Evaluation of Employees' Exposures to Organic Solvent Vapors during Screen Printing

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DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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].

Contents

Report

Appendix A

Appendix B

Acknowledgments

Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
cc/min	Cubic centimeters per minute
CFR	Code of Federal Regulations
fpm	Feet per minute
HHE	Health hazard evaluation
HVAC	Heating, ventilating, and air-conditioning
MSDS	Material safety data sheet
NAICS	North American Industry Classification System
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PBZ	Personal breathing zone
PEL	Permissible exposure limit
ppm	Parts per million
PPE	Personal protective equipment
REL	Recommended exposure limit
STEL	Short-term exposure limit
TLV	Threshold limit value
TWA	Time-weighted average
UL	Underwriters Laboratory Incorporated
WEEL	Workplace environmental exposure limit

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation (HHE) at Inter Sign National, Inc., in Baltimore, Maryland. The HHE request concerned potential health effects from exposure to organic solvent vapors during screen printing and spray painting. NIOSH visited the company in December 2007.

What NIOSH Did

- We took full-shift air samples for toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone.
- We took short-term air samples for toluene, isopropyl alcohol, and acetone.
- We measured airflow in the spray paint booth.
- We used ventilation smoke tubes to check air movement in the screen printing area.
- We evaluated personal protective equipment use.
- We identified fire safety hazards.

What NIOSH Found

- Employees' full-shift exposures to toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone did not exceed occupational exposure limits.
- Exposure to the mixture of solvents slightly exceeded American Conference of Governmental Industrial Hygienists recommendations.
- Short term exposure to isopropyl alcohol may exceed short term exposure limits during screen printing and screen washing.
- Employees did not always wear proper protective gloves when working with chemicals.
- Protective eyewear was not worn to protect against chemical splashes.
- Lacquer thinner for daily use was not stored in approved containers.
- Excessive amounts of lacquer thinner were stored in the spray paint booth.
- Containers were not properly bonded when flammable liquids were poured from one container to another.

What Managers Can Do

- Investigate replacing solvent-based screen printing products with alternatives that have low or no solvents.
- Improve ventilation in the screen printing area.
- Provide and require employees to wear properly fitting NIOSH-approved respirators when screen washing or printing until solvent exposures are reduced.
- Provide employees with chemical protective gloves made of Viton®/butyl combination or laminate plastic film.

- Require employees to use eye protection and chemical protective gloves when handling hazardous chemicals.
- Provide proper flammable safety containers for storing and dispensing of daily use lacquer thinner.
- Do not permit more than a one-day supply of lacquer thinner or screen inks to be stored in the spray paint booth.
- Require the use of bonding cables to electrically connect containers of flammable liquids when pouring from one container into another.
- Complete a personal protective equipment hazard assessment.
- Train employees how to properly use and store personal protective equipment.
- Implement a comprehensive respiratory protection program.
- Complete a hazard communication program to inform employees about the hazardous chemicals they could be exposed to.
- Label all chemical containers with identity and hazard warning information.
- Contact the Maryland Safety and Health Consultation Program to help identify and provide recommendations to correct safety hazards.

What Employees Can Do

- Wear gloves when handling hazardous chemicals.
- Wear safety glasses when transferring hazardous chemicals, and when using chemicals in a way that might cause chemical splashes.
- Wear respiratory protection when screen printing or screen washing until ventilation in the screening areas is improved.
- Dispose of lacquer-thinner-soaked cleaning towels and tissue paper into closed containers immediately after use. Prepare and use only what is needed for the immediate job.
- Use safety containers approved for flammable liquids for daily use of lacquer thinner.
- Electrically bond containers when pouring flammable liquids from one container to another.
- Store flammable liquids in the flammable material storage cabinets.

Summary

On November 14, 2006, NIOSH received a request for an HHE from the management of Inter Sign National, Inc., in Baltimore, Maryland. Management of the company was concerned about potential adverse health effects from employees' exposures to organic solvents in lacquer thinner and screen printing inks. In response to these concerns, NIOSH conducted a site visit on December 5–6, 2007. During the site visit NIOSH met with management and employee representatives, observed work activities, assessed PPE use, evaluated ventilation for the screen printing and spray painting operations, and measured exposures to toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone.

Full shift exposure to toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone did not exceed OELs. However, exposure to the mixture of solvents slightly exceeded the ACGIH TLV. Short term exposure to isopropyl alcohol during screen printing and screen washing could exceed STELs. Improved ventilation in the screen printing area is recommended. The use of nonsolvent or low solvent alternatives for screen printing should be investigated for feasibility.

Full-shift monitoring results indicated that air contaminant concentrations for the screen printer, screen printer helper, spray painter, and an area sample in the screening area were below OELs. Additionally, exposure to the combined mixture (additive exposure) of toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone was low, based on NIOSH RELs and OSHA PELs. However, using ACGIH TLVs, additive exposure for the screen printer helper and the area sample indicated slight overexposure to the organic solvent mixture, and the screen printer was nearly overexposed to the mixture of solvents.

Short-term air samples for toluene, isopropyl alcohol, and acetone revealed isopropyl alcohol concentrations during screen printing and screen washing have the potential to exceed the NIOSH and ACGIH STELs. Short term concentrations of toluene and acetone were well below applicable STELs. We recommend that the company investigate replacing solvent-based screen printing products with nonsolvent or low solvent alternatives.

