NIOSH HEALTH HAZARD EVALUATION REPORT

HETA #2000-0374-2998
Engineered Fabrics Corporation
Rockmart, Georgia

May 2006

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

PREFACE

The Hazard Evaluation 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 employers 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. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Loren Tapp, Dino Mattorano, Charles Mueller, Angela Weber, and Chris Reh of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Robert McCleery, Greg Burr, David Sylvain, Max Kiefer, Lisa Delaney, Josh Harney, Jenise Brassell, Deborah Sammons, Marian Coleman, Erica Jones, Debra Feldman, Daniel Rhodes, and Tony Alleman. Dermatological review was provided by Boris Lushniak. Analytical support was provided by Ardith Grote and Data Chem Laboratories. Desktop publishing was performed by Elaine Moore and Robin Smith. Editorial assistance was provided by Ellen Galloway.

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Highlights of the NIOSH Health Hazard Evaluation

[eeg1]

The National Institute for Occupational Safety and Health received an employee request for a health hazard evaluation (HHE) at Engineered Fabrics Corporation in Rockmart GA. Employees submitted the HHE request because of concerns about headache; dizziness; fatigue, memory loss; and respiratory, nasal, and skin problems. NIOSH investigators conducted an investigation in September 2000, February 2001 and July 2001 to look at solvent exposure in the Large Spray (LS) and Small Spray (SS) Departments.

What NIOSH Did

- We took personal breathing zone (PBZ) air samples for solvents.
- We collected urine and blood from employees to see how much solvent was present in their bodies.
- We collected information on solvent penetration through gloves onto the skin.
- We surveyed employees about health symptoms.

What NIOSH Found

- PBZ air solvent concentrations were low.
- Solvents penetrated work gloves in as little as 60 minutes.
- Urine solvent measurements showed some LS employees were overexposed to methylethyl ketone (MEK) (10% of employees) and toluene (16% of employees).
- LS employees reported significantly more memory problems and headache than plaster (PL) employees did.
- Employees with higher MEK exposure had significantly more symptoms of fatigue, incoordination, and muscle weakness.
- No relationship between toluene exposure and symptoms was found.

What Managers Can Do

- Provide tools for employees to use to grasp materials rather than using their hands. This will minimize skin contact with solvents.
- Select better gloves to prevent solvent penetration.
- Train employees on proper personal protective equipment (PPE) use, skin care, and PPE limitations.
- Establish a medical surveillance program to review trends in employee illnesses and injuries.

What the Employees Can Do

- Do not eat, drink, smoke, or chew gum in areas where solvents are used.
- Always wash hands before eating, drinking, or smoking.
- Use proper PPE to prevent solvents from contacting the skin.
- Use soap and water to clean hands rather than solvents.
- Maintain healthy skin; moisturize if dry; clean if dirty; use cotton glove liner if sweaty.
- Report health concerns to the plant Medical Unit.

What To Do For More Information:

We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513-841-4252 and ask for HETA Report #2000-03742998

Health Hazard Evaluation Report 2000-0374-2998
Engineered Fabrics Corporation
Rockmart, Georgia
May 2006

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SUMMARY

On July 26, 2000, the National Institute for Occupational Safety and Health (NIOSH) received a confidential request for a health hazard evaluation (HHE) from employees of Engineered Fabrics Corporation (EFC) in Rockmart, Georgia. EFC manufactures aircraft fuel cells. The employees reported headache; dizziness; fatigue; memory loss; and respiratory, nasal, and skin problems believed to be related to solvent exposures (toluene, acetone, and methyl ethyl ketone [MEK]) used in the Large Spray (LS) and Small Spray (SS) fuel cell departments.

NIOSH personnel conducted an initial site visit September 28–29, 2000, and interviewed several employees who reported dermatitis and acute neurological symptoms potentially related to exposures in their work environment. To determine if worker symptoms were related to solvent exposure, NIOSH personnel returned to EFC the week of February 27, 2001, to conduct environmental exposure monitoring and administer questionnaires to LS, SS, and plaster (PL) workers. (Plaster workers were selected as the comparison group because they have minimal solvent exposure.) Although airborne exposures to MEK, toluene, and acetone were well below current occupational exposure limits (OELs), we observed a significant potential for dermal exposure to solvents in LS and SS workers. Questionnaire responses from 142 LS and SS workers indicated that work-related eye, nose, and throat irritation and neurological symptoms were occurring in this workforce. Eighteen EFC participants had skin rashes; nine were consistent with work-related dermatitis (six LS, two SS, and one former SS employee). Based on these findings, we planned further assessment of solvent exposures using biological monitoring.

During the week of July 30, 2001, NIOSH investigators collected baseline and end-of-shift (EOS) urine samples in conjunction with baseline and EOS questionnaire data from 90 consenting employees (72 LS and 18 PL). Solvent exposures were assessed by collecting full-shift personal breathing zone (PBZ) air samples. In addition, eight LS participants were selected to evaluate glove breakthrough of MEK using a commercially available sensor.

