Evaluation of Health Concerns at a Printed Circuit Board Manufacturing Plant

Srinivas Durgam, MSPH, MSChE, CIH
Carlos Aristeguieta, MD, MPH
Chandran Achutan, PhD

Health Hazard Evaluation Report
HETA 2007-0201-3086
Sanmina-SCI® Corporation
Huntsville, Alabama
August 2009

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
NIOSH *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

Appendix C

Acknowledgments

Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
AI	Auto insertion
AL	Action level
ARU	Air rotation unit
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	ASTM International
BLL	Blood lead level
cc/min	Centimeter
cm	Cubic centimeters per minute
CFR	Code of Federal Regulations
CNS	Central nervous system
DAS	Defense and aerospace section
dB	Decibels
dB(A)	Decibels, A-weighted scale
EPA	Environmental Protection Agency
GA	General area
HEPA	High-efficiency particulate air
HHE	Health hazard evaluation
HVAC	Heating, ventilating, and air-conditioning
Hz	Hertz
IEQ	Indoor environmental quality
Lpm	Liters per minute
MEK	Methyl ethyl ketone
MERV	Maximum efficiency reporting value
mg	Milligram
mm	Millimeter
MS	Medical section
MSDS	Material safety data sheet
MVOC	Microbial volatile organic compounds
µg	Microgram
µg/dL	Micrograms per deciliter
$\mu g/ft^2$	Micrograms per square foot
$\mu g/m^3$	Micrograms per cubic meter
µm	Micrometer

Abbreviations (continued)

NAICS	North American Industry Classification System
NCB	Balanced noise criteria
NIHL	Noise-induced hearing loss
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
PPE	Personal protective equipment
ppm	Parts per million
REL	Recommended exposure limit
RH	Relative humidity
STEL	Short term exposure limit
TD	Thermal desorption
TLV®	Threshold limit value
TWA	Time-weighted average
VOC	Volatile organic compound
WEEL	Workplace environmental exposure level
ZPP	Zinc protoporphyrin

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 Sanmina-SCI® Corporation (Sanmina-SCI) in Huntsville, Alabama. The requestors were concerned about exposure to lead solder paste and fumes, dust, mold, and noise from the air rotation units (ARUs). Health effects mentioned in the HHE request included cough, burning eyes, nosebleeds, loss of voice, headache, sinus infection, bronchitis, and respiratory problems. Site visits were made in July and December 2007.

What NIOSH Did

- We looked at work processes and practices in printed circuit board manufacturing.
- We conducted medical interviews and reviewed the medical records of some employees.
- We sampled the air, work surfaces, and employees' hands for lead.
- We sampled the air for volatile organic compounds.
- We measured noise levels at auto insertion stations and checked the room acoustics near the ARUs.
- We checked the air flow pattern of the local exhaust hoods.
- We reviewed previous air sampling records, injury and illness records, the respiratory protection program, and material safety data sheets.

What NIOSH Found

- One employee's exposure when cleaning the wave solder machines exceeded the Occupational Safety and Health Administration (OSHA) action limit and was close to the OSHA permissible exposure limit for airborne lead.
- Lead was found on employees' hands, on work surfaces, and in a break room.
- We were unable to identify the cause of any of the employee symptoms.
- Employees were not overexposed to the volatile organic compounds that were measured.
- Auto insertion operators' noise exposures were very low.
- The room acoustics near the ARUs were appropriate as the production environment did not require telephone communication, and communication between employees was minimal.
- Several local exhaust hoods were not functioning properly. These included three hoods in the medical section and two hoods in the defense and aerospace section.
- The written respiratory protection program did not state which work tasks required respiratory protection nor the type of respirators that employees should wear.
- Employees were concerned about general housekeeping, thermal comfort, and maintenance of the ARUs.

What Managers Can Do

- Comply with the OSHA lead standard requirements.
- Use engineering controls such as portable exhaust hoods when removing solder dross and cleaning wave solder machines.
- Improve general housekeeping practices to ensure break rooms and work surfaces are clean.
- Clean the ARUs that have mold present and maintain them per manufacturer's recommendations.
- Identify in the written respiratory protection program which job tasks and job locations require respiratory protection. The level of protection should also be noted.
- Improve communication with employees about maintenance and filter change-out dates for ARUs.

What Employees Can Do

- Wash hands thoroughly before eating, drinking, smoking, and leaving work to minimize lead exposure.
- Report maintenance and housekeeping problems to your supervisor.
- Tell your supervisor if you have health problems or concerns related to work and follow-up with the occupational health office.
- Learn about the workplace hazards and exposures at Sanmina-SCI and how to protect yourself.

Summary

NIOSH received a confidential employee request to evaluate exposure during the fabrication, assembly, and testing of printed circuit boards. We found a potential health hazard from exposure to lead. We recommend implementing the requirements of the OSHA lead standard and using engineering controls such as portable exhaust hoods when removing solder dross and cleaning wave solder machines. We also recommend regularly cleaning and maintaining ARUs and improving general housekeeping and personal hygiene practices.

NIOSH received a confidential employee request for an HHE at Sanmina-SCI® Corporation (Sanmina-SCI) located in Huntsville, Alabama. Employees were concerned about exposure to solder paste and fumes during the fabrication, assembly, and testing of printed circuit boards, and noise. Other exposure concerns included copy machine toner, asbestos, mold, and dust. Health effects mentioned in the HHE request included cough, burning eyes, nosebleeds, loss of voice, headache, sinus infection, bronchitis, and respiratory problems.

On July 9–10, 2007, we conducted our first site visit. We toured the facility to observe work processes and practices, conducted confidential medical interviews with 40 employees, and collected GA air samples for VOCs and surface wipe samples for lead and tin. We reviewed air sampling records, injury and illness records, the respiratory protection program, and MSDSs. We also reviewed the PPE used for the solder dross cleaning operation and the maintenance schedule for the ARUs.

We conducted a second site visit on December 12–13, 2007. We collected air samples for lead and specific VOCs. We conducted noise dosimetry at the AI stations, evaluated the room acoustics near ARUs, evaluated the effectiveness of local exhaust hoods for the wave solder and surface mount machines, and collected hand wipe samples to assess lead contamination on skin.

We found that a wave solder operator (cleaning wave solder machines) was exposed to an airborne lead concentration of 49 $\mu g/m^3$, which exceeded the OSHA AL (30 $\mu g/m^3$) and was close to the OSHA PEL (50 $\mu g/m^3$). However, during normal wave solder activities, wave solder operators had lead exposures well below the OSHA AL. We found lead on work surfaces and on hands of employees despite hand washing. We also sampled larger surface areas of the break room tables to ensure they were clean but found detectable levels of lead. Air sampling results for specific VOCs indicated that employee exposures were well below all applicable OELs. Full-shift noise exposures for the AI operators in the MS and DAS were well below the NIOSH REL, and the room acoustics were appropriate for the work environment.

A consultant's IEQ assessment report from 2007 identified mold in several ARUs, prompting the company to address employee concerns about odors and mold contamination. Our review of air sampling data collected by the company in March 2007 indicated that the airborne carbon black concentrations resulting from Xerox™ toner cartridge cleaning were below OELs. We did not evaluate asbestos exposure, another concern listed in the original HHE request, because management informed us that asbestos-containing material was identified and being managed-in-place.

Some of the employees we interviewed were concerned about thermal comfort and exposure to dust and solvents. Most interviewed employees did not report work-related symptoms. Furthermore, the upper respiratory symptoms reported by some employees are common in the general population.

We recommend following all requirements of the OSHA lead standard (29 CFR 1910.1025). We recommend using engineering controls such as portable exhaust hoods when removing solder dross and cleaning wave solder machines. General housekeeping practices should be improved to keep break rooms and work surfaces clean. We also recommend cleaning and maintaining the ARUs to ensure mold growth does not occur in the future. Additionally, we recommend revising the written respiratory protection program to address inconsistencies between the written program and current employee respirator use.

Keywords: NAICS 334412 (Printed circuit board manufacturing), lead, mold, VOC, wave solder, solder dross cleaning, air rotation unit, noise

Introduction

NIOSH received a confidential employee request for an HHE at Sanmina-SCI in Huntsville, Alabama. Sanmina-SCI employees were concerned about exposure to solder paste and fumes during the fabrication, assembly, and testing of printed circuit boards as well as copy machine toner, asbestos, mold, dust, and noise. Employees reported cough, burning eyes, nosebleeds, loss of voice, headache, sinus infection, bronchitis, and respiratory problems.

We conducted our first site visit on July 9–10, 2007, which included confidential medical interviews with 40 employees and a tour of the facility to observe work processes and practices. We collected GA air samples for VOCs and surface wipe samples for lead and tin. We reviewed air sampling records, the respiratory protection program, injury and illness records, and other pertinent records. The findings of our first site visit were shared with the employee and management representatives in an interim letter dated November 15, 2007. We conducted a second site visit on December 12–13, 2007, during which we collected PBZ and GA air samples for lead and specific VOCs. We also conducted dosimetry to assess employee exposures to noise, collected hand wipe samples to assess lead contamination on skin, and evaluated the effectiveness of the local exhaust hoods for wave solder and surface mount technology machines.

Facility and Process Description

Sanmina-SCI is an electronics manufacturer specializing in printed circuit board fabrication, assembly, and testing for different end user applications. The facility is divided into the MS (Plant 438) and the DAS (Plant 437). The MS also includes employees working on assembly and quality check of blood glucose monitors. All together, approximately 2,300 employees work either three 10-hour shifts on Monday–Thursday or two 12-hour shifts on Friday–Sunday. Although both sections share the main workspace and have similar tasks and equipment, the health concerns originated exclusively from the MS.