We observed employees leaving cleaning towels or tissue paper soaked with lacquer thinner on a work desk near the screen printing tables. Evaporation of solvents from these items can contribute to worker exposures. We recommend that employees only use what is needed for the immediate task and promptly dispose of solvent soaked towels and tissue paper in closed containers after use.

The screen printing area did not have exhaust ventilation. Ventilation smoke tubes indicated little air movement in the work area. Opening the window near the screen printing table and operating the fan at the window would improve ventilation. We noted that the window is only opened and the fan used during

warm weather. Therefore, we recommend installing an exhaust ventilation system for screen printing. Ventilation of the spray paint booth was found to be sufficient.

We recommend that all employees performing screen printing and screen washing wear NIOSH-approved respiratory protection until engineering or administrative controls reduce exposures to the mixture of organic solvents to below the ACGIH TLV. Based on the measured exposure, elastomeric half-mask respirators equipped with organic vapor cartridges would provide adequate protection. Employees wearing respirators must be properly fitted with the respirators, receive training on respirator use, and undergo medical evaluations for respirator use. The company must also prepare a written respirator program that documents how they comply with OSHA respiratory protection program requirements.

We observed work activities that might cause splashing of screen printing chemicals into the eyes or onto the hands of workers. Protective eyewear was not worn, and available gloves were not appropriate to protect against the chemicals in lacquer thinner and screen printing inks. We recommend that the company provide gloves made of Viton®/butyl combination or laminate plastic film. Employees should consistently wear gloves and protective safety glasses or goggles when using chemicals. An emergency eyewash station should also be installed in the work area. The company needs to complete a PPE hazard assessment including written documentation of a hazard assessment and PPE training, as is required by OSHA PPE standards.

Fire safety hazards in the workplace were observed, including improper plastic containers used for lacquer thinner, excessive quantities of lacquer thinner stored in the spray paint booth, and dispensing and receiving containers of flammable liquids without proper bonding. Containers in the screening area were not properly labeled according to OSHA hazard communication program requirements. Additionally, the company had not completed a written hazard communication program or completed employee training, which are both required by OSHA to inform workers about the dangers of chemicals they are exposed to in the workplace.

Keywords: NAICS 339950 (Sign Manufacturing), screen printing, silk screening, organic solvent, lacquer thinner, toluene, n-hexane, isopropyl alcohol, acetone, cyclohexanone, dermal exposure, PPE

INTRODUCTION

In November 2006, NIOSH received a management request for an HHE at Inter Sign National, Inc., in Baltimore, Maryland. Company management and employees were concerned about possible adverse health effects from exposures to organic solvents from screen printing and spray painting. On December 5–6, 2007, NIOSH visited the facility to collect air samples, assess PPE used by employees, and evaluate exhaust ventilation of the screen printing and spray painting operations.

Inter Sign National, Inc., designs, fabricates, and screen prints acrylic architectural signs for a variety of businesses such as healthcare, schools, office, retail, religious institutions, leisure industry, and government. The company is housed in a four-story 35,000-square-foot building that measures approximately 120 feet long and 30 feet wide. Screen printing and spray painting are performed in separate work areas on the third floor. Administration, customer service, sales, design, screen preparation, and cut-out of acrylic signs are conducted on other floors of the building. The building has zoned heating and air conditioning, and each floor has two HVAC units except for the third floor, which has only one unit. The third floor has seven windows that are sometimes opened when the weather is warm. Inter Sign National, Inc. has 22 employees, but only three employees are involved in screen printing and spray painting. All employees work on the day shift.

Prior to printing, employees on the fourth floor prepare screens by affixing the appropriate design image and lettering to the screen as specified by the work order. For printing, the screen is placed on top of the sign after which the screen printer pours ink (Nazdar® System 2 gloss vinyl screen ink) onto the screen and then uses a squeegee to evenly spread the ink across the screen and transfer the screen image onto the sign. After screen printing, the completed signs are placed on a drying rack nearby in the screening area. Excess unused ink is removed from the screen and dumped into a container designated for used ink. The remaining ink residue is removed from the screens with a solvent-based screen wash (PPG Industries DTL10 acrylic lacquer thinner). The screen printer thoroughly soaks the screen with screen wash and then uses disposable shop towels to clean the screens and soak up excess screen wash. Saturated towels are disposed of in a waste container with a self-closing lid. Clean screens air dry in the screening area and are then returned to the design and preparation area. For most of the day the screen printer works at a table in the screen printing area preparing signs for screen printing and mixing inks, when necessary. The screen printer helper works at a table near

Introduction (continued)

the screen printer and assists with preparation of signs for screen printing. The screen printer helper occasionally prepares inks and cleans screens. The screen printing area has two screen printing tables, but only one is used at a time. Screen printing is usually performed for 4 to 5 hours each day.

Signs are spray painted in a Global company spray booth (Model FP-1288.125), which measures approximately 8 feet x 12 feet x 9 feet. The spray booth was installed in late 2006. Prior to that, spray painting was performed on the open floor. Spray painting is typically conducted for less than 4 hours each day. The spray painter works in other areas of the building for the remainder of the work shift.

