19/2007	MIG welder	6690/C03	477	**224**/13:22	26	9
		4954/C07	479	**364**/13:26	42	13
		6681/C09	474	**547**/10:16	54	12
		721/C11	475	37/06:55	11	5
		4895/C04	474	27/08:40	15	9
		6738/C05	473	44/09:02	17	9
		4959/C06	472	32/10:07	17	11
		4899/C08	479	27/13:51	17	9
		4898/C01	475	78/10:12	21	9
NIOSH REL-TWA						35
NIOSH REL-C				200		
OSHA PEL-TWA						50
ACGIH TLV-TWA						25
Results in bold exceeded the NIOSH ceiling limit.						

Sample #	Sample Time (minutes)	Sample Volume (liters)	Concentration (mg/m³)	TWA (mg/m³)	8 –hour TWA (mg/m³)
Table C3. Results for TGIC air samples collected on painters – September 18, 2007					
First Shift					
Painter D	79	70	0.013	0.013	0.002
Painter B	67	59	0.014	0.014	0.002
Painter A	74	68	0.066	0.066	0.010
Painter C	80	66	0.35	0.35	**0.058***
Second Shift					
Painter E	144	128	0.038	1.4†	**0.89**
Painter E	161	143	2.3		
Painter F	143	126	0.029	.016†	.010
Painter F	157	138	0.005		
Painter G	144	133	0.71	0.37†	**0.23**
Painter G	160	147	0.06		
Painter H	144	120	0.13	0.54†	**0.34**
Painter H	160	133	0.90		
ACGIH TLV					0.05

* Samples in bold exceeded the ACGIH 8-hour TLV-TWA.

† $TWA = \frac{(C_1T_1) + (C_2T_2)}{T_1 + T_2}$

This TWA reflects the average of two samples collected on a painter during an 8 hour shift where C_1 = the concentration for the 1st sample, and C_2 = the concentration for the 2nd sample, and T_1 and T_2 = the respective sampling times.

Table C4. Results for air samples for respirable dust and TiO_2* collected on painters				
Sample Date	Sample #	Sample Time	Concentration (mg/m^3) Respirable Dust	TiO_2
09/18/2007	Painter A	503	4.5	NA†
	Painter B	501	1.5	NA
	Painter C	511	1.1	0.17
	Painter D	490	**5.6**‡	1.0
09/19/2007	Painter A	510	1.6	0.32
	Painter B	509	0.37	NA
	Painter C	508	1.6	0.30
	Painter D	503	3.4	NA
	Painter I	500	0.07	0.01
	Painter J	261	ND§	–
09/20/2007	Paint Room Area	494	0.20	0.035
	Painter B	498	3.9	0.80
	Painter C	511	**8.4**	NA
	Paint Room Area	492	0.21	0.04
	Painter D	500	3.7	NA
	Painter A	512	2.5	NA
	Painter I	461	0.32	0.03
OSHA PEL-TWA			5	5¶
NIOSH REL-TWA			None	LFC**
ACGIH			3††	10

* Some respirable dust samples were also analyzed for TiO_2.
†NA = Not analyzed for TiO_2.
‡samples in bold exceeded OSHA PEL for respirable dust.
§ND = Not detected.
¶The OSHA PEL-TWA shown for TiO_2 is for respirable dust. The OSHA PEL for TiO_2 as total dust is 15 mg/m^3.
**LFC = Lowest feasible concentration.
††TLV for particles (insoluble or poorly soluble) not otherwise specified (PNOS).

Table C5. Results for total dust air samples collected on painters

Sample Date	Sample #	Sample Time (minutes	Concentration (mg/m³)
09/18/2007	Painter C	428	12
	Painter B	431	**29***
	Painter D	407	**22**
	Painter A	419	**24**
09/19/2007	Painter A	509	5.9
	Painter B	507	2.0
	Painter C	507	15
	Painter D	504	**24**
	Painter I†	500	0.98
09/20/2007	Painter D	499	**16**
	Painter C	511	**130**
	Painter B	497	**80**
	Paint Room Area	490	0.80
	Painter I†	461	0.85
OSHA PEL-TWA			15
ACGIH TLV-TWA			10‡

* Results in bold exceeded the OSHA PEL-TWA for total particles not otherwise regulated.
† Painter I was filling the paint dispensing container and cleaning parts, but not painting.
‡ TLV is for insoluble or poorly soluble inhalable particles that do not have a TLV and are of low toxicity.

Table C6. Noise level measurements – September 19–20, 2007		
Location	Noise Levels (dBA)	Notes
B001K CNC Press	88.0 – 90.2	Peak noise of 119.6 dB when completed sheet slams against table to help remove edge
B004S CNC Press	85.8	
B003V CNC Press	91.1	Employee grinding
Between B004S and B003V CNC Presses	83.4 – 84.9	
B005V CNC Press	83.5	
PP21 Shear Press	93.4	
Between PB1 and PB2 Press Brakes	90.8	
Between PB3 and PB4 Press Brakes	85.1 – 89.0	Peak noise of 124 dB from dropping metal parts into bin
Between PB5 and PB6 Press Brakes	83.9 – 84.6	
Between PB7 and PB8 Press Brakes	85.2	
PB14 Press Brake	83.1	No other nearby equipment operating except PP03
PP02 Punch Press	90.2	Peak noise level of 124.4 dB from metal impacts
PP03 Punch Press	85.8	
PP04 Punch Press	87.9 – 88.8	Peak noise level of 120.4 dB from metal impacts
Between PP09 and PP11 Punch Presses	81	Small parts
PP17 Grinder/Sander	84.2	
KMT Chop Saw	96.5	
Grinding area near locker room	89.6 – 90.6	Noise measured during grinding
Grinding area at end of central production line	88.2	
MIG welding near locker room	86.0 – 87.6	Nearby grinders also operating
MIG welding at center production line	84.6 – 86.1	
Spot welding at center production line	82.9 – 83.5	
Spot welding at line closet to monorail conveyor	79.2	
Monorail conveyor spot cleaning area	72.4	
Powder paint booth	83.8 – 86.5	
Monorail conveyor loading area	75.1	
Final assembly area	72.9 – 80.5	

Acknowledgments and Availability of Report

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