This facility manufactures printed circuit boards using wave solder and surface mount technologies. Wave soldering is a large-scale fabrication process by which various electronic components are inserted into or placed on the printed circuit board after which the loaded board is passed across a wave or cascade of molten solder contained in a tank. The solder adheres to the exposed metallic areas of the board creating a reliable mechanical and electrical connection.

At least once per shift, wave solder operators conduct the solder dross cleaning operation, which involves using a ladle to remove the dross floating on top of molten solder. Residual molten solder inadvertently collected during the dross cleaning operation is separated using a sieve, and the remaining dross is disposed of in a drum that is sealed with a lid. Employees performing dross cleaning are required to wear heat resistant gloves over the disposable nitrile gloves, a face shield, and an apron. In addition to dross cleaning, employees also periodically clean and maintain the wave solder machines.

Surface mount technology involves placing the electronic components onto printed circuit boards containing lead-tin solder pads. Solder paste is loaded onto the solder pads using a stencil, and the printed circuit boards travel through an infrared reflow soldering oven. In the reflow oven the temperature is gradually raised to solder the electronic component leads to the circuit board. The boards are then washed with hydrocarbon-based solvents to remove excess flux residue.

The MS has four wave solder and eight surface mount lines. Wave solder lines 1, 2, and 3 use lead-free solder (96.5% tin), and wave solder line 4 uses solder composed of 63% tin and 37% lead. The DAS has five wave solder lines and six surface mount lines. The DAS also has ruggedization and conformal coating and bonding operations where the finished printed circuit boards are fitted with additional structural supports and hand-brushed or sprayed with an acrylic copolymer to provide increased environmental and mechanical protection. Spraying during conformal coating is conducted in a ventilated open-face bench-top spray booth. The employees (sprayers) were observed wearing safety glasses and air-purifying elastomeric half-facepiece respirators equipped with organic vapor cartridges while spraying.

Both the wave solder and surface mount lines have enclosed local exhaust hoods to capture and direct solvent and/or molten solder vapors to the outside of the building. The enclosed local exhaust hoods on the wave solder machines have a pressure gauge to monitor hood performance. General dilution ventilation for both the MS and DAS is provided by outdoor air. ARUs, which are single-packaged 100% recirculating air-conditioning systems in each side of the facility, provide circulation and cooling.

Introduction (continued)

The AI operation involves machine insertion of electronic components onto a printed circuit board by punching through it. The AI operator remains by the machine until the components are inserted and then exchanges the completed circuit board for a blank one.

The company has a joint employee/management health and safety committee but no onsite medical care. When employees experience health concerns or become ill on the job, they are to report to their supervisor. If necessary, an ill employee is referred by human resources to an occupational health center in Huntsville, Alabama.

Assessment

Industrial Hygiene Evaluation

During our site visit in July 2007, we observed the copy machine toner cleaning operation, AI operation, and solder dross cleaning operation. AI operators had the potential for being exposed to excessive noise levels, and the management informed us that their noise exposures had not been assessed. We therefore decided to evaluate this concern during our next site visit. The copy machine toner operation did not have a high dust generation potential, air sampling results provided by the management were well below the applicable OELs, and the employees used a HEPA vacuum cleaner to clean up any residual carbon black/toner dust. Therefore, we did not evaluate this issue further. Management also informed us that asbestos-containing material had been identified and was managed-in-place, so we did not evaluate this issue further. We examined the preventive maintenance schedule for the reflow ovens and ARUs, reviewed the PPE used for the solder dross cleaning operation, and reviewed the MSDSs provided by the company. We also reviewed the company's respiratory protection program and the industrial hygiene sampling data for the conformal coating operation and solder dross cleaning operation. Management informed us that an IEQ investigation focused on evaluating mold had been conducted in response to employee health concerns and provided a copy of the report for our review.

During this initial visit, we collected eight screening GA air samples for VOCs using TD tubes. In the MS, the GA air samples were collected at wave solder line 2 and surface mount lines 6 and 7, and between surface mount lines 1 and 2. In the DAS, the

GA air samples were collected at surface mount lines 1 and 4 and the conformal coating and bonding operations. We collected 12 surface wipe samples for lead and tin from the MS (six samples), DAS (four samples), and the southeast and southwest break rooms (one sample each). Details on sampling methods used for GA air and surface wipe samples are described in Appendix A.

During the follow-up evaluation in December 2007, we collected air samples on employees in both sections. We collected full-shift PBZ and GA air samples for lead on MS and DAS employees working on or around wave solder machines. Based on results obtained for VOCs on the screening samples, we collected air samples for MEK, toluene, xylene, styrene, 2-butoxyethanol, n-butyl acetate, and benzyl alcohol on MS and DAS employees working on the wave solder and surface mount lines, and on DAS employees in the conformal coating and bonding operations.

Hand wipe samples for lead were collected from 60 available production employees to assess lead contamination on skin. Participants were instructed to perform their normal hand-washing practices prior to eating lunch. Following this, their hands (including between the fingers) were wiped for approximately 30 seconds using pre-moistened Palintest® towelettes, which were then placed into a sterile plastic container.

We evaluated the airflow patterns into and around the enclosed local exhaust hoods for the wave solder and surface mount lines in the MS and DAS using ventilation smoke tubes. We also evaluated noise exposures by collecting personal full-shift noise dosimetry measurements on five AI operators over a period of 2 days. NoisePro™ noise dosimeters were worn by the employees while they performed their daily activities. We collected area noise measurements in the MS and DAS to evaluate employees' exposures when working near the ARUs. Information on noise exposure limits and health effects and a discussion of room acoustics is provided in Appendix B.

Details on the methods used in this evaluation for lead, VOCs, and noise are explained in Appendix A. The OELs and potential health effects for lead, VOCs, and noise are discussed in Appendix B.

Assessment (continued)

Medical Evaluation

We conducted confidential medical interviews on July 9–10, 2007, with employees selected from a roster provided by management and employees who asked to be interviewed. All were from the MS morning shift (shift 4A). The interview included questions about job title, length of employment, exposures, and work-related symptoms. Medical records release forms were obtained from employees who saw a medical provider for possible work-related symptoms.

We also spoke with management representatives to learn about employee health resources and procedures and reviewed the OSHA Form 300, Log of Work-Related Injuries and Illnesses, for 2005, 2006, and 2007.

Results

Industrial Hygiene Evaluation

Detailed sampling results for VOCs and lead are presented in Appendix C.

From the GA VOC air sampling results obtained during our first site visit we identified the following solvents to quantitate on our second visit – MEK, toluene, xylene, styrene, 2-butoxyethanol, n-butyl acetate, and benzyl alcohol. Employees with various job titles (wave solder operators, surface mount loaders, sprayers, patch coaters, and ruggedizers) working in the MS and DAS were selected for PBZ sampling. The PBZ concentration ranges for VOCs are presented in Table 1. Styrene was not detected in any of the air samples. Xylene concentrations should be considered as estimates because the calibration curve that was used to calculate xylene concentrations was run 4 weeks after the original analysis of the other analytes. Overall, the measured VOC concentrations were low and below all applicable OELs.

Table 1. PBZ air sample concentration ranges for VOCs

Solvent	Air Concentration (ppm) MS	Air Concentration (ppm) DAS
Toluene	0.17–0.26	0.38–3.0
Xylene*	0.063–0.11	0.15–4.0
n-Butyl acetate	0.99–1.5	1.9–40.
MEK	0.072–0.099	0.045–4.7
2-Butoxyethanol	0.0062–0.0095	0.0069–0.0089
Benzyl alcohol	0.57–2.6	0.70–1.6

* Estimated concentrations

Lead and tin were found in the surface wipe samples collected during our first site visit (Table C1). Concentrations of lead on work surfaces ranged from 60 to 3500 µg/ft², and tin concentrations ranged from 450 to 6800 µg/ft². Lead (2.3 µg/ft²) and tin (15 µg/ft²) were detected in surface wipe samples collected from the southeast break room table but were not detected in the southwest break room.

The PBZ concentrations of lead for wave solder operators in the MS ranged from trace (between 0.32 and 0.96 µg/m³) to 18 µg/m³. The PBZ concentrations of lead for wave solder operators in the DAS ranged from trace to 49 µg/m³. The highest PBZ concentration of lead was obtained on an employee cleaning the wave solder machines.

We collected hand wipe samples for lead from 23 MS and 37 DAS employees at lunch and asked whether they had washed their hands just prior to providing the wipe sample. Seven of the 60 wipe samples (3 from MS, 4 from DAS) showed a color change indicating the presence of lead. Three of the four wipe samples collected from DAS that tested positive for lead were from employees who had washed their hands prior to sample collection.

The personal noise dosimetry results are described in Table 2. None of the noise measures exceeded the NIOSH REL, OSHA PEL, or OSHA AL.

Table 2. Full-shift noise exposures for employees working at the AI stations

Location	Job Title	*Percent Dose OSHA AL	OSHA PEL	NIOSH REL
MS	AI Technician	6.6	0.8	23.4
	AI Operator	7.5	0.3	23.5
	AI Technician	6.7	1.1	23.1
	AI Operator	9.6	1.2	33.2
DAS	AI Technician	20.7	5.4	67.7
	AI Technician	8.5	2.6	32.9
	AI Technician	4.7	1.5	27.2
	AI Technician	10.7	1.8	33.5

*The various dose percentages are the amounts of noise accumulated during a work day, with 100% representing the maximum allowable daily dose.

The third octave band data were combined into octave bands to simplify their analysis and to compare the area (room) noise values to the NCB criterion [ANSI/ASA 1995]. The octave band data for the MS area is shown in Figure 1, and the octave band data for the DAS area is shown in Figure 2. The NCB-65 curve represents recommended acoustical noise criteria limits necessary for occupied indoor work spaces where communication and speech are not required [ANSI/ASA 1995].