Assessment

On December 5, 2007, full-shift PBZ air samples for toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone were collected on the screen printer and screen printer helper. Both employees worked in the screen printing area for most of the work shift, except for two 15-minute breaks and a few times when they briefly (2 to 5 minutes) went to another work area in the building. On the day of air monitoring, the screen printer also left the screen printing area in the late morning for a meeting that lasted 40 minutes. A general area sample for these air contaminants was also collected at a stationary location approximately 8 feet behind the screen printing table to represent solvent concentrations in the general work area. On December 6, 2007, PBZ air samples for isopropyl alcohol, toluene, acetone, n-hexane, and cyclohexanone were collected on the spray painter. The spray painter worked in the paint booth for about 3 hours. During screen printing and spray painting, concentrations of isopropyl alcohol, toluene, and acetone were also measured near employees using Draeger Safety direct reading colorimetric indicator tubes and a Draeger Accuro® bellows pump (Draeger Safety, Luebeck, Germany).

Airflow across the face of the spray booth was measured with a TSI VelociCalc air velocity meter (TSI Incorporated, Shoreview, Minnesota). Ventilation smoke tubes were used to observe air flow patterns in the screen print area and in the paint spray booth.

Additional details about air sampling methods are provided in Appendix A.

Screen Printing and Spray Painting

Time-weighted average air monitoring results are provided in Table 1. Air contaminant concentrations were below OELs established by NIOSH, OSHA, and ACGIH. Air contaminant concentrations were similar for the screen printer, screen printer helper, and area sample. Toluene concentrations were 74% to 84% of the ACGIH TLV. With the exception of cyclohexanone, the spray painter's exposures were more than 30% less than the screen printer's and screen printer helper's exposures. Although spray painting was only performed for about 3 hours, as is typical, it is anticipated that if spray painting were performed for the entire work shift, full shift TWA exposures would be similar.

Table 1. Time-weighted average air sampling results for organic solvents

Job Title	Sample Time (minutes)	Concentration (ppm)				
		Toluene	n-Hexane	Isopropyl alcohol	Acetone	Cyclohexanone
Screen Printer	459	15	5.1	10	27	0.42
Screen Printer Helper	419	17	5.7	9.8	31	0.28
Area Sample Screen Printing	426	16	4.8	10	26	0.33
Spray Painter	178	9.8	2.9	6.9	14	0.60
NIOSH REL		100	50	400	250	25 (skin)
OSHA PEL		200	500	400	1000	50
ACGIH TLV		20	50 (skin)	200	500	20 (skin)

Employees' exposures to the five organic solvents measured during the survey were below OELs. However, these chemicals have similar adverse health effects in the body (refer to Appendix B), and evaluating exposure based solely on the exposure limits for the individual organic solvents may underestimate the potential for adverse health effects from exposure to a mixture of these chemicals. Therefore, the combined additive effect of exposure to these chemicals was evaluated.

Additive exposure was calculated using the following formula:

$$AE = C_1/L_1 + C_2/L_2 + \ldots + C_n/L_n$$

Where:
AE = additive exposure index for the air contaminant mixture
C_n = measured airborne concentration of the contaminant
L_n = corresponding occupational exposure limit for the air contaminant

If the calculated additive exposure index is greater than unity (1.0), the employee is considered to be overexposed to the mixture of chemicals [CFR 2006; ACGIH 2007].

Results of calculated additive exposures are provided in Table 2. Using NIOSH and OSHA exposure limits, the calculated additive exposures to organic solvents were less than 50% of unity. However, based on ACGIH TLVs, the screen printer helper and area sample results indicate exposures to the mixture of organic solvents from screen printing were slightly greater than unity (1.0), indicating overexposure to the mixture of chemicals. Additive exposure for the screen printer was just below unity.

Table 2. Calculated additive exposures to organic solvents (toluene, n-hexane, isopropyl alcohol, acetone, cyclohexanone) based on NIOSH, OSHA, or ACGIH criteria

Job Title	Calculated additive exposure index		
	NIOSH	OSHA	ACGIH
Screen Printer	0.40	0.14	0.97
Screen Printer Helper	0.44	0.16	**1.09**
Area Sample Screen Printing	0.40	0.15	**1.02**
Spray Painter	0.25	0.10	0.64

Overexposure to a chemical mixture with additive properties occurs if unity (1.0) is exceeded, as shown in bold.

Results of air sampling for isopropyl alcohol, toluene, and acetone during screen printing and spray painting using direct reading colorimetric detector tubes are provided in Table 3. Because detector tube results have a standard deviation of 25%, the range for these results is also reported in the table. These results indicate that airborne concentrations of isopropyl alcohol during screen printing, but not spray painting, potentially exceeded the NIOSH and ACGIH STELs (OSHA does not have a STEL for isopropyl alcohol). Toluene and acetone concentrations were well below applicable STELs.