Inhalation exposures to all sampled solvents were higher in LS than in PL; however, all PBZ air sample results were below relevant OELs. MEK was detected on the inside of all eight workers' gloves after they donned new gloves and worked with solvents. Breakthrough times ranged from 60 to 295 minutes.

EOS urine sampling revealed 10% of LS workers with MEK concentrations at or above the American Conference of Governmental Industrial Hygienists' (ACGIH®) Biological Exposure Indices (BEI®) and 16% with o-cresol (a metabolite of toluene) concentrations at or above the BEI. None of the PL workers'

levels exceeded the BEI. Six percent of LS and 13% of PL workers had EOS urine concentrations of hippuric acid (another metabolite of toluene) at or above the BEI.

LS employees were significantly more likely than PL employees were to report neurological symptoms in the month prior to the evaluation. Workers with an MEK level at or above 1.0 µg/mL (half the BEI) had a significantly greater chance of having symptoms of fatigue, incoordination, and muscle weakness. No significant relationship between EOS urine o-cresol levels and EOS symptoms was found.

NIOSH investigators concluded that a health hazard from excessive exposure to MEK and toluene existed among EFC employees at the time of our evaluation. Overexposures to MEK and toluene were predominantly due to dermal absorption rather than inhalation. LS workers reported significantly more neurological symptoms than PL workers did. This report details recommendations to reduce solvent exposure including engineering, administrative, and personal protective equipment controls.

Keywords: NAICS Code: 336413 Other Aircraft Parts and Auxiliary Equipment Manufacturing; MEK; toluene; HMDI; acetone; n-hexane; xylenes; neurological symptoms; dermal exposure; biological monitoring

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INTRODUCTION

On July 26, 2000, the National Institute for Occupational Safety and Health (NIOSH) received a confidential request for a health hazard evaluation (HHE) from employees of Engineered Fabrics Corporation (EFC) in Rockmart, Georgia. The employees reported headache; dizziness; fatigue; memory loss; and respiratory, nasal, and skin problems related to exposures to toluene, acetone, and methyl ethyl ketone (MEK) used in the Large Spray (LS) and Small Spray (SS) fuel cell departments.

NIOSH personnel conducted an initial site visit September 28–29, 2000. This visit included an opening conference with management and employee representatives, a walk-through inspection of the areas of concern with review of work practices, review of the chemical inventory, confidential employee interviews, review of medical records, and interview of the company physician.

NIOSH performed two additional site visits to evaluate EFC employee exposures, including 1) environmental sampling, observation of work practices, and questionnaires conducted the week of February 27, 2001; and 2) environmental sampling, biological monitoring, dermal exposure assessment, and questionnaires conducted during the week of July 30, 2001. This report includes findings from all site visits and concludes our evaluation.

On October 5, 2002, individual notification letters were sent to all participants including their confidential biological sampling results, an explanation of these results, and a summary of the biomonitoring results among all participants. Management, union representatives, and requestors were sent copies of a sample notification letter with confidential information removed (Appendix A). An additional letter concerning confined space issues and recommendations regarding EFC worker entry into large fuel cells to perform job tasks involving solvents was sent in October 2002 (Appendix B).

BACKGROUND

EFC is the world's largest manufacturer of aircraft fuel tanks, and is housed in a facility originally built for the Goodyear Tire and Rubber Company in 1929. In addition to fuel tanks, EFC manufactures ice guards, coated fabrics, and specialty products such as airship envelopes, upholstery, and railcar flex sections. There are several aircraft fuel tank production lines at EFC including crash resistant and bulletproof tanks, bladder tanks, large fuel cell, and small fuel cell.

At the time of the evaluation, EFC employed 420 hourly and 130 salaried employees. Sixty to seventy percent of employees were members of the United Food and Commercial Workers Union. Of the 420 hourly employees, 140 worked in LS, 22 in SS, and 18 in Plaster (PL) departments. First shift employees made up 90% of the workforce; of the remaining workers, about 25 hourly employees worked second shift and 5 to 7 worked third shift. LS was the only area with 24 hour a day production. LS employees included workers with the following job titles: Reverse (or Female) Build (LSRB), Male Build (LSMB), Repair (LSR), Final (LSF), Join (LSJ), Leak Test (LSJP), Preform, and Spray Combo.

Process Description

Manufacturing fuel cells for aircraft is a labor-intensive process that involves the manual assembly of thin layers of fabric over or inside of a pre-formed mold. Molds are made on-site in the PL department without the use of solvents and consist of either a plaster or cardboard form. Layers of fabric (mainly nylon, Kevlar™, and polyester) are assembled in the LS and SS departments using polyurethane adhesives (referred to as cements). These cements contain uncured urethane pre-polymer (made from diisocyanate), an amine curative, MEK, toluene, and smaller amounts of other additives. Cements are manually applied by brush without local exhaust ventilation or sprayed on in a paint spray booth. During the layering process, cells dry either through air curing or with the aid of

an autoclave. The inner plaster or cardboard form is removed, by either soaking or physically breaking it. The result is a flexible fuel bladder that expands when fuel is introduced.