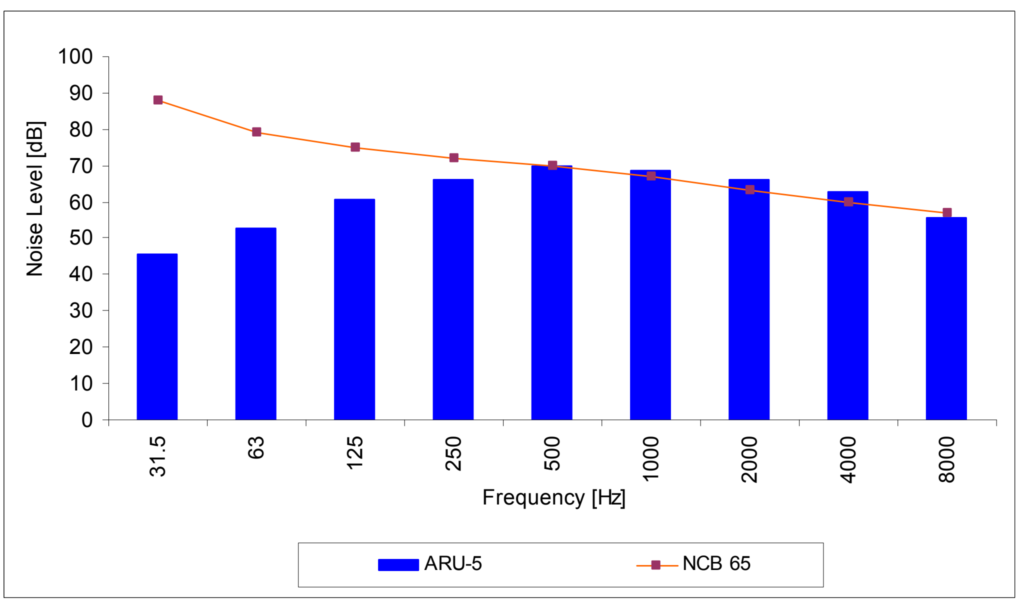

Figure 1. MS spectral data and comparison with NCB curve

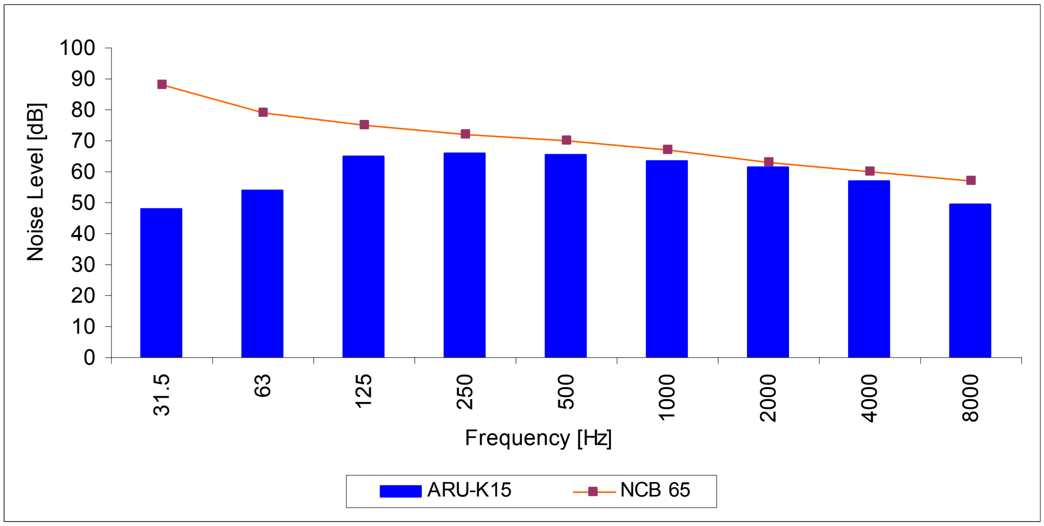

Figure 2. DAS spectral data and comparison with NCB curve

Local exhaust hoods enclosed the molten solder and solvent wash areas of the wave solder lines and the reflow oven on the surface mount lines. Table 3 presents the results for the enclosed local exhaust hoods for MS and DAS. The point where materials entered the enclosed local exhaust hood is identified as A and the point where they exited the hood is identified as B. With the exception of a few lines, visible smoke was captured at entry and exit points of the enclosed local exhaust hoods.

Table 3. Evaluation results of enclosed local exhaust hoods

MS			DAS		
Line	A	B	Line	A	B
WS1	+	–	SM1	–	+
WS2	+	+	SM2	+	+
WS3	+	–	SM3	–	+
WS4	+	+	SM4	+	+
SM1	+	+	WS Common	+	+
SM2	–	–	WS GE1	+	+
SM3	+	+	WS GE2	+	+
SM4	+	+			
SM5	+	+			
SM6	+	+			
SM7	+	+			
SM8	+	+			

WS = Wave solder SM = Surface mount

(+) = Smoke captured (–) = Smoke not captured

Document Review

Sanmina-SCI conducted full-shift PBZ and GA air sampling on three occasions during 2006–2007 for VOCs, lead, tin, and carbon black during Xerox™ toner cartridge cleaning. All air sampling results were below applicable OELs.

On May 2, 2007, a consultant assessed IEQ to evaluate the presence of mold. The IEQ assessment revealed the presence of *Penicillium* species on the interior surfaces of ARU-1 and ARU-5 (wipe samples) and standing water several inches deep in the condensate drain pans. The indoor mold air concentrations were lower than the outdoor mold air concentrations. *Cladosporium* and *Basidospores* species were present in highest concentrations in one outdoor air sample and in three of the four indoor air samples. However, *Cladosporium* and *Penicillium* species were present in highest concentrations in another indoor air sample that was collected near ARU-1, indicating the presence of a possible mold source and moisture problems within the work environment.

During this evaluation, employees expressed concern that ARU air filters were changed irregularly. However, our review of the HVAC maintenance logs showed that air filters in the ARUs were changed on schedule every 2 months.

One section of the written respiratory protection program states that respirator use is not mandatory anywhere within the plant during normal operations, though management allows medically cleared and trained employees to voluntarily use air-purifying elastomeric half-mask respirators equipped with organic vapor cartridges. In another section, the written program lists examples when employees must wear respirators, such as while cleaning wave solder machines, conducting emergency operations, and "when the environment is believed to have contaminants."

Medical Evaluation

We interviewed 40 employees, 35 of whom were selected from the employee roster provided by management, and 5 who asked to be interviewed. Sixteen employees worked on or around the surface mount lines, 21 worked in the blood glucose monitor assembly area of MS, and 3 worked in other locations. The average age was

Results (continued)

45 years, and 33 were female. The average length of employment was 9 years, and the average length at the current job title was 5 years. Thirty-one employees reported problems with temperature regulation (it was too cold or alternating cold/hot), 27 reported dust coming from air conditioning vents and ARUs, 18 reported noise from the machines and air guns, 12 reported exposure to fumes (mostly isopropyl alcohol vapors and flux fumes), and 6 reported exposure to gases or mists. A common general concern was that the filters on the ARUs were not changed often enough, because buildup of dust on work surfaces was visible.

Twenty-three employees reported no work-related symptoms. The most commonly reported work-related symptoms were upper respiratory (18 each with runny nose, cough, and sinusitis); 16 reported fatigue, frequently related to overtime; and 7 reported at least one episode of loss of voice. A review of four available medical records documented no work-related medical problems. The OSHA Form 300, Log of Work-Related Injuries and Illnesses, only listed injuries, but not illnesses or diseases.

We noted a discrepancy between the health concerns reported by the HHE requestors and the ones received by management's environment, health, and safety engineer. Throughout our evaluation, management frequently learned of health concerns from NIOSH first, even though management reported that they routinely queried supervisors and health and safety committee representatives about health and safety concerns.

Discussion

One of six PBZ air samples for lead exceeded the OSHA AL of 30 $\mu g/m^3$ and was close to the OSHA PEL of 50 $\mu g/m^3$. This employee, a wave solder operator, was cleaning and maintaining the wave solder machines without a respirator and did not work a full 8-hour shift. This result suggests a potential for lead overexposure during cleaning activities. However, during normal wave solder activities, wave solder operators had lead exposures well below the OSHA AL (30 $\mu g/m^3$).

Currently there are no OELs for surface metal contamination in occupational settings. Our sampling showed the presence of lead and tin on work surfaces. We also sampled a larger surface area (12 inch by 12 inch) of the break room tables to ensure that they were clean and found detectable levels of lead and tin in one of the break rooms. This suggests that workplace contamination is being tracked into the break rooms by employees' footwear, clothing, or hands, and that these areas should be kept cleaner. Additionally, three of the seven hand wipe samples that tested positive for lead were from employees who had washed their hands prior to sample collection. These results indicate that employees need to be aware of the workplace hazards related to lead. Management should improve general housekeeping practices, and employees should practice good personal hygiene to minimize lead exposures resulting from hand-to-mouth contact.

Based on our noise evaluation we believe that without a process change, there is no need to further monitor AI employees' noise exposures. Because telephone communication is not required in the production areas, and communication between employees is minimal, the acoustical effects experienced by employees with work stations near the ARUs are within the criteria specified by the NCB 55–70 curves. More information on NCB curves is provided in Appendix B.

In both the MS and DAS, the local exhaust hoods for wave solder and surface mount lines in each section were connected to a single fan that served as the air mover. Our ventilation evaluation revealed that local exhaust hoods on two wave solder lines and one surface mount line in MS and on two surface mount lines in DAS were not effectively capturing process emissions. This could be the result of the local exhaust ventilation systems being imbalanced or improperly maintained. Face and/or capture velocity design specifications for the exhaust hoods were not known and hence could not be quantitatively evaluated.