Table 3. Colorimetric detector tube air sample results

Work Activity (time sample collected)	Concentration (ppm) Measured (Range)		
	Toluene	Isopropyl alcohol	Acetone
Screen printing (9:00 a.m.)	50 (38 – 62)	500 (375 – 625)	40 (30 – 50)
Break (2:00 p.m.)	7 (5 – 9)	200 (150 – 250)	Not Detected
Screen printing (2:45 p.m.)	25 (19 – 31)	500 (375 – 625)	Not Detected
Spray painting (11:10 a.m.)	5 (4 – 6)	25 (19 – 31)	40 (30 – 50)
NIOSH STEL	150	500	No STEL
OSHA STEL	300 Ceiling 500 Peak (10 min.)	No STEL	No STEL
ACGIH STEL	No STEL	400	750

Spray Booth Ventilation

Airflow into the spray booth was measured with an air velocity meter. The face of the booth is 10 feet wide and 6.75 feet high. Air velocity measurements were taken at the center of each of the 18 filter panels across the face of the booth. Exhaust velocity across the face of the booth averaged 215 fpm (range: 170 to 336 fpm). This average exhaust velocity exceeds the range of 125–175 fpm required by OSHA for large booths [29 CFR 1910.94(c)] and 100–200 fpm recommended by ACGIH [ACGIH 2007]. The volumetric flow rate of the spray booth, based on the average air velocity and dimension of the booth face, was 14,512 cubic feet per minute.

Other Observations

- Employees using hazardous chemicals, such as lacquer thinner, did not always wear chemical protective gloves when performing activities that might result in exposure to the skin (e.g., cleaning the screen printing squeegee). Additionally, the gloves provided were made of latex, which is not a proper glove material for lacquer thinner and other screen printing chemicals.

- During activities that might result in chemical splashes to the eye, such as dispensing or pouring chemicals, employees did not wear protective eyewear. Additionally, emergency eyewash stations were not available in the immediate work area.
- Plastic containers were used to contain lacquer thinner screen wash (Figure 1), a class 1B flammable liquid. These containers were 2-quart capacity, which is greater than the 1-quart volume permitted by OSHA regulation, and were not approved containers for flammable liquids [29 CFR 1910.106(d)(2)(iii)].

Figure 1. Plastic containers used for lacquer thinner were not approved containers for flammable liquids.

- Five 5-gallon containers of lacquer thinner, which was more than a 1-day supply of lacquer thinner, were stored in the spray paint booth [29 CFR 1910.107(e)(2)].
- No bonding wire was used to connect dispensing and receiving containers of flammable liquids to prevent possible accumulation of a static charge and spark when pouring flammable liquids from one container into another container [29 CFR 1910.106(e)(6)(ii)].
- No PPE hazard assessment that includes a written PPE hazard assessment and documentation of employee training had been completed, as required by OSHA [29 CFR 1910.132].
- No hazard communication program that includes employee training and a written program to inform employees of the hazards of the chemicals they work with had been implemented, as required by OSHA [29 CFR 1910.1200].

Results (continued)

- Several containers of hazardous chemicals were not properly labeled with the identity of the hazardous product and with hazard warning information (to warn employees of the hazards of exposure to the chemicals), as required by OSHA [29 CFR 1910.1200(f)(5)]. Examples include:
    - Half-gallon containers of screen wash (lacquer thinner)
    - Small containers of screen inks on a table next to the screening table
    - Five-gallon containers of screen wash in the third floor safety cabinet (the 0.5-gallon screen wash containers were filled from these larger containers)
    - Gallon-size container of lacquer thinner in paint booth used to clean ink off tools

- Although no reportable injuries or illnesses had occurred during the year, the company had not maintained OSHA's Form 300 Log of Work-Related Injuries and Illnesses [29 CFR 1904].

Discussion

Screen Printing

Air monitoring results indicted that the TWA exposures to toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone for the screen printer, screen printer helper, and general area sample did not exceed NIOSH, OSHA, or ACGIH 8-hour OELs. Other investigators have similarly found exposures to individual organic solvents in screen printing operations to be below OELs [Samimi 1982; White et al. 1995; Horstman et al. 2001; NIOSH 2001]. A NIOSH investigation of solvent exposures during silk screening on highway traffic signs found that exposures to 2-ethoxyethyl acetate exceeded the NIOSH REL, but exposures to all other organic solvents were well below OELs [NIOSH 1995]. Although 8-hour TWA concentrations of organic solvents were below OELs, the concentrations of toluene were about 80% of the ACGIH TLV. Toluene is one of the primary components (40%–70%) in the screen wash. A study of solvent exposures at small screen printing plants in the Netherlands also identified high toluene concentrations in the plants. Toluene concentrations in the screening area in four of the nine plants investigated were above ACGIH TLV levels [Verhoeff et al. 1988].

We evaluated the combined or additive exposures to organic solvents because the solvents in screen wash and screen printing inks have similar toxic effects in the body. Results revealed that exposure to the mixture of solvents slightly exceeded ACGIH TLVs, primarily because the ACGIH TLV for toluene is only 20 ppm. In contrast, exposures did not exceed NIOSH and OSHA OELs, because NIOSH and OSHA have substantially higher exposure limits for toluene. Other researchers have also found overexposure to the combined mixture of screen printing solvents [Samimi 1982; White et al. 1995; Horstman et al. 2001]. The screen printer estimated that about 1 gallon of lacquer thinner is used for screen printing and washing each day. However, if the amount of lacquer thinner used increases, subsequent solvent exposures would likely also increase.

Figure 2. Evaporation of solvent from lacquer thinner soaked towels on a workbench near the screen printing table.