Metal fittings, loops, and other specialty connections are attached to the fuel cells in the LS and SS departments. Brush-applied solvents (MEK, toluene, and acetone) are used to clean adhesives from the surfaces of cells during the process of attaching fittings and other materials around pre-cut holes, and during the joining of different parts of the cells.

There is no central heating, ventilating, and air-conditioning system serving the two fuel cell departments. Comfort fans disperse solvent vapors throughout the areas. Personal protective equipment (PPE) includes safety glasses and gloves (nitrile, neoprene-latex blend, and latex). Employees working in the spray paint booth wear Tyvek™ suits and powered air-purifying respirators (PAPRs) with loose-fitting hoods. One particular task where two employees stand inside a large fuel cell to join two molds together with cement also requires the use of PAPRs with loose-fitting hoods.

A contract physician runs an on-site medical unit one-half day a week; no nursing staff is available. If a medical problem arises when the doctor is not in, the employee is sent to the local emergency department. Pre-placement physicals include a medical history, physical examination, audiometry, vision test, chest x-ray, and spirometry. For those in the respirator program, a physical examination, spirometry, and a chest x-ray are performed yearly.

METHODS

February 2001

NIOSH investigators designed an evaluation of the EFC workplace to determine whether worker symptoms were related to solvent exposure. LS and SS workers were selected as the exposed group, and PL workers, who do not work with solvents, were selected as the comparison group. Both groups participated in air sampling (to determine solvent exposure) and questionnaire surveys (to determine symptom prevalence).

Industrial Hygiene Evaluation

Environmental Sampling, Qualitative Evaluation, and HMDI Sampling

The purpose of the sampling conducted during the February 2001 site visit was to determine airborne solvent exposures, and to identify any compounds that would interfere with future biomonitoring efforts. Solvent exposures were also measured in the PL department to verify that PL employees were not exposed to the solvents of concern. Exposures to methylene bis-(4-cyclohexylisocyanate) (HMDI), used in the cements in the small and large fuel cell departments, were also characterized because exposure to HMDI has been shown to cause some of the health effects reported by EFC employees.

Solvents

The solvent exposure assessment included the collection of full-shift PBZ air samples for MEK, acetone, and toluene in the LS, SS, and PL departments. All were collected using Anasorb CMS tubes. Anasorb CMS tubes were changed during the employees' lunch break to avoid potential breakthrough on the tubes; therefore, the full-shift time-weighted averages (TWA) reported are based on a combination of the morning and afternoon exposures. Battery-operated sampling pumps (SKC Pocket Pump™) calibrated to a nominal flow rate of 0.05 liters per minute (Lpm) were connected to the collection media with Tygon® tubing. The SKC pumps are constant-flow sampling devices and were pre- and post-calibrated using a primary standard (BIOS® Dry Cell). Because no analytical method was available for the three solvents on the same sorbent, conditions from NIOSH Manual of Analytical Methods (NMAM) Methods 7082, 1300, 2500, and 1501 were used, with modifications.[1]

Qualitative Air Sampling

Qualitative air monitoring was conducted to identify volatile organic compounds (VOCs) in the SS, LS, and PL departments. A total of seven general VOC area air samples were collected over the 2 sampling days with reusable multibed thermal desorption (TD) tubes and low-flow air sampling pumps as previously described. Flow rates of 0.05 Lpm were used for the area monitoring, and the sample times were approximately 30 minutes. Analysis was performed using gas chromatography/mass spectrometry. Reconstructed total ion chromatograms were obtained for each sample, and all were scaled the same for comparison. Each peak in the chromatogram was identified.

Methylene bis-(4-cyclohexylisocyanate) (HMDI)

The exposure assessment consisted of PBZ and area air sampling to determine task-related HMDI inhalation exposures during the spray and hand-brush application of the cement, and during the mixing and pouring of a cement batch. PBZ air samples for HMDI were collected during two cement spraying tasks (one each in the LS and SS areas), during three hand-brush cement application tasks, while adding HMDI to the cement mixing vessel ("charging the reactor"), and while pouring newly mixed cement into drums ("batch catching"). In addition, four area air samples were collected at reverse-build work stations in the LS area to estimate workers' HMDI exposure during hand-brush cement application.