A majority of the employees we interviewed expressed thermal discomfort concerns. Thermal comfort is known to be affected by environmental factors such as air speed, humidity, vertical air temperature difference, and floor temperatures, and also by personal factors such as age, level of clothing, and gender [ASHRAE 2005]. ASHRAE indicates that industrial plants are usually designed to have a temperature between 60°F and 90°F with a maximum of 60% humidity; sedentary workers, such as those at Sanmina-SCI, prefer 72°F in the winter and 78°F in the summer [ASHRAE 2007]. The conditions specified above are those in which 80% or more of the occupants would be expected to find the environment thermally acceptable. Additional information on evaluating factors that influence perception of thermal comfort, such as clothing and draft (undesired cooling due to air movement), can be found in ANSI/ASHRAE Standard 55-2004 or the ASHRAE Fundamentals Handbook [ANSI/ASHRAE 2004; ASHRAE 2005].

Subsequent to the NIOSH site visit, Sanmina-SCI cleaned ARU-1 and ARU-5 to address employee concerns about odors and mold contamination, with plans to evaluate and clean the remaining ARUs in the facility. While studies have shown that mold can produce VOCs (see Appendix B), these concentrations are typically low and vary with environmental conditions. In an industrial work environment like Sanmina-SCI where multiple solvents are used, it is more likely that any VOC concentrations present are from solvent use rather than mold. It is also important to understand that it is not possible to distinguish between "safe" and "unsafe" levels of mold and that no exposure guidelines for mold in air exist. However, in susceptible individuals, airborne mold can cause upper respiratory symptoms. The potential for health problems is an important reason to prevent indoor mold growth and to remediate any indoor mold contamination (see Appendix B for more information on mold and possible health effects).

Our evaluation revealed that employee exposures to VOCs were low and below their respective OELs. The upper respiratory symptoms reported by some employees have been associated with exposure to mold in susceptible individuals, but are nonspecific and common in the general population. The average adult has two to three upper respiratory infections per year, while children have between six and eight [Benninger et al. 2003]. Lipscomb reported 1-year symptom prevalence rates from three populations in California. The top four health complaints in these populations were stuffy nose or congestion, irritated eyes, allergies or asthma, and headaches [Lipscomb et al. 1992]. Sinusitis is the most frequently reported chronic disease in the United States, topping arthritis, allergies, and hypertension [Benson and Marano 1993]. Fourteen percent of U.S. adults reported physician-diagnosed sinusitis in 2003, according to the National Health Interview Survey [CDC 2005].

Document Review

Our review of maintenance documents for the ARUs revealed that MERV 6 filters are currently used. The ARU manufacturer suggests using filters with a dust-spot efficiency of 25%–30% and an average arrestance of greater than 90% [Johnson Air Rotation System

2008]. These specifications correspond to a MERV 7 filter [ANSI/ASHRAE 2007]. The filter change-out schedule documentation for ARU-4 and ARU-5 indicated that air filters were being changed every 2 months, but employees were still concerned about dust levels in the facility. This suggests that measures taken by management to control ambient dust levels may go unnoticed by employees and indicates the need for more effective communication in this area. The manufacturer also recommends installing a pressure gauge to monitor the performance of the filters, which will help establish the filter change-out schedule [Coons 2008]. The consultant's IEQ assessment revealed standing water several inches deep in the condensate drain pans of the two ARUs. The ARU manufacturer recommends checking the condensate drain pan at least monthly or more frequently depending on the environmental conditions to ensure there is no standing water [Coons 2008].

Employees were voluntarily wearing respirators during spraying in the conformal coating area. The written respiratory protection program required the use of a respirator when cleaning wave solder machines, but did not identify the appropriate type of respirator that employees are required to wear when conducting this task. We also did not observe the employee wearing a respirator when cleaning the wave solder machines. This reflects inconsistencies in the written respiratory protection program and current respirator use among Sanmina-SCI employees.

Conclusions

We were unable to identify the cause of any of the employee symptoms. The most common symptoms reported by employees were upper respiratory, which are common in the general population. We did identify that employees cleaning wave solder machines may be exposed to airborne lead concentrations approaching the NIOSH REL and OSHA PEL of 50 $\mu g/m^3$. However, when conducting normal day-to-day activities, the lead exposure to wave solder operators is below both the NIOSH REL and OSHA PEL. The surface and skin wipe sampling identified lead on work surfaces, a break room table, and employees' hands despite hand washing. Employee exposures to VOCs and noise were below applicable OELs. The room acoustics for employees working near the ARUs were appropriate for the work environment. Management should clean the ARUs to remove any visible signs of mold growth and use at a minimum MERV 7 air

Conclusions (continued)

filters. The written respiratory protection program was found to be deficient with inconsistencies between the written program and current practice.

Recommendations

The following recommendations should improve employee health and safety at this facility.

1. Use engineering controls such as portable exhaust hoods when removing solder dross and cleaning wave solder machines. The local exhaust hoods for the wave solder and surface mount lines need to be periodically evaluated to ensure that they are performing per manufacturer's specifications.

2. Comply with all requirements of the OSHA lead standard (29 CFR 1910.1025) including but not limited to the following:

    a. Institute an industrial hygiene monitoring program for assessing airborne lead exposure for employees working with leaded solder or having the greatest potential for airborne lead exposure. For example, conduct additional air sampling to verify that employees cleaning wave solder machines are not exposed to lead exceeding the OSHA AL or PEL.
    b. Institute a maintenance program for evaluating the enclosed local exhaust hoods used to control exposure to lead. The effectiveness of these hoods should be evaluated at least every 3 months and within 5 days of a production, process, or control change.

3. Improve general housekeeping practices to ensure break rooms and work surfaces are clean. Commercial cleaning wipes for removing lead and other heavy metals are available and should be used every shift to keep work surfaces such as control consoles clean. HEPA vacuum cleaners should be used when vacuuming work areas to minimize entrainment of dust in the air.

4. Encourage employees to practice good personal hygiene, including thoroughly washing hands before eating any food, prior to and after using the restroom, and prior to leaving work. Prohibit eating, drinking, smoking, and application of cosmetics in the work areas.

5. Clean ARUs to remove visible signs of mold growth. Use MERV 7 air filters, and conduct maintenance on ARUs per the manufacturer's recommendations that includes checking that the condensate drain pans are not clogged.

6. Revise the written respiratory protection program to identify the job tasks for which a respirator is required, type of respirator needed, and locations where respirator use is required. Respiratory hazards should be evaluated for job tasks where respiratory protection is currently required to ensure that the respirators worn are necessary and appropriate. Job tasks where employees voluntarily wear respirators should also be noted in the written program and all applicable requirements of the OSHA Respiratory Protection Standard (29 CFR 1910.134) should be met.

7. Address employee thermal comfort concerns by evaluating areas reported to be too cold or alternating between too hot and too cold. Additionally, ensure that temperature and RH in work areas are within the recommended ASHRAE guidelines.

8. Require that employees inform their supervisor and the health and safety committee representative about their health concerns if they are work-related. Encourage employees with health concerns to seek evaluation and care from a physician who is residency trained in and/or board certified in occupational medicine and is familiar with the types of exposures employees may have had and their health effects. We recommend using the occupational health clinic under contract, but employees may choose a different health care provider. Occupational medicine physicians can be located through a variety of sources, including the Association of Occupational and Environmental Clinics at www.aoec.org, and the American College of Occupational and Environmental Medicine at www.acoem.org.

9. Communicate health and safety related changes to employees promptly. For example, document and inform employees when ARU filters are changed and housekeeping is performed. This could be achieved by affixing a visible sticker to the ARU stating the filter change date and by posting housekeeping checklists.

10. Train employees about the potential exposures and hazards present at the workplace and how to protect themselves.

References

ANSI/ASA [1995]. Criteria for evaluating room noise, standard S12.2-1995. New York, NY: Acoustical Society of America/American National Standards Institute.

ANSI/ASHRAE [2004]. Thermal environmental conditions for human occupancy, standard 55-2004. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ANSI/ASHRAE [2007]. Method of testing general ventilation air-cleaning devices for removal efficiency by particle size, standard 52.2-2007. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE [2005]. Thermal comfort. In: 2005 ASHRAE handbook–Fundamentals. I-P edition. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., pp. 8.1–8.29.

ASHRAE [2007]. Industrial air conditioning. In: 2007 ASHRAE Handbook–HVAC Applications. I-P Edition. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., p. 12.4.

Benninger MS, Ferguson BJ, Hadley JA, Hamilos DL, Jacobs M, Kennedy DW, Lanza DC, Marple BF, Osguthorpe JD, Stankiewics JA, Anon J, Denneny J, Emanuel I, Levine H [2003]. Adult chronic rhinosinusitis: definitions, diagnosis, epidemiology, and pathophysiology. Otolaryngol Head Neck Surg *129*(3 Suppl): S1–S32.

Benson V, Marano MA [1993]. Current estimates from the National Health Interview Survey, 1993, National Center for Health Statistics. Vital Health Stat Series 10- No 190.

CDC [2005]. Summary Health Statistics for U.S. Adults: National Health Interview Survey, 2003. [www.cdc.gov/nchs/data/series/sr_10/sr10_225.pdf]. Date accessed: August 2008.

CFR. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Coons H (hcoons@arizoncompanies.com) [2008]. Maintenance procedure/schedule for Johnson air rotation system. Private e-mail message to Srinivas Durgam (sdurgam@cdc.gov), May 8.

Johnson Air Rotation System [2008]. System specification for heating and cooling. [www.johnson-marcraft.com/air_rotation_12.html]. Date accessed: May 14.