While full-shift TWA exposures to isopropyl alcohol were well below OELs, detector tube measurements for isopropyl alcohol collected during screen printing showed that short-term exposures have the potential to exceed NIOSH and ACGIH STELs. Given the low full-shift TWA concentrations for isopropyl alcohol, the high levels measured with the detector tubes were somewhat unexpected. However, researchers have found that high short-term airborne concentrations of solvents can occur, particularly during screen cleaning and washing [White et al. 1995; Horstman et al. 2001; Leung et al. 2005]. Detector tube measurements were not collected during screen washing because the time spent washing a screen was generally less than the time needed to collect detector tube measurements for acetone, toluene, and isopropyl alcohol. However, air contaminant concentrations during screen washing would be as high as those measured during screen printing or possibly greater because more lacquer thinner is used during screen washing than is used in the inks for screen printing.

Figure 3. Evaporation of solvent from lacquer thinner soaked tissue paper on a workbench near the screen printing table may contribute to employee exposure.

Sometimes lacquer-thinner-soaked cleaning towels used for cleaning rubber squeegees are left on the work desk near the screen printing table (Figure 2). Additionally, the work desk had a stack of tissue paper that was soaked with lacquer thinner (Figure 3). The tissue paper is used for cleaning excess ink off plastic. Solvents will continue to evaporate from the towels and tissue paper during nonuse and can contribute to overall solvent concentrations in the work area. Presoaking of cleaning towels immediately prior to use and properly disposing of used towels and tissue paper into closed containers following use will help minimize solvent evaporation from these items.

Some exposure to solvents occurs because of evaporation from lacquer-thinner-soaked items that are left out on work tables and from the residual solvent vapors remaining in the work area due to poor ventilation. However, most exposure occurs during screen printing and screen washing, even though these tasks are performed for a relatively small percentage of the workday. In a study of 10 small screen printing shops, researchers found that the time spent screen printing and washing represented less than one third of the workday, but resulted in most of the solvent exposure [Horstman et al. 2001]. Therefore, efforts to reduce exposures should focus on reducing air contaminant levels generated by screen printing and screen washing, such as through improving ventilation in the screen printing area. Additionally, the use of nonsolvent or low solvent (particularly low toluene) alternatives for screen washing and screen printing should be investigated for feasibility.

Results for the screen printer, screen printer helper, and area sample were nearly identical. We would have expected the screen printer to have the highest exposures because that employee works more closely with the screen inks and screen wash. This lack of difference is probably related to poor ventilation in the screen printing area, which may have resulted in a relatively even distribution of air contaminants in the area.

The screen printer reported commonly feeling fatigued at the end of the work day. Recovery from fatigue usually occurred after a few days without exposure. Fatigue can be caused by many factors, and linking these fatigue symptoms directly to solvent exposures without medical evaluation or testing is difficult. However, other studies of screen printing workers have found that fatigue was more common in workers exposed to solvents than in workers not exposed to solvents [Ng et al. 1990; Horstman et al. 2001].

On the day of air monitoring the temperature outside was below 30°F. As a result, the window near the screening table was not opened, and the fan next to the window was not operating. The screening area does not have exhaust ventilation, with the exception of the fan, when used, and the window, when opened. Observation of air flow using ventilation smoke tubes revealed little air movement. On days when the window is opened and the fan used, overall air contaminant levels should be lower, but the effectiveness of this ventilation may be affected by outdoor wind speed and direction. Because exposure to the mixture of screening solvents exceeded the ACGIH TLV and short-term concentrations during screen printing have the potential to exceed NIOSH and ACGIH STELs, improved ventilation in the screening area is needed. Opening the window near the screen printing table and using an exhaust fan to direct air outdoors could help reduce exposures, but installing a properly designed exhaust ventilation system would provide better and more consistent contaminant control.

Until ventilation is improved in the screen printing area or solvent exposures are reduced through substitution of less hazardous chemicals, all employees performing screen printing and screen washing should wear respiratory protection. Based on the measured exposure, NIOSH-approved elastomeric half-mask respirators equipped with organic vapor cartridges would provide adequate protection. Employees wearing respirators must be properly fitted with the respirators, receive training on respirator use, and undergo medical evaluations for respirator use. The company must prepare a written respirator program that documents how they comply with OSHA respiratory protection program requirements.

Spray Painting

The spray painter only painted for about 3 hours during air monitoring, but the air monitoring results are considered representative of full-shift exposures. Exposures to toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone solvents during spray painting were below OELs, and generally lower than exposures during screen printing. This result was expected given that spray painting is conducted in a spray booth with exhaust ventilation, whereas the screen printing area has no exhaust ventilation. Exhaust velocity of the spray booth exceeded OSHA requirements and met ACGIH recommended rates for spray booths. Visual observation of ventilation smoke tube traces in the spray booth during simulated spray painting also revealed that the booth adequately draws air away from an employee's typical work position when holding the spray nozzle about 2 feet from the face. However, if the spray painting were performed with the nozzle held closer to the face, turbulent air currents could pull spray paint mist and vapors back toward the worker's face. Therefore, spray painters should continue to hold the spray nozzle at arm's length during spray painting.

Dermal Exposure

While inhalation of organic solvents is a well known route of workplace exposure, dermal exposure to organic solvents can also be an important exposure pathway in the workplace and contributes to potential adverse health effects. Organic solvents dissolve the protective fat in the epidermis and allow chemicals to be absorbed into the body and cause skin irritation. The rate of absorption through the skin depends upon the degree of lipid and water solubility of the solvent [Rosenberg et al. 1997]. For some solvents, overexposure can occur after dermal contact even if airborne exposures are below OELs. ACGIH has given cyclohexanone and n-hexane a skin notation indicating the potential for dermal absorption [ACGIH 2009]. NIOSH has given cyclohexanone a skin designation [NIOSH 2005].

The screen printer, screen printer helper, and spray painter wore Microflex® Safegrip™ extended cuff powder-free latex exam gloves. The screen printer wore these gloves when cleaning the screen, but did not wear gloves during other screen printing activities. Some dermal exposure of hands to screen inks and lacquer thinner was observed, particularly when employees cleaned the squeegee screening tool. Furthermore, latex is not an appropriate glove material for the chemicals in the inks or lacquer thinner because the solvents in these products can degrade latex relatively quickly. Additionally, some people are allergic to latex. Inks and lacquer thinner are composed of a combination of several chemicals, and the gloves selected must provide adequate protection from these chemical components. Gloves made of Viton®/butyl or laminate plastic film such as Ansell Barrier® (triple-layer polyethylene, polyamide, polyethylene) or North Silvershield®/4H® (triple-layer polyethylene, ethylene vinyl alcohol, polyethylene) would provide better protection from the solvents encountered during screen printing and spray painting [Forsberg and Mansdorf 2007]. One of the challenges regarding selection of chemical protective gloves is finding gloves that provide necessary features such as fit and dexterity to allow workers to perform their work while still providing appropriate chemical protection. Therefore, it is important to consider chemical protection needs along with job needs when selecting and purchasing protective gloves.

Personal Protective Equipment Hazard Assessment

All employers are required by OSHA to complete a comprehensive assessment of their workplaces to determine if hazards are present, or likely to be present, that would require the use of PPE such as safety glasses, protective gloves, safety shoes, or other PPE. Lack of appropriate PPE may result in injuries, including eye injuries caused by projected debris or chemical splashes, burns or skin injuries from chemical splashes, skin absorption of hazardous chemical agents, head or foot injuries from falling objects, lacerations from sharp objects or edges, and trauma from falls. Employees must also be trained to know when PPE must be used, what type of PPE is required, how to properly adjust and wear the PPE, what are the limitations of the PPE (e.g., what it will not protect them against), how to properly take care of the PPE, or in the case of disposable PPE, how to know when it is time to dispose of it. OSHA requires the employer to document in writing that the PPE hazard assessment and employee training have been completed.

Hazard Communication Program

Employers using hazardous chemicals are required by OSHA to implement a hazard communication program to provide employees with information necessary to protect themselves from the physical and health hazards associated with using chemicals. Employees who are not aware of the hazards of the chemicals are less likely to handle the chemicals safely. Employees who do not know the health effects of chemical exposure may not recognize symptoms of overexposure, leading to delayed, or inadequate treatment, or misdiagnosis of illness. A hazard communication program includes a written program that describes and documents how the requirements for material safety data sheets, container labeling, and employee training will be achieved. The written program must also include a list of all hazardous chemicals that are used at the facility, the methods that will be used to inform employees of the hazards of nonroutine tasks, and the methods used to inform contract employees of the hazards of chemicals they may be exposed to at the facility.

Conclusions

Employees' full-shift TWA exposure to toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone from screen printing and spray painting did not exceed OELs. However, employee exposure to the mixture of these solvents indicated an overexposure based on the ACGIH TLVs. Additionally, short duration exposure to isopropyl alcohol during screen printing or screen washing could reach or exceed the NIOSH or ACGIH STELs. While ventilation in the paint spray booth is adequate, improved ventilation in the screening area is needed to reduce employee exposures.

Skin contact with lacquer thinner during some screen printing activities was observed, and the use of chemical protective gloves was inconsistent. Furthermore, protective gloves available for use by employees were not suitable for the screen printing and spray painting chemicals. In addition, employees did not use eye protection when pouring or dispensing hazardous chemicals.

A personal protective hazard assessment including written documentation of a hazard assessment and training had not been completed. Additionally, the company had not completed a hazard communication program or completed employee training to inform workers about the hazards of chemicals they use.

Several fire safety hazards in the workplace were identified. These included improper plastic containers for lacquer thinner storage, more than a 1-day supply of lacquer thinner stored in the spray paint booth, and dispensing and receiving containers of flammable liquids not properly bonded when flammable liquids were poured from one container to another.

Based on our findings, we recommend the actions listed below to create a healthier work place. We encourage Inter Sign National, Inc. to use these recommendations to develop an action plan based, if possible, on the hierarchy of controls approach (refer to Appendix B: Occupational Exposure Limits and Health Effects). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and/or personal protective equipment may be needed.

Elimination and Substitution

Elimination or substitution of a toxic/hazardous process material is a highly effective means for reducing hazards. Incorporating this strategy into the design or development phase of a project, commonly referred to as "prevention through design," is most effective because it reduces the need for additional controls in the future.

1. Investigate whether nonsolvent or low-solvent-based screen printing chemicals and screen washes might be feasible. Contact trade organizations, such as the Specialty Graphic Imaging Association to determine what nonsolvent or low-solvent-based options are available and whether other companies have been able to successfully use them (website: www.sgia.org/, phone: 888-385-3588).

Engineering Controls

Engineering controls reduce exposures to employees by removing the hazard from the process or placing a barrier between the hazard and the employee. Engineering controls are very effective at protecting employees without placing primary responsibility of implementation on the employee.

1. Improve ventilation in the screen printing area. Due to the relatively low volume of screen printing, an explosion-proof window fan that exhausts air out the window at the screen printing table might provide enough ventilation to reduce organic solvent concentrations. However, a properly

designed local exhaust system, such as a slot ventilation hood (Figure 4), would provide better capture and exhaust of solvent vapors.

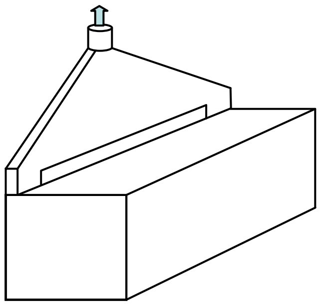

Figure 4. Example of a slot ventilation hood for the screen printing table.

Administrative Controls

Administrative controls are management-dictated work practices and policies to reduce or prevent exposures to workplace hazards. The effectiveness of administrative changes in work practices for controlling workplace hazards is dependent on management commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that control policies and procedures are not circumvented in the name of convenience or production.

1. Reduce evaporation of solvents into the workplace from cleaning towels and tissue paper soaked with lacquer thinner by preparing these items immediately prior to use and disposing into closed containers following use.

Personal Protective Equipment

PPE is the least effective means for controlling employee exposures. Proper use of PPE requires a comprehensive program and calls for a high level of employee involvement and commitment to be effective. The use of PPE requires the choice of the appropriate equipment to reduce the hazard and the development of supporting programs such as training, change-out schedules, and medical assessment if needed. PPE should not be relied upon as the sole method for limiting employee exposures. Rather, PPE should be used until engineering and administrative controls can be demonstrated to be effective in limiting exposures to acceptable levels.

1. Provide employees with respiratory protection for use during screen printing tasks until product substitution or improved ventilation in the screen printing area reduces organic solvent exposures. Based on the measured exposures, NIOSH-approved, elastomeric half-mask respirators equipped with organic vapor cartridges would provide adequate protection. Employees wearing respirators must be properly fitted with the respirators, receive training on respirator use, and undergo medical evaluations for

respirator use. The company must prepare a written respirator program that documents how they comply with OSHA respiratory protection program requirements. Refer to OSHA's *Small Entity Compliance Guide* for additional guidance on developing a respiratory protection program at www.osha.gov/Publications/secgrev-current.pdf.

2. Provide appropriate chemical resistant gloves to protect against skin contact with screen printing and spray painting products such as lacquer thinner and screen printing inks. Based on the primary ingredients in screen inks and lacquer thinner, gloves made of Viton®/butyl combination or laminate plastic film such as Ansell Barrier® (polyethylene, polyamide, polyethylene combination) or North Silvershield®/4H® (polyethylene, ethylene vinyl alcohol, polyethylene combination) would provide better protection from the solvents encountered during screen printing and spray painting [Forsberg 2007].

3. Provide and require employees to wear protective eyewear when using hazardous chemicals and performing activities that might result in chemical splashes.

4. Install an emergency eye wash station in the screen printing area. The eye wash can be either plumbed or self-contained, but must be capable of providing adequate liquid for at least 15 minutes of drenching or flushing of the eyes.

Fire Safety

Figure 5. A better solution for daily storage and dispensing of flammable liquids is a safety can with a plunger mechanism.

1. Do not use plastic containers for lacquer thinner or any other flammable or combustible liquids, unless the plastic container has been approved by the UL for use with flammable liquids. Additionally, use a UL-approved plastic container that can hold no more than one quart of a flammable liquid such as lacquer thinner. A better container for daily use of lacquer thinner is a UL-approved metal safety container with a plunger dispensing mechanism (Figure 5).

2. Electrically ground containers of flammable liquids and make sure that dispensing and receiving containers are properly bonded before transferring flammable liquids (Figures 6 and 7). The National Fire Protection Association Standard 30: Flammable and Combustible Liquids Code has additional guidance on safe storage, handling, and use of volatile substances and is available at www.nfpa.org/catalog/category.asp?category%5Fname=Hazardous+Materials&Page=1&src=catalog.

3. Do not store more than a 1-day supply of lacquer thinner, screen inks, or other flammable liquids in the spray paint booth. Use the flammable material storage cabinets for storage.

Figure 6. Proper electrical grounding and bonding of containers of flammable liquids helps prevent accumulation of static charges that could ignite the liquids.

Figure 7. Example of electrical grounding and bonding cables.

Safety and Health Programs

1. Contact the Maryland Occupational Safety and Health Consultation Program to help identify and correct safety hazards, and for guidance on completing a PPE hazard assessment and hazard communication program. The Maryland consultation program provides free assistance in identifying and addressing safety and health hazards for companies that agree to correct hazards. Refer to the Maryland consultation program website for more information at www.dllr.state.md.us/labor/volc.html. Information about PPE can also be found on the OSHA website at www.osha.gov/SLTC/personalprotectiveequipment/index.html. Examples of written PPE hazard assessment and training documentation can be obtained by calling the Maryland Consultation Program at 866-225-0478 or emailing aalcarese@dllr.state.md.us. Guidance on hazard communication program requirements and an example written hazard communication program are available on the Maryland Safety and Health Consultation Program website at www.dllr.state.md.us/labor/rtkhaztox/index.html#web.

2. Maintain an OSHA Form 300 Log of Work-Related Injuries and Illnesses each calendar year. A copy of the OSHA Log and instructions for properly completing the log are available on the OSHA website at www.osha.gov/recordkeeping/new-osha300form1-1-04.pdf.

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Appendix A: Methods

Material safety data sheets for the screen inks and screen wash were obtained from the company prior to the site visit. After review of MSDSs, toluene, n-hexane, isopropyl alcohol, acetone, and cyclohexanone were selected for environmental sampling. These chemicals were selected because they can cause central nervous system depression, had NIOSH or OSHA exposure limits, were greater than 5% of the composition of the screen ink or screen wash, and had NIOSH analytical methods to support environmental sampling.

Full-shift air samples for toluene, n-hexane, and isopropyl alcohol were collected on charcoal tubes, and full-shift air samples for acetone and cyclohexanone were collected on Anasorb® CMS tubes. For full-shift PBZ air samples the sampling media were attached to the employee's shirt collar within the breathing zone (breathing zone is defined as an area in front of the shoulders with a radius of 6 to 9 inches). Area samples were collected by attaching the sample media to a shelf located approximately 8 feet from the screen printing table. Tygon® tubing was used to attach the sample media to air sampling pumps, which drew air through the media at a sampling flow rate of 100 cc/min. Each air sampling pump was calibrated before and after use. The samples were analyzed by gas chromatography using a flame ionization detector based on NIOSH Method 1400 (for isopropyl alcohol), NIOSH Method 1500 (for toluene and n-hexane), and NIOSH Method 2555 (for acetone and cyclohexanone) [NIOSH 2008].

Short term "grab" air samples (air samples that take approximately 1 or 2 minutes to collect) for toluene, isopropyl alcohol, and acetone were also measured directly using Draeger Safety direct reading colorimetric indicator tubes and a hand-powered Draeger Accuro® bellows pump (Draeger Safety, Luebeck, Germany). The detector tubes are used by drawing air through the tube with a bellows-type pump. The resulting length of the stain in the tube produced by a chemical reaction with the sorbent is proportional to the concentration of the air contaminant. Detector tube samples were collected approximately 1 meter from the worker.

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Occupational Exposure Limits

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 workers 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 workers 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 worker 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- to 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 United States, 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 2005]. NIOSH also recommends different types of risk management practices (e.g., engineering controls, safe work practices, worker 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 United States 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 2009]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2009].

Outside the United States, 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 United States, available at www.dguv.de/bgia/en/gestis/limit_values/index.jsp. 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 worker health that focuses resources on exposure controls by describing how a risk needs to be managed. Information on control banding is available at 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.

Health Effects: Organic Solvents

Organic solvents are a large class of chemicals that contain carbon and have a sufficiently high vapor pressure to allow some of the compound to exist in the gaseous state at room temperature. These chemical compounds are commonly used for tasks such as cleaning, painting, printing, degreasing, thinning, and extraction. Occupational exposure criteria exist for some individual organic solvents, but do not exist for organic solvents as a group. Some of the organic solvents used in this facility include toluene, n-hexane, isopropyl alcohol, acetone, cyclohexanone, 2-propoxyethanol, naphtha, isohexane, 1-methoxy-2-propyl acetate, and 3-methylpentane. These chemicals are ingredients in the lacquer thinner or screen printing inks.

Inhalation and dermal exposure are both important routes of exposure to organic solvents in the workplace. Absorption through the skin depends upon the degree of lipid and water solubility of the solvent [Rosenberg et al. 1997]. Almost all organic solvents cause irritation of the skin because they remove fat from the skin. Solvents are also among the leading causes of occupational skin disease [Cone 1986]. Organic solvents may cause minimal to mild irritation of the respiratory system [Blanc et al. 1991]. This irritation is usually restricted to the upper airways, mucous membranes and eyes, and it generally resolves quickly without long-term effects [Rosenberg et al. 1997].

Almost all volatile organic solvents can acutely cause nonspecific central nervous system depression. The symptoms of significant acute solvent exposure are similar to those from drinking too many alcoholic beverages, including headache, nausea and vomiting, dizziness, slurred speech, impaired balance, poor concentration, disorientation, and confusion. These symptoms go away quickly upon cessation of exposure [Gerr and Letz 1998]. Subtle, reversible decrements in performance on attention and reaction time testing have been observed with acute exposures to solvents, but may not be directly attributable to nervous system dysfunction, since similar effects are seen when the main effect of exposure is headache or eye irritation. Rarely, death from respiratory depression can occur at very high exposure levels.

Peripheral neuropathies and chronic central nervous system disorders (organic affective syndrome and mild chronic toxic encephalopathy) have been reported among workers chronically exposed to solvents [NIOSH 1987]. Organic affective syndrome is characterized by fatigue, memory impairment, irritability, difficulty in concentration, and mild mood disturbance. Mild chronic toxic encephalopathy is manifested by sustained personality or mood changes such as emotional instability, diminished impulse control and motivation, and impairment in intellectual function such as diminished concentration, memory, and learning capacity. The extent to which chronic neurotoxicity is reversible remains to be established. There is controversy over whether long-term exposure to solvents can cause toxic encephalopathy. Employees in whom this has been described generally have at least 10 years of relatively intense exposure to solvents.

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Acknowledgments and Availability of Report

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found. HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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