PBZ air samples were collected using a 37-millimeter (mm) quartz fiber filter impregnated with 1-(9-anthracenylmethyl) piperazine (MAP). The area air samples were collected using a MAP-containing midget impinger and a MAP-impregnated quartz fiber filter in series. Battery-operated sampling pumps calibrated to a nominal flow rate of 1.5 Lpm were connected to the collection media with Tygon® tubing. The filters were removed from the cassette immediately after sampling and placed in a jar containing 5 milliliters (mL) of MAP in acetonitrile solution. The impinger solutions were transferred to glass vials. The samples were shipped cold to the lab. In the lab, acetic anhydride was added to the filter samples and allowed to react with the excess MAP, after which the samples were filtered and concentrated for analysis by high performance liquid chromatography (HPLC). The impinger solutions were subjected to solid-phase extraction prior to analysis by HPLC with fluorescent/ultraviolet detection.

Medical Evaluation

Questionnaire

NIOSH investigators administered questionnaires to all employees working in the SS, LS, and PL departments during the week of February 27, 2001. Management arranged for groups of 20–30 workers to fill out the questionnaire in a designated room during their shift; NIOSH personnel were present to assist with any questions. The purpose of the questionnaire was to determine the extent of work-related neurological, irritant, and skin symptoms consistent with solvent exposures. The questionnaire covered work history, medical history, demographic information, job tasks, types and use of PPE, and symptoms potentially related to work. For data analysis, symptoms were considered work-related if the participant answered "yes" to the symptom *and* "yes" to either 1) "Do you think it is related to work?" or 2) "Did/does it improve during time away from work?" Information on non-occupational exposures (current use of tobacco products, alcohol use, and solvent exposure outside of the workplace) was obtained to evaluate possible factors that might influence the study results. Consenting participants reporting a current skin rash underwent a medical evaluation including visual examination and photos of their skin irritation.

July 2001

Based on data collected during the February 2001 evaluation, NIOSH investigators hypothesized that the predominant route of employee exposure to solvents was through the skin, and that biological monitoring was needed

to assess total solvent exposure uptake (body burden). NIOSH investigators conducted a third evaluation from July 30–August 3, 2001 among LS and PL employees. LS employees were chosen for the exposure group because they were larger in number and had slightly higher exposures compared to SS employees. PL employees were chosen as the comparison group.

Airborne solvent exposures in the LS and PL departments were assessed as previously described by collecting full-shift PBZ air samples. Samples were collected on Anasorb® CMS tubes using battery-operated sampling pumps calibrated to a nominal flow rate of 50 mL/min. PBZ air samples were analyzed for MEK, toluene, acetone, xylene, and n-hexane using a combination of conditions from NIOSH Methods 2500, 1501, 1300, and 1500.

Glove Evaluation and Dermal Exposure Assessment

Gloves were evaluated for chemical breakthrough using a commercially available qualitative sensor. The Permea-Tec™ sensor consists of a colorimetric indicator strip on top of a 2-centimeter (cm) square charcoal pad. The pad and indicator are attached to an adhesive strip similar to an adhesive bandage. The colorimetric indicator is a microencapsulated sensor that is applicable for polar solvents like MEK and acetone.

Eight workers (9% of study participants) participating in air sampling and biological monitoring were selected from the LS department based on their potential for dermal solvent exposure. At the beginning of the work shift, workers were asked to obtain a new pair of gloves. Prior to donning the gloves, Permea-Tec™ sensors were placed in the center of the palm on one hand. The sensors were checked every 30 minutes or when convenient for the worker, and the times were recorded. Chemical breakthrough time was estimated and represents a time range, from the time the indicator color change was observed back to the previous time it was checked. For example, if a worker's indicator was checked at 8:30 a.m. with no color change and again at 9:00 a.m. with a color change, then that worker's glove breakthrough time would be estimated at 90 to 120 minutes if he/she started work at 7:00 a.m.. For worst case solvent breakthrough conditions, only one hand (the non-brush-holding hand) was sampled. NIOSH investigators observed that it was commonplace to hold a brush in one hand (usually the dominant) during cement and solvent application while the other hand held the fabric and reinforcement pads in place. As a result, the non-dominant or non-brush hand was continually in contact with the cement or solvent for most of the day.

Medical Evaluation

On July 26, 2001, NIOSH investigators held informational meetings for all PL and LS employees to explain the upcoming study, recruit participants, obtain informed consent from participants, and counsel participants on avoiding certain substances prior to the start of testing to prevent potential interference with blood and urine analyses.

Biological Monitoring and Questionnaires

On July 30, 2001, NIOSH investigators met all LS and PL participants at the entrances to the plant as they were reporting to work to begin the weeklong evaluation. Baseline urine samples in conjunction with baseline questionnaire data were collected pre-shift. The baseline questionnaire covered medical history, lifestyle habits that could influence the urinalysis results, and symptoms in the month prior to the survey that were potentially due to solvent exposure. Baseline urine samples were analyzed for acetone, MEK, toluene metabolites (hippuric acid and o-cresol), n-hexane metabolite (2,5-hexanedione [2,5-HD]), and xylene metabolites (methylhippuric acids).

On August 1 and 2, 2001, end of shift (EOS) urine samples, in conjunction with questionnaire data, were collected from participants. These EOS urine samples were analyzed for acetone, MEK, hippuric acid, o-cresol, and methylhippuric acids. Information collected

from the questionnaire was analyzed to determine the prevalence of symptoms during work hours of the survey week and to identify nonoccupational factors that could affect the findings.