Lipscomb JA, Satin KP, Neutra RR [1992]. Reported symptom prevalence rates from comparison populations in community-based environmental studies. Arch Environ Health 47(4):263–269.

Lead

Air samples for lead were collected on 37-mm diameter, 0.8-µm pore size mixed cellulose ester filters using SKC Air Check® 2000 air sampling pumps calibrated at a flow rate of 2 Lpm. The inlet port of the sampling pump was connected to the sampling media with Tygon® tubing. For PBZ samples, the sampling media was attached to the employee's lapel within the breathing zone, roughly defined as an area in front of the shoulders with a radius of 6 to 9 inches. The GA air samples were placed near the worker's work station or location.

We collected six PBZ and two GA full-shift air samples, which were analyzed by inductively coupled argon plasma-atomic emission spectroscopy according to NIOSH Method 7303 [NIOSH 2009].

Lead and Tin in Surface Dust

We collected 10 surface wipe samples for lead and tin, 6 in the MS and 4 in the DAS. Surface dust samples were collected with pre-moistened Ghost wipe® towelettes according to NIOSH Method 9102 [NIOSH 2009]. The collection procedure was as follows: (1) identify the area to be sampled; (2) put on a pair of disposable nitrile gloves; (3) place wipe flat on surface as defined by the 10 cm by 10 cm disposable template and wipe surface using three to four horizontal S-strokes, side-to-side so that entire surface is covered; (4) fold the exposed side of the wipe in and wipe the area with 3 to 4 vertical S-strokes; (5) fold the wipe once more and wipe the area with 3 to 4 horizontal S-strokes and; (6) fold the pad, exposed side in, and place in a sterile container. A new template and a pair of disposable gloves were used for each wipe sample. The wipe samples were digested and analyzed by inductively coupled argon plasma-atomic emission spectroscopy according to NIOSH Method 9102 with modifications [NIOSH 2009].

We also collected two surface wipe samples from the southeast and southwest break rooms using a similar surface sampling technique, but we sampled a 12 inch by 12 inch surface area to ensure that break room tables were clean and devoid of lead contamination.

Lead on Skin

Hand wipe samples were collected and analyzed according to NIOSH Method 9105 [NIOSH 2009]. A commercially available dust wipe (Palintest®) conforming to the ASTM Standard E 1792 (Specifications for Wipe Sampling Materials for Lead in Surface Wipes) was used to collect all samples. After collection, each wipe was sprayed with a 5% leaching solution of acetic acid to solubilize lead and lead compounds into lead ions. The wipe was then sprayed with a chilled solution of sodium rhodizonate, a chemical that reacts colorimetrically to the presence of lead by changing from yellow to red. The visual limit of identification for the method is approximately 17–20 µg per sample.

Volatile Organic Compounds

SKC Pocket Pumps® air sampling pumps calibrated at a flow rate of 50 cc/min were used for sampling airborne VOCs. All air sampling pumps were calibrated before and after use. We collected eight GA screening air samples using TD tubes, four samples each in the MS and DAS areas of the facility. The GA air samples were placed near a worker's work station or location. The TD tubes were analyzed for VOCs by a gas chromatograph equipped with a mass selective detector per NIOSH Method 2549 [NIOSH 2009]. We developed a sampling protocol for our next site visit based on observing the operations, reviewing MSDSs, and analyzing the screening VOC air sampling results. As similar work processes were performed in the MS and DAS, we sampled employees in both sections.

Toluene, Styrene, and Xylenes

We collected 16 PBZ and 3 GA full-shift air samples on beaded charcoal tubes (50/100 mg) using sampling pumps calibrated at a flow rate of 100 cc/min. All samples were analyzed initially for toluene with a gas chromatograph equipped with a flame ionization detector according to NIOSH Method 1501 [NIOSH 2009]. These samples were subsequently analyzed for styrene and xylenes using the same NIOSH analytical method. These concentrations have been reported as estimates as they were not part of the initial analyses.

n-Butyl Acetate

We collected 16 PBZ and 4 GA full-shift air samples on beaded charcoal tubes (50/100 mg) using sampling pumps calibrated at a flow rate of 50 cc/min. All samples were analyzed for n-butyl acetate with a gas chromatograph equipped with a flame ionization detector according to NIOSH Method 1450 [NIOSH 2009].

Methyl Ethyl Ketone

We collected 14 PBZ and 4 GA full-shift air samples on Anasorb carbon molecular sieve sorbent tubes (75/150 mg) using sampling pumps calibrated at a flow rate of 100 cc/min. All samples were analyzed for MEK with a gas chromatograph equipped with a flame ionization detector according to NIOSH Method 2555 [NIOSH 2009].

2-Butoxyethanol

We collected 15 PBZ and 5 GA full-shift air samples on beaded charcoal tubes (50/100 mg) using sampling pumps calibrated at a flow rate of 100 cc/min. All samples were analyzed for 2-butoxyethanol with a gas chromatograph equipped with a flame ionization detector according to NIOSH Method 1403 [NIOSH 2009].

Benzyl Alcohol

We collected 13 PBZ and 5 GA full-shift air samples on XAD-7 sorbent tubes (50/100 mg) using sampling pumps calibrated at a flow rate of 200 cc/min. All samples were analyzed for benzyl alcohol with a gas chromatograph equipped with a flame ionization detector according to OSHA method PV 2009 [OSHA 2009].

Noise

We collected personal full-shift noise dosimetry measurements using NoisePro™ noise dosimeters from Quest® Technologies (Oconomowoc, Wisconsin). The noise dosimeters were attached to the wearer's belt, and a small remote microphone was fastened to the wearer's shirt at a point midway between the ear and the outside of the shoulder. A windscreen provided by the manufacturer of the dosimeter was placed over the microphone during recordings. At the end of the sampling period, the dosimeter was removed and paused to stop data collection. The information stored in the dosimeters was downloaded to a personal computer for interpretation with QuestSuite® Professional II computer software. The dosimeters were calibrated before and after the measurement periods according to the manufacturer's instructions.

The Quest dosimeters collect data for comparison with the three different noise criteria used in this evaluation, the OSHA PEL and AL and the NIOSH REL. Table A1 summarizes the dosimeter settings used in this evaluation.

Table A1. Dosimeter settings

Parameters	OSHA AL	OSHA PEL	NIOSH REL
Response	Slow	Slow	Slow
Exchange rate	5	5	3
Criterion level	90 dB(A)	90 dB(A)	85 dB(A)
Threshold	80 dB(A)	90 dB(A)	OFF
Upper limit	115 dB(A)	115 dB(A)	115 dB(A)

The OSHA guidelines use a 90 dB(A) criterion level and a 5-dB exchange rate. The difference between the two OSHA criteria is in the threshold level employed – a 90 dB(A) threshold for the PEL and an 80 dB(A) threshold for the AL. The threshold level is the lower limit of noise values included in the calculation of the exposure; values less than the threshold are ignored by the dosimeter. The NIOSH guidelines differ from OSHA in that the criterion level is 85 dB(A), and it uses a 3-dB exchange rate. There is no threshold requirement, so the threshold level for the dosimeters used in this evaluation was set to OFF. This allowed for the integration of all sound levels including those below 80 dB(A).

The spectral area noise measurements were made with a Quest Technologies Sound Pro™ Real-Time Analyzer Model SE/DL and a ½" diameter random incidence response microphone. The analyzer allows for the analysis of noise into its spectral components in a real-time mode. The ½" diameter microphone has a frequency response range (± 2 dB) from 4 Hz to 21,000 Hz that allows for the analysis of sounds in the region of concern. One-third octave bands consisting of center frequencies from 25 Hz to 20,000 Hz were integrated for 30 seconds and stored in the analyzer for later analysis. The analyzer also calculates the overall unweighted value as a sound pressure level.

References

NIOSH [2009]. NIOSH manual of analytical methods (NMAM®), 4th ed. Schlecht PC, O'Connor PF, eds. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 94–113 (August, 1994); 1st Supplement Publication 96–135, 2nd Supplement Publication 98–119; 3rd Supplement 2003–154. [www.cdc.gov/niosh/nmam/].

OSHA [2009]. Sampling & analytical methods-benzyl alcohol. [www.osha.gov/dts/sltc/methods/partial/pv2009/2009.html]. Date accessed: June 2009.

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- 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, 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 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 2008]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2008].

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.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. Information regarding 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.

Lead

Occupational exposure to lead occurs via inhalation of lead-containing dust and fumes and ingestion of lead particles from contact with lead-contaminated surfaces. In cases where careful attention to hygiene (for example, hand washing) is not practiced, smoking cigarettes or eating may represent another route of exposure among workers who handle lead and then transfer it to their mouth through hand contamination. Industrial settings associated with exposure to lead and lead compounds include smelting and refining, scrap metal recovery, automobile radiator repair, construction and demolition (including abrasive blasting), and firing range operations [ACGIH 2007]. Occupational exposures also occur among workers who apply and/or remove lead-based paint or among welders who burn or torch-cut metal structures.

Acute lead poisoning, caused by intense occupational exposure to lead over a brief period of time can cause a syndrome of abdominal pain, fatigue, constipation, and in some cases alteration of CNS function [Moline and Landrigan 2005]. Symptoms of chronic lead poisoning include headache, joint and muscle aches, weakness, fatigue, irritability, depression, constipation, anorexia, and abdominal discomfort. These symptoms usually do not develop until the BLL reaches 30–40 µg/dL [Moline and Landrigan 2005]. Overexposure to lead may also result in damage to the kidneys, anemia, high blood pressure, impotence, and infertility and reduced sex drive in both sexes. Studies have shown subclinical effects on heme synthesis, renal function, and cognition at BLLs <10 µg/dL [ATSDR 2007]. Inorganic lead is reasonably anticipated to cause cancer in humans [ATSDR 2007].