On August 3, 2001, end-of-work-week (EWW) blood samples for toluene were collected at the start of the shift, and EOS/EWW urine samples for 2,5-HD were collected.

Analyses of urine and blood specimens

Urine and blood samples were prepared for transport and shipped to DataChem Laboratories for analysis. Urine samples were analyzed for acetone and MEK using gas chromatograph with flame ionization detection (GC-FID). Urine samples were analyzed for o-cresol using GC-FID according to NIOSH Method 8305.[1] Urine samples were analyzed for hippuric acid congeners (hippuric acid, 2-methyl hippuric acid, co-elutents 3- and 4-methyl hippuric acids) by high pressure liquid chromatography (HPLC) according to NIOSH Method 8301.[1] Urine samples were analyzed for 2,5-HD (with hydrolysis) using GC-FID. Blood samples were analyzed by GC-FID. Samples were analyzed for toluene by GC/FID headspace according to a modified version of NIOSH Method 8002.[1]

Statistical Analyses

Descriptive statistics were provided to summarize the data from the questionnaires, the air sampling, and the urine sampling. The Wilcoxon two-sample test was used to compare urine solvent levels for the LS and PL groups. To evaluate factors that might affect the results of the urine analyses, linear regression models were used. The paired t-test was used to determine whether solvent levels in the urine increased from baseline to end of shift. The Spearman correlation coefficient was used to compare 8-hour TWA air concentrations of solvents to their respective EOS urine concentrations. To compare symptom reporting for those in the LS and PL job categories, either the chi-square test or the Fisher's exact test was used, and the odds ratio (OR) was reported. The OR is defined as the odds of a LS worker reporting a symptom divided by the odds of a PL worker reporting that symptom. Therefore, an OR > 1 would indicate that a LS worker might be more likely to report the symptom. For the statistical tests a p-value was also reported. If the p-value is 0.05 or less, the result is described as statistically significant and one can confidently state that the result is not likely due to chance.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increases the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[2] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®)

Threshold Limit Values (TLVs®),[3] and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[4] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criteria.

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing 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, employers should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect its employees from hazards, even in the absence of a specific OSHA PEL.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended STEL or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

Biological Exposure Index

In addition to the TLVs for airborne chemical exposures, ACGIH has established biological levels of exposure called Biological Exposure Indices (BEIs®) for a subset of chemicals. TLVs refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. Biological monitoring provides another means to assess exposure and health risk to workers, and BEIs are guidance values for assessing biological monitoring results. ACGIH BEIs generally indicate concentrations below which nearly all workers should not experience adverse health effects and typically correspond to air TLV levels. Biological measures of exposure are preferred over measuring airborne concentrations alone for agents that can have significant absorption via other routes, as the value takes into account inhalation, skin absorption, and ingestion. Therefore, a biological measure of exposure can be viewed as a means of assessing an employee's total exposure to a substance.[5] BEIs for the solvents measured in this HHE are given in Table 1.

Occupational Exposure Limits

Occupational safety and health professionals attempt to identify working environments with the potential to cause health problems before these problems occur. TLVs and BEIs are used as upper limits of exposure. As workplace exposures approach these levels, the need for monitoring and surveillance becomes greater. OSHA, NIOSH, and ACGIH occupational exposure limits (OELs) for the solvents used most often at EFC are summarized in Table 1, and discussed below.

Methylene bis-(4-cyclohexylisocyanate) [HMDI]

HMDI belongs to a class of chemicals known as isocyanates and shares characteristics of other chemicals in the class. Isocyanates are irritating to the skin, mucous membranes, eyes, and respiratory tract.[6,7] The most common adverse health outcome associated with isocyanate exposure is asthma due to sensitization; less prevalent are contact dermatitis (both irritant and allergic forms) and hypersensitivity pneumonitis (HP), a restrictive respiratory disease affecting the lung parenchyma (bronchioles and alveoli).[8,9]

NIOSH has established an REL of 0.01 parts per million (ppm) or 110 micrograms per cubic meter ($\mu g/m^3$) as a ceiling limit for HMDI.[7] ACGIH has established an 8-hour TLV-TWA of 0.005 ppm or 54 $\mu g/m^3$ to minimize pulmonary irritation and possible respiratory or skin sensitization.[3] There is no OSHA PEL for HMDI.

Solvents

The term solvent applies to any substance that dissolves another substance, yielding a solution. Solvents can be water based (aqueous) or hydrocarbon based (organic). Most industrial solvents are organic and are used for tasks such as cleaning, degreasing, thinning, and extraction.[10] Common organic solvents include acetone, toluene, xylene, mineral spirits, and MEK.