In most cases, an individual's BLL is a good indication of recent exposure to lead, with a half-life (the time interval it takes for the quantity in the body to be reduced by half its initial value) of 1–2 months [Lauwerys and Hoet 2001; Moline and Landrigan 2005; NCEH 2005]. Most lead in the body is stored in the bones, with a half-life of years to decades. Bone lead can be measured using x-ray techniques, but these are primarily research based and are not widely available. Elevated ZPP levels have also been used as an indicator of chronic lead intoxication, however, other factors, such as iron deficiency, can cause an elevated ZPP level, so the BLL is a more specific test for evaluating occupational lead exposure.

The NIOSH REL for inorganic lead is 50 µg/m^3 as an 8-hour TWA. This REL is consistent with the OSHA PEL, which is intended to maintain employee BLLs below 40 µg/dL; medical removal is required when an employee has a BLL of 60 µg/dL, or the average of the last three tests at 50 µg/dL or higher [29 CFR 1910.1025; 29 CFR 1962.62]. For employees exposed to lead for more than 8 hours in a work day, the OSHA lead standard for general industry mandates mathematically-derived exposure limits. Employees shall not be exposed to airborne lead in excess of 400 divided by the number of hours worked. For example, an employee working a 10-hour day should be exposed to airborne lead at levels no greater than 40 µg/m^3 (400 divided by 10) measured as a TWA [29 CFR 1910.1025].

NIOSH conducted a literature review of the health effects data on inorganic lead exposure and found evidence that some of the adverse effects on the adult reproductive, cardiovascular, and hematologic systems, and on the development of children of exposed employees can occur at BLLs as low as 10 µg/dL [NIOSH 1998a]. At BLLs below 40 µg/dL, many of the health effects would not necessarily be evident by routine physical examinations but represent early stages in the development of lead toxicity. In recognition of this, voluntary standards and public health goals have established lower exposure limits to protect employees and their children. The ACGIH TLV for lead in air is 50 µg/m^3 as an 8-hour TWA, with employee BLLs to be controlled to ≤ 30 µg/dL. A national health goal is to eliminate all occupational exposures that result in BLLs >25 µg/dL [DHHS 2000]. The Third National Report on Human Exposure to Environmental Chemicals found the geometric mean blood lead among noninstitutionalized, civilian males in 2001–2002 was 1.78 µg/dL [NCEH 2005].

OSHA requires medical surveillance on any employee who is or may be exposed to an airborne concentration of lead at or above the AL, which is 30 µg/m^3 as an 8-hour TWA for more than 30 days per year [29 CFR 1910.1025]. Blood lead and ZPP levels must be done at least every 6 months and more frequently for employees whose blood leads exceed certain levels. In addition, a medical examination must be done prior to assignment to the area, and should include detailed history, blood pressure measurement, blood lead, ZPP, hemoglobin and hematocrit, red cell indices, peripheral smear, blood urea nitrogen, creatinine, and a urinalysis. Additional medical exams and biological monitoring depend upon the circumstances, for example, if the blood lead exceeds a certain level.

Lead and Tin in Surface Dust

There are no OSHA or NIOSH criteria for acceptable levels of surface contamination of metals in occupational settings; however, lead- and tin-contaminated surfaces in the workplace represent a potential source of exposure for employees. The U.S. EPA and the U.S. Department of Housing and Urban Development currently recommend the following clearance levels for lead on surfaces after residential lead abatement or interim control activities: uncarpeted floors, 100 µg/ft^2; interior window sills, 500 µg/ft^2, and window wells, 800 µg/ft^2 [EPA 1994].

In the workplace, generally little or no correlation exists between surface lead and tin levels and employee exposures because ingestion exposures are highly dependent on personal hygiene practices and available facilities for maintaining personal hygiene. OSHA, in its substance-specific standards, requires maintaining all surfaces as free as practicable of accumulations of lead. It is difficult to predict employees' exposures to surface contaminants because of variation in personal hygiene habits, contamination of hands and clothing, and the capacity for the contaminant to become airborne and inhaled. Therefore, surface contamination results provided in this report should be used as a relative indicator of contamination. In homes with a family member occupationally exposed to lead, care must be taken to also prevent "take home" exposure to lead, that is, lead carried into the home on clothing, skin, and hair, and in vehicles [Grandjean and Bach 1986].

Volatile Organic Compounds

VOCs describe a large class of chemicals that are organic (i.e., 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 compounds are emitted in varying concentrations from numerous indoor sources including, but not limited to, carpeting, fabrics, adhesives, solvents, paints, cleaners, waxes, cigarettes, and combustion sources.

Toluene

Toluene is a colorless, aromatic organic liquid containing a six-carbon ring (a benzene ring) with a methyl group (CH_3) substitution. Inhalation and skin absorption are the major occupational routes of entry. Toluene can cause acute irritation of the eyes, respiratory tract, and skin [NIOSH 2005]. The main effects reported with excessive (inhalation) exposure to toluene are CNS depression and neurotoxicity at concentrations much higher than those measured in this evaluation [Vincoli 1997; Hathaway and Proctor 2004].

The NIOSH REL for toluene is 100 ppm for up to a 10-hour TWA. NIOSH has also set a recommended STEL of 150 ppm for a 15-minute sampling period. The ACGIH TLV is 20 ppm for an 8-hour TWA. The OSHA PEL for toluene is 200 ppm for an 8-hour TWA.

n-Butyl Acetate

n-Butyl acetate is a colorless or yellowish organic liquid with a characteristic fruit-like odor. It is typically used as a solvent for nitrocellulose, oils, fats, resins, waxes, and camphor and in the manufacture of lacquer and plastics. Inhalation and dermal absorption are the major occupational routes of entry. Studies have shown that in humans, n-butyl acetate can affect the throat and cause eye and nose irritation at concentrations higher than those measured in this evaluation [ACGIH 2007]. Since it is a defatting solvent, repeated or prolonged skin contact will remove the natural lipids from the skin, which can cause drying, fissuring, and dermatitis. The NIOSH REL for n-butyl acetate is 150 ppm for up to a 10-hour TWA. The OSHA PEL and ACGIH TLV for n-butyl acetate is 150 ppm for an 8-hour TWA. These agencies have also set a STEL of 200 ppm for a 15-minute sampling period for this substance.

Methyl Ethyl Ketone

MEK, a colorless, flammable organic solvent with a characteristic odor similar to acetone, is typically used as a solvent in the surface coating and synthetic resin industries [ACGIH 2007]. Occupational exposure occurs primarily through inhalation. Short duration inhalation exposure to concentrations much higher than those measured in this evaluation may cause slight nose and throat irritation, mild eye irritation, headaches, and throat irritation as well as an objectionable odor [Hathaway and Proctor 2004]. Continued or prolonged skin contact with MEK liquid can cause dermatitis. The NIOSH REL for MEK is 100 ppm for up to a 10-hour TWA. The OSHA PEL and ACGIH TLV are 200 ppm for 8-hour TWA, with a STEL of 300 ppm.

2-Butoxyethanol

2-Butoxyethanol, a widely used solvent and cleaning agent, is also known as ethylene glycol monobutyl ether, or Butyl Cellosolve®. This colorless liquid solvent has a reported odor threshold (mild ether-like) of 0.1 ppm [NIOSH 1990]. Toxic effects associated with human exposure to 2-butoxyethanol concentrations much higher than those measured in this evaluation include eye and nasal irritation, headache, vomiting, and disturbed taste [NIOSH 1990; ACGIH 2007; Hathaway and Proctor 2004]. The NIOSH REL is 5 ppm for up to a 10-hour TWA and OSHA PEL is 50 ppm for 8-hour TWA. The ACGIH TLV is 20 ppm and is recommended to minimize the potential irritant effects.

Benzyl Alcohol

Benzyl alcohol is a white liquid with a faint aromatic odor. It is widely used in cosmetics, as a preservative, solvent, and a local anesthetic. Inhalation is of benzyl alcohol vapors at concentrations much higher than those measured in this evaluation can cause headache, nausea, vomiting, and diarrhea [Nair 2001; Cheremisinoff 2003]. The odor threshold for benzyl alcohol is 5.5 ppm. AIHA has set an 8-hour TWA

WEEL of 10 ppm for benzyl alcohol. NIOSH, OSHA, and ACGIH have not established an OEL for this chemical.

Mold

The types and severity of symptoms related to exposure to mold in the indoor environment depend in part on the extent of the mold present, the extent of the individual's exposure, and the susceptibility of the individual (for example, whether he or she has pre-existing allergies or asthma). In general, excessive exposure to mold may produce health problems by several primary mechanisms, including (1) allergy or hypersensitivity, (2) infection, and (3) toxic effects. A review of the scientific literature on VOCs generated by microorganisms (referred to as microbial VOCs [MVOCs]) indicates that different microorganism species are known to generate VOCs during various stages of their growth. The diversity of MVOCs generated by microorganisms is also well documented [Nilsson et al. 2004; Schleinbinger et al. 2008]. A recent study investigating MVOCs in mold and mold-free environments concluded that the MVOCs identified in the study weakly correlated with the location of the visible mold. The study also concluded that confounding factors like humidity and chemicals in the environment can affect the results. Additionally, the low emission rates of MVOCs from mold also result in low airborne concentrations that are harder to measure and, hence, harder to correlate with the location of visible mold [Schleinbinger et al. 2005, 2008].

Allergic responses are the most common type of health problem associated with exposure to mold. Health symptoms may include sneezing; itching of the nose, eyes, mouth, or throat; nasal stuffiness and runny nose; and red, itchy eyes. Repeated or single exposure to mold or mold spores may cause previously nonsensitized individuals to become sensitized. Molds can trigger asthma symptoms (shortness of breath, wheezing, cough) in persons who are allergic to mold. A recent review of the scientific literature concluded that exposure to molds in the indoor environment may make pre-existing asthma worse, but also concluded that there was not enough evidence to determine whether exposure to mold in the indoor environment could cause asthma [Institute of Medicine 2000]. People with weakened immune systems (immune-compromised or immune-suppressed individuals) may be more vulnerable to infections by molds. For example, *Aspergillus fumigatus* is a mold that has been found almost everywhere on every conceivable type of substrate and has been known to infect the lungs of immune-compromised individuals after inhalation of the airborne spores [Wald and Stave 1994]. Healthy individuals are usually not vulnerable to infections from airborne mold exposure.

Noise

The primary sources of evaluation criteria for noise in the workplace are the NIOSH REL [NIOSH 1992], and the U.S. Department of Labor, OSHA PEL [29 CFR1910.95]. Employers are encouraged to follow the more protective NIOSH REL, although they are required to adhere to the OSHA PEL for compliance purposes.

NIHL 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 [Ward et al. 2000]. 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, NIHL 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 dB(A) is the preferred unit for measuring sound levels to assess employee noise exposures. The dB(A) 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 which are audible to the human ear. Because the dB(A) scale is logarithmic, increases of 3 dB(A), 10 dB(A), and 20 dB(A) represent a doubling, tenfold increase, and hundred-fold increase of sound energy, respectively. It should be noted that noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise specifies a maximum PEL of 90 dB(A) for of 8 hours per day [29 CFR 1910.95]. 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 dB(A) for no more than 4 hours, to 100 dB(A) for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dB(A) is allowed by this exchange rate. The duration and sound level intensities can be combined in order to calculate an employee's daily noise dose according to the formula:

$$\text{Dose} = 100 \times (C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n)$$

where C_n indicates the total time of exposure at a specific noise level and T_n indicates the reference duration for that level as given in Table G-16a of the OSHA noise regulation. During any 24-hour period, an employee is allowed up to 100% of his daily noise dose. Doses greater than 100% exceed the OSHA PEL.

The OSHA regulation has an additional AL of 85 dB(A); 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 protection device, 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 dB(A), feasible engineering or administrative controls shall be implemented to reduce the employees' exposure levels.

NIOSH, in its Criteria for a Recommended Standard, proposes an exposure criterion of 85 dB(A) as a TWA for 8 hours, 5 dB less than the OSHA standard [NIOSH 1998b]. The criterion also uses a more conservative 3-dB exchange rate in calculating exposure limits. Thus, an employee can be exposed to 85 dB(A) for 8 hours, but to no more than 88 dB(A) for 4 hours or 91 dB(A) for 2 hours. The NIOSH REL for a 12-hour exposure is 83 dB(A) or less.

Because of the different 8-hour criteria and exchange rates, the dose equations used to calculate the equivalent TWA values are different for the NIOSH and OSHA criteria.
The OSHA dose equation is

$$TWA = 16.61 \times \log_{10} [Dose/100] + 90,$$

and the NIOSH equation is

$$TWA = 10.00 \times \log_{10} [Dose/100] + 85.$$

The occupational noise regulation promulgated by OSHA and the NIOSH criterion are designed to prevent hearing losses from exposures to intense noise levels. However, noise of intensities lower than that which may cause a loss of hearing can be disruptive in the workplace.

Interference with speech is a possible result of unwanted noise. The noise can interfere with the efficiency and productivity of the staff and can be detrimental to the occupants' comfort, health, and sense of well being. One set of noise criteria for occupied interior spaces, the NCB curves, has been devised to limit noise to levels where satisfactory speech intelligibility is achieved [Beranek 1988, 1989; ANSI/ASA 1995]. The noise criteria were devised through the use of extensive interviews with personnel in offices, factories, and public places along with simultaneously measured octave band sound levels. The interviews consistently showed that people rate noise as troublesome when its speech interference level is high enough to make communications difficult. The recommended space classifications and suggested noise criteria range for steady background noise heard in various indoor occupied activity areas are shown in Table B1.

Table B1. Suggested NCB range for various occupied indoor areas*

Type of space and acoustical requirements	NCB curve values†
Concert halls, opera houses, and recital halls	10–15
Large auditoriums, large drama theatres, and large churches	Not to exceed 20
Small auditoriums, small theaters, small churches, music rehearsal rooms, large meeting and conference rooms, and executive offices	Not to exceed 30
Bedrooms, hospitals, residences, apartments, hotels	25–40
Private or semi-private offices, small conference rooms, classrooms, libraries	30–40
Large offices, reception areas, retail shops and stores, cafeterias, restaurants	35–45
Lobbies, lab work spaces, drafting and engineering rooms, general secretarial areas	40–50
Light maintenance shops, industrial plant control rooms, office and computer equipment rooms, kitchens, and laundries	45–55
Shops, garages	50–60
Work spaces where speech or telephone communication not required	55–70

* ANSI/ASA S12.2-1995 Criteria for Evaluating Room Noise
† Third octave band data were combined into octave bands to simplify their analysis and to compare the area room noise values to the NCB criterion [ANSI/ASA 1995].

References

ACGIH [2007]. Documentation of threshold limit values and biological exposure indices for chemical substances and physical agents. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

ACGIH [2008]. 2008 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

AIHA [2008]. 2008 Emergency response planning guidelines (ERPG) and workplace environmental exposure levels (WEEL) handbook. Fairfax, VA: American Industrial Hygiene Association.

ANSI/ASA [1995]. Criteria for evaluating room noise, standard S12.2-1995. New York, NY: American National Standards Institute/Acoustical Society of America.

ATSDR [2007]. Toxicological profile for lead. Atlanta, GA: U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry.

Beranek LL [1988]. Criteria for noise and vibration in communities, buildings, and vehicles. In: Beranek LL, ed. Noise and vibration control. Rev. ed. Cambridge, Massachusetts: Institute of Noise Control Engineering, pp. 554–623.

Beranek LL [1989]. Balanced noise criterion (NCB) curves. J Acoust Soc Am *86*(2):650–664.

CFR. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Cheremisinoff NP [2003]. Industrial solvents handbook. New York: Marcel Dekker.

DHHS [2000]. Healthy people 2010: Understanding and Improving Health. 2nd ed. Washington, DC: U.S. Department of Health and Human Services [www.health.gov/healthypeople/Document/default.htm].

EPA [1994]. Guidance on residential lead based paint, lead-contaminated dust, and lead-contaminated soil. Washington, DC: U.S. Environmental Protection Agency, Office of Prevention, Pesticides and Toxic Substances. Memorandum from Lynn Goldman, Assistant Administrator, July 14, 1994.

Grandjean P, Bach E [1986]. Indirect exposures: the significance of bystanders at work and at home. Am Ind Hyg Assoc J *47*(12):819–824.

Hathaway GJ, Proctor NH, ed. [2004]. Chemical hazards of the workplace, 5th ed. Hoboken, NJ: John Wiley and Sons, Incorporated.

Institute of Medicine [2000]. Executive Summary. In: Clearing the air: asthma and indoor air exposure. Washington, DC: National Academy Press, pp. 1–18.

Lauwerys RR, Hoet P [2001]. Biological monitoring of exposure to inorganic and organometallic substances. In: Industrial chemical exposure: guidelines for biological monitoring. 3rd ed. Boca Raton, FL: CRC Press, LLC, pp. 21–80.

Moline JM, Landrigan PJ [2005]. Lead. In: Textbook of clinical occupational and environmental medicine, Rosenstock L, Cullen MR, Brodkin CA, and Redlich CA, eds., 2nd ed. Philadelphia, PA: Elsevier Saunders, pp. 967–979.

Nair B [2001]. Final report on the safety assessment of benzyl alcohol, benzoic acid, and sodium benzoate. Int J Toxicol *20*(3)(Suppl):23–50.

NCEH [2005]. Third national report on human exposure to environmental chemicals. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Environmental Health. NCEH Publication number 05-0570.

Nilsson A, Kihlstrom E, Lagesson V, Wessen B, Szponar B, Larsson L, Tagesson C [2004]. Microorganisms and volatile organic compounds in airborne dust for damp residences. Indoor Air *14*(2):74–82.

NIOSH [1990]. Criteria for a recommended standard: occupational exposure to ethylene glycol monobutyl ether and ethylene glycol monobutyl ether acetate. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 90-118.

NIOSH [1992]. Recommendations for occupational safety and health: compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100.

NIOSH [1998a]. Protecting workers exposed to lead-based paint hazards: a report to Congress, revised. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-112.

NIOSH [1998b]. Criteria for a recommended standard: occupational noise exposure (revised criteria 1998). Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-126.

NIOSH [2005]. NIOSH pocket guide to chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2005-149. [www.cdc.gov/niosh/npg/]. Date accessed: August 2008.

Schleibinger H, Laubmann D, Brattig C, Mangler M, Eis D, Ruden H [2005]. Emission patterns and emission rates of MVOC and the possibility for predicting hidden mold damage. Indoor Air *15*(Suppl 9):98–104.

Schleibinger H, Laussmann D, Bornehag CG, Eis D, Rueden H [2008]. Microbial volatile organic compounds in air of moldy and mold-free environment. Indoor Air *18*(2):113–124.

Suter AH [1978]. The ability of mildly hearing-impaired individuals to discriminate speech in noise. Washington, DC: U.S. Environmental Protection Agency, Joint EPA/USAF study, EPA 550/9-78-100, AMRL-TR-78-4.

Vincoli JW [1997]. Risk management for hazardous chemicals. Boca Raton, FL: CRC Press.

Wald P, Stave G [1994]. Fungi. In: Physical and biological hazards of the workplace. New York, NY: Van Nostrand Reinhold, p. 394.

Ward WD, Royster LH, Royster JD [2000]. Anatomy & physiology of the ear: normal and damaged hearing. In: Berger EH, Royster LH, Royster JD, Driscoll DP, Layne M, eds. The noise manual. 5th ed. Fairfax, VA: American Industrial Hygiene Association, pp. 101–122.

Table C1. Surface wipe sample results for lead and tin (July 10, 2007)

Work Location		Sample Area (cm²)	Surface Dust Concentration (µg/ft²) Lead	Surface Dust Concentration (µg/ft²) Tin
MS	Line 1, Surface mount, control console	100.00	3500	6800
	Line 4, Surface mount, work station	100.00	60.	800
	Line 3, Surface mount, work station	100.00	190	450
	Line 2, Wave solder, work station	100.00	2700	4800
	Line 2, Wave solder, control console	100.00	2900	5600
DAS	Wave solder Electrovert	100.00	1100	2100
	Line 4, Surface mount, OPI station	100.00	180	1100
	Wave solder (Common), near reflow oven	100.00	ND	ND
	Wave solder (Common), wash station	100.00	330	1100
	Hand soldering station	100.00	310	320
Break room southeast, table		929.03*	2.3	15
Break room southwest, table		929.03*	ND	ND
LOD = Limit of detection (µg/sample)			0.6	2.0

ND = not detected, the mass/sample is below the LOD

* Wipe sample was collected from a 12 inch by 12 inch area

Table C2. Air sample results for lead (December 12–13, 2007)

Work Location	Job Title	MS Sampling Time (minutes)	MS Air Concentration (µg/m³)	DAS Sampling Time (minutes)	DAS Air Concentration (µg/m³)
PBZ Air Samples					
Wave solder	Operator	610	Trace	338	49
	Operator	339	18	409	1.8
	Operator			424	19
	Operator			385	Trace
GA Air Samples					
Between wave solder Line 2 and 3		626	ND		
Between wave solder Line 2 and 4		607	ND		
NIOSH REL			50		50
OSHA PEL			50		50
ACGIH TLV			50		50
MDC			0.32		0.32
MQC			0.96		0.96

Trace = Sample result was between the MDC and MQC
ND = not detected, the concentration is below the MDC
MDC = Minimum detectable concentration calculated by dividing the method limit of detection by the average sample volume collected (0.93 m^3).
MQC = Minimum quantifiable concentration calculated by dividing the method limit of quantitation by the average sample volume collected (0.93 m^3).

Table C3. Air sample results for MEK (December 12–13, 2007)

Work Location	Job Title	MS Sampling Time (minutes)	MS Air Concentration (ppm)	DAS Sampling Time (minutes)	DAS Air Concentration (ppm)
PBZ Air Samples					
Surface mount	Operator	578	0.083		
	Operator	371	0.099		
	Operator	565	0.072		
	Operator	560	0.078		
Wave solder	Loader	631	0.074		
	Loader	614	0.083		
	Quality check	619	0.076		
Coating	Patch coater			552	3.1
Coating	Patch coater			579	4.7
Coating	Sprayer			517	1.7
Coating	Sprayer			467	1.9
Bonding	Ruggedizer			469	0.50
Bonding	Ruggedizer			445	0.60
Bonding	Masker			447	0.45
GA Air Samples					
GE Area				534	0.61
Surface mount Line 2				541	0.11
Repair cage		605	0.08		
SRT Machine		508	0.11		
NIOSH REL			200		200
OSHA PEL			200		200
ACGIH TLV			200		200

Table C4. Air sample results for toluene (December 12–13, 2007)

Work Location	Job Title	MS Sampling Time (minutes)	MS Air Concentration (ppm)	DAS Sampling Time (minutes)	DAS Air Concentration (ppm)
PBZ Air Samples					
Surface mount	Operator	579	0.19	502	0.40
	Operator	579	0.18	525	0.56
	Operator	374	0.17		
	Inspector	349	0.26		
Repair cage	Surface mount repair	576	0.20		
Wave solder	Loader	613	0.22		
	Loader	631	0.19		
	Wash operator			491	0.38
Coating	Sprayer			461	1.7
Coating	Sprayer			515	2.2
Coating	Sprayer			466	3.0
GE Area	Sprayer			477	2.2
Bonding	Ruggedizer			468	1.4
Bonding	Ruggedizer			455	1.4
GA Air Samples					
Surface mount Line 3				549	0.30
Surface mount Line 7, Operator station		591	0.22		
Wave solder Line 3		623	0.20		
NIOSH REL			100		100
OSHA PEL			200		200
ACGIH TLV			20		20

Table C5. Air sample results for 2-butoxyethanol (December 12–13, 2007)

		MS		DAS	
Work Location	Job Title	Sampling Time (minutes)	Air Concentration (ppm)	Sampling Time (minutes)	Air Concentration (ppm)
PBZ Air Samples					
Surface mount	Operator	510	0.0095		
	Operator	576	0.0087		
	Operator	552	0.0071		
	Operator	566	0.0070		
	Operator	371	0.0090		
	Operator	562	0.0079		
Repair cage	Surface mount repair	574	0.0068		
Wave solder	Inspector	604	0.0062		
	Operator			427	0.0077
	Wash operator			438	0.0089
Coating	Patch coater			550	0.0075
Coating	Sprayer			475	0.0079
GE Area	Sprayer			480	0.0069
GE Area	Solderer			578	0.0075
Bonding	Ruggedizer			564	0.0077
GA Air Samples					
Surface mount Line 3				408	0.014
Surface mount Line 4				561	0.0081
Repair cage		606	0.0079		
Surface mount Line 7, Operator station		590	0.0080		
SRT Machine		514	0.0093		
NIOSH REL			5		5
OSHA PEL			50		50
ACGIH TLV			20		20

Table C6. Air sample results for n-butyl acetate (December 12–13, 2007)

Work Location	Job Title	MS Sampling Time (minutes)	MS Air Concentration (ppm)	DAS Sampling Time (minutes)	DAS Air Concentration (ppm)
PBZ Air Samples					
Surface mount	Operator	578	1.1		
	Operator	560	1.1		
	Operator	552	1.2		
	Operator	565	1.1		
	Operator	562	0.99		
	Operator	509	1.3		
	Midoven operator			531	1.9
Repair cage	Surface mount repair	576	0.99		
Wave solder	Inspector	604	1.5		
Coating	Patch coater			580	40.
Coating	Sprayer			515	20.
Coating	Sprayer			462	4.8
Coating	Sprayer			516	25
Bonding	Masker			448	3.2
Bonding	Ruggedizer			578	2.7
Bonding	Ruggedizer			566	3.8
GA Air Samples					
Wave solder Common Area B				446	1.1
Surface mount Line 2, OIS station				541	1.6
Repair cage		607	1.3		
SRT machine		510	1.4		
NIOSH REL			150		150
OSHA PEL			150		150
ACGIH TLV			150		150

Table C7. Air sample results for benzyl alcohol (December 12–13, 2007)

Work Location	Job Title	MS Sampling Time (minutes)	MS Air Concentration (ppm)	DAS Sampling Time (minutes)	DAS Air Concentration (ppm)
PBZ Air Samples					
Surface mount	Operator	509	1.3	527	1.2
	Operator	573	2.6		
	Operator	566	0.84		
	Operator	373	0.57		
	Inspector	349	0.59		
	Solderer			501	0.90
	Midoven operator			525	1.4
Repair cage	Surface mount repair	573	0.95		
Wave solder	Quality check	605	0.86		
	Wash operator			439	1.4
	WS operator			426	0.70
GE Area	Solderer			480	1.6
GA Air Samples					
Wave solder Line 3		625	2.5		
Cage		565	2.0		
SRT machine		512	1.7		
Surface mount Line 4				561	2.0
Surface mount Line 3B				550	1.9

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.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of NIOSH. Mention of any company or product does not constitute endorsement by NIOSH. In addition, citations to websites external to NIOSH do no constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these websites. All Web addresses referenced in this document were accessible as of the publication date.

This report was prepared by Srinivas Durgam, Carlos Aristeguieta, and Chandran Achutan of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies. Industrial hygiene field assistance was provided by Lilia Chen. Medical field assistance was provided by Timothy Ballard. Analytical support was provided by Bureau Veritas North America. Health communication assistance was provided by Stefanie Evans. Editorial assistance was provided by Ellen Galloway. Desktop publishing was performed by Robin Smith.

Copies of this report have been sent to employee and management representatives at Sanmina-SCI® Corporation, the state health department, and the OSHA Regional Office. This report is not copyrighted and may be freely reproduced. The report may be viewed and printed at www.cdc.gov/niosh/hhe. Copies may be purchased from the National Technical Information Service at 5825 Port Royal Road, Springfield, Virginia 22161.

Below is a recommended citation for this report:
NIOSH [2009]. Health hazard evaluation report: evaluation of health concerns at a printed circuit board manufacturing plant, Huntsville, AL. By Durgam S, Aristeguieta C, Achutan C. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA No.2007-0201-3086.

NIOSH *National Institute for Occupational Safety and Health*

Delivering on the Nation's promise: Safety and health at work for all people through research and prevention.

To receive NIOSH documents or information about occupational safety and health topics, contact NIOSH at:

1-800-CDC-INFO (1-800-232-4636)

TTY: 1-888-232-6348

E-mail: cdcinfo@cdc.gov

or visit the NIOSH web site at: **www.cdc.gov/niosh.**

For a monthly update on news at NIOSH, subscribe to NIOSH eNews by visiting **www.cdc.gov/niosh/eNews.**

SAFER • HEALTHIER • PEOPLE™