Inhalation and dermal exposure are important routes of exposure to organic solvents in the workplace. Absorption through the skin depends upon the degree of lipid and water solubility of the solvent.[10] Almost all organic solvents cause irritation of the skin because they remove fat from the skin. Organic solvents may cause minimal to mild irritation of the respiratory system.[11] This irritation is usually restricted to the upper airways, mucous membranes, and eyes, and it generally resolves quickly without long-term effects.[10]

Almost all volatile, fat-soluble organic solvents can acutely cause nonspecific central nervous system depression. The symptoms of significant acute solvent exposure are similar to those from drinking too many alcoholic beverages, including headache, nausea and vomiting, dizziness, slurred speech, impaired balance, disorientation, and confusion. These symptoms go away quickly upon cessation of exposure.[12] Rarely, death from respiratory depression can occur at very high exposure levels. Subtle, reversible decrements in performance on attention and reaction time testing have been observed with acute exposures to solvents, but may not be directly attributable to nervous system dysfunction, as similar effects are seen when the main effect of exposure is headache or eye irritation.[12] There is controversy over whether long-term exposure to solvents can cause toxic encephalopathy, which is a constellation of symptoms such as fatigue, irritability, depression, headaches, and forgetfulness. Workers in whom this has been described generally have at least 10 years of relatively intense exposure to solvents.[12]

MEK

MEK is a colorless liquid with a sharp, sweet odor. It is used as a solvent and in making plastics, textiles, paints, and glues. Nonoccupational exposure to MEK is uncommon, but it can be found in some products used in hobby activities and household cleaning. In the workplace, the major route of exposure is inhalation, but dermal absorption of liquid MEK can be significant.[13] At EFC, MEK is used frequently in the LS and SS areas. Mixtures that contain MEK in LS and SS include: 01C16, 01C22, 1187C, 1210C, 1211C, 1829C, 1857C, 1859C, 1895C, 5063C, 5070C, 5071C, 5904C, 5907C, 5939C, 5949C, 5963C, 5966C, 80C10, 82C12, 82C30, MEK, Metzic, and Pliobond 20.

Some studies conclude that MEK has a lower order of toxicity than other solvents; however, others find exposure to a mixture of solvents that includes MEK accentuates the toxicity of other solvents, such as other ketones, n-hexane, chloroform, toluene, and carbon tetrachloride.[13] It is not clear whether long-term health effects result from repeated MEK exposure, but one study suggests that this type of exposure may damage the nervous system, including symptoms of reduced memory and concentration, personality changes, fatigue, sleep disturbances, reduced coordination, "pins and needles" sensations in the arms and legs, and effects on nerves that supply internal organs.[14]

Biomarker for MEK

The ACGIH BEI for MEK measured as urinary MEK is 2 µg/mL, collected at the end of the shift. This urinary level corresponds with a TWA daily exposure of 200 ppm of MEK. Because of MEK's short half-life in the body, urine measurements indicate exposure on the day of sampling only. Ingestion of alcoholic beverages may alter the relationship between levels of MEK in the environment and in the body, causing an over-estimation of total exposure. Dermal exposure and heavy physical workload also increase MEK concentrations in the urine.[5]

Toluene

Toluene is a colorless, volatile liquid with a sweet strong odor. It is used as a solvent, in fuel, and in making other chemicals, perfumes, medicines, dyes, explosives, and detergents. Non-occupational exposures include paints, strippers, glues, auto exhaust, auto fuel, printers, cosmetics, inks, household cleaners, and cigarette smoking. Inhalation is the most common route of exposure in the workplace; however, toluene can be absorbed through the skin. Other factors that may influence the amount of toluene in the blood include drinking alcohol (increases blood toluene level), smoking, significant obesity, exposure to other solvents, and physical activity.[15] EFC uses toluene as one of the ingredients in the following mixtures: 01C16, 01C22, 01C25, 1451C, 1829C, 5063C, 5071C, 5904C, 5907C, 5939C, 5963C, 80C10, 82C30, Dalstic, Metzic, 1222C, and rubber solvent.

In addition to general solvent health effects previously listed, long-term exposure to toluene may damage the liver, kidneys, and brain. Chronic inhalation exposure is teratogenic in animals, i.e., it damages the developing fetus.[15]

Biomarkers for Toluene

Hippuric acid is a metabolite of toluene that is excreted in the urine but can also be found in the urine from the metabolism of certain acidic foods (e.g., berries, plums, cranberries, and prunes) and the food preservative sodium benzoate found in fruit juices and sodas. Background urinary hippuric acid levels in western populations range from 500 to 1500 mg/g creatinine. The BEI for urinary hippuric acid is 1.6 grams per gram of creatinine (or 1600 milligrams per gram of creatinine [mg/g creat]) collected EOS, and is based on an 8-hour TWA air exposure level of 50 ppm. Excretion of urinary hippuric acid has a half-life of 2 to 3 hours. Drinking alcohol reduces the metabolism of toluene to hippuric acid and can lead to a lower level of hippuric acid in the urine. [5]

Another metabolite of toluene is urinary o-cresol. The BEI for urinary o-cresol is 0.5 milligrams per liter (or 0.5 micrograms per milliliter [µg/mL]) collected EOS. Factors that may influence the concentration of o-cresol in urine include cigarette smoking, drinking alcoholic beverages, and exercise. [5]

Levels of toluene in the blood appear to build up throughout the workweek, and sampling should be done at the end of at least 3 work days.[5] The recommended BEI for toluene measured as blood toluene is 0.05 milligrams toluene per liter of blood, collected at the start of the last shift of the week, and is an indicator of the weekly TWA exposure to toluene.

Acetone

Acetone is a clear, colorless liquid with a mildly pungent, sweet odor. It is used primarily to make other chemicals and as a solvent for resins, paints, inks, varnishes, lacquers, and in adhesives, thinners, and clean-up solvents (including some nail polish removers). Non-occupational exposures include polish and paint removers, household cleaning and waxing products, certain cosmetics, and cigarette smoke. Acetone is normally produced metabolically by all humans and may be present in significant amounts in the urine of diabetics. Disulfiram (Antabuse), a drug used to help alcoholics avoid drinking alcohol, may increase levels of acetone in the body. Inhalation is the major route of acetone exposure in the workplace; dermal absorption is minimal. High acetone air levels can lead to general health effects seen with solvents.[16] Acetone is used directly and in the following mixtures in both LS and SS areas: 2379C, Metzic, and 1222C.

Biomarker for Acetone

The BEI for acetone measured as urinary acetone is 50 µg/mL and is based on the current ACGIH TLV-TWA, which was set to control irritation of the mucous membranes. Acetone has a short half-life in the body (around 2 hours or less), and an EOS urine sample may not demonstrate exposure that occurred early in an 8-hour shift, so sampling time is critical. It is also possible to obtain a false positive in a

diabetic or in an individual who is fasting, taking Antabuse, or exposed to 2-propanol. [5]

N-Hexane

N-hexane is a flammable, colorless liquid with a mild gasoline-like odor that is primarily used as a solvent and thinner for glue. Non-occupational exposure to n-hexane is uncommon, but it can be a minor component of inks, paints, glues, and gasoline. Inhalation is the major route of exposure in the workplace, although dermal absorption via the liquid or vapor form can also raise biological levels of n-hexane significantly.[17] N-hexane is found in the following EFC solvent mixtures: 01C16, 01C22, 01C25, 232C, 513C, and rubber solvent.

In addition to general solvent health effects previously listed, long-term exposure to n-hexane can damage the peripheral nervous system, causing numbness, tingling, and/or muscle weakness in the hands, feet, arms, and legs (i.e., polyneuropathy).[17]

Biomarker for n-hexane

N-hexane accumulates in fatty tissue with repeated exposure. When exposure ceases, the n-hexane is released back into the bloodstream, metabolized (mostly) to 2,5-hexanedione (2,5-HD), and eliminated in the urine. Due to the accumulation properties of n-hexane, urine must be collected EOS at the end of the workweek. At the time of our data collection and analysis, the BEI for n-hexane, collected EOS EWW to indicate a TWA-weekly exposure to n-hexane, was 5 mg/g of creatinine, measured as 'total' urinary 2,5-HD (with hydrolysis). (During 2003, a new ACGIH recommendation was adopted that changed the BEI to 0.4 mg/L, measured as 'free' 2,5-HD [without hydrolysis] after further studies indicated that this determination would more closely reflect the risk of the exposed workers to the peripheral neurotoxicity of n-hexane. The 'total' 2,5-HD [with hydrolysis] is several times higher in concentration than the 'free' 2,5-HD when the same urine sample is analyzed.) The following factors can affect the biological levels: exposure to methyl n-butyl ketone, and coexposure to toluene and MEK. [5]

Xylene

Xylene is a clear liquid with a sweet odor. A mixture of xylene isomers (ortho, meta, and para xylenes) is commonly used as a solvent, in making dyes, pesticides, lacquers and enamels, and in gasoline. Xylenes are also used in histology laboratories. Non-occupational exposure to xylenes can be found in paints, varnishes, thinners, and some adhesives used in the home. Inhalation is the major route of exposure in the workplace; however, skin contact with liquid xylenes (but not vapors) is also a significant route of absorption.[18] EFC uses xylenes in the following mixtures: 01C16, 1210C, 1211C, 1829C, 82C12, Metzic, and Vargic.

In addition to general solvent health effects previously listed, chronic exposure to xylenes can damage the kidneys and the nervous system. Xylenes may damage the developing fetus. [18]

Biomarker for Xylenes

Urinary excretion of methylhippuric acids (i.e., metabolites of xylenes) accounts for about 95% of the amount of absorbed xylenes. The recommended BEI for xylenes measured as total urinary methylhippuric acids, collected EOS, is 1.5 g of total methylhippuric acids/g of creatinine (or 1500 mg/g creatinine). The following factors can affect the biological levels: nonoccupational exposure to household products containing xylene, ingestion of aspirin; and consumption of alcohol (causing underestimation of exposure). Coexposure to ethylbenzene inhibits the formation of methylhippuric acids. [5]

RESULTS

February 2001

Industrial Hygiene Evaluation

Solvents

Results from the PBZ air samples collected for MEK, acetone, and toluene are shown in Tables

2–5. Tables 2 and 3 contain the results from samples collected in the LS department on February 28, 2001, and March 1, 2001, respectively. Table 4 contains results from the SS department over the 2-day sampling period, as well as two PBZ samples collected from the return goods repair department. Table 5 contains the results from the comparison group in the PL department. A summary of all results is presented in Table 6. Concentrations of MEK, acetone, and toluene were similar in LS and SS. All exposures were below current OELs. Observation of LS and SS work practices, however, revealed a significant potential for dermal exposure to solvents in those departments. Only trace concentrations of these solvents were detected in the PL department.

Qualitative Air Sampling

Area sample sites in the LS fuel cell department included: join, repair, breakout, and male build. Single samples were collected in SS, return goods repair, and the PL department. Major components identified on some or all the samples were MEK, toluene, acetone, hexane, and xylene. Although solvents were not being used in the PL department, trace levels of MEK, toluene, and acetone were found. No exposures were identified that would interfere with NIOSH plans for biomonitoring.

HMDI Sampling

The air samples obtained during two cement spraying tasks (one each in LS and SS areas) indicated HMDI exposures of 131.2 and 27.2 $\mu g/m^3$, respectively (Table 7). The samples were collected over the course of the task for 31 and 47 minutes, respectively. The HMDI concentration in the LS booth was above the NIOSH ceiling REL of 110 $\mu g/m^3$. Workers in this area were provided with personal protective equipment that was adequately protective from these exposures (i.e., supplied-air respirators, Tyvek™ suits, and natural rubber gloves).

Low levels of HMDI, ranging from 0.4 to 1.9 $\mu g/m^3$, were detected at the reverse build work stations. No HMDI was detected in the two samples where SS workers used a hand-brush to apply cements, or in the sample where "joint sealing" was performed in the LS area. Finally, HMDI was not detected in the sample taken during charging the reactor with HMDI, or while performing batch catching.

Medical Evaluation

Of the 180 LS, SS, and PL employees at work on the day the questionnaire was administered, 177 (98%) participated. These included 124 LS, 18 SS, and 19 PL employees; the other sixteen employees could not be categorized by job type (eleven chose more than one job type and five chose "other") and were excluded from the analysis. Thus, the findings below are based on information from 161 employees. Demographic information and other important characteristics for each job category are given in Table 8. LS and SS areas had a larger proportion of female employees (85% and 72%, respectively) compared to PL (21%). LS had the lowest average worker age (39.6 years) and number of years at EFC (4 years). Thirty-eight percent (35% of LS, 44% of SS, and 47% of PL) reported current smoking; 24% (24% LS, 11% SS, and 37% PL) reported having at least one drink in the month prior to the survey, and 28% (33% LS, 17% SS, and 11% PL) workers reported handling solvents (including nail polish remover) outside of the workplace. The average number of reported alcohol drinks consumed per month was 1.7 drinks (range 0 to 48) for LS workers, 0.4 drinks (range 0 to 6) for SS, and 7.0 drinks (range 0 to 99) for PL workers.

One hundred percent of LS, 94% of SS, and 58% of PL workers reported wearing gloves at work. In the LS and SS areas, the most common primary barrier gloves worn were the neoprene/latex blend. These were worn by 69% and 72%, respectively. Twenty-six percent of LS, 29% of SS, and 17% of PL workers reported wearing a second glove underneath the major barrier glove. Seventy-nine percent of LS, 56% of SS, and 59% of PL workers who wore gloves at work reported reusing them. Thirty-eight percent of LS, 6% of SS, and 19% of PL workers used barrier cream at work. A breakdown of percentages of types of gloves

worn as primary barrier gloves and "undergloves," and the number of pairs of gloves worn per day by job category is given in Table 9.

Overall, LS and SS employees reported a greater percentage of work-related symptoms in the 6 months prior to the survey than PL (see Table 10). The most prevalent work-related symptoms (from most to least prevalent) included unusual fatigue or drowsiness; eye, nose, and throat irritation; frequent headache; dizziness or lightheadedness; nausea or upset stomach; and difficulty with memory or concentration. LS and SS workers had higher reported rates for occasionally and frequently needing to step away for fresh air than PL workers.

A greater percentage of LS and SS employees reported having a skin problem during the past 12 months than PL workers (33%, 44%, and 11% respectively). Eighteen LS employees and one PL employee had consulted a doctor for their skin condition. Eighteen employees (15 LS, 2 SS, and 1 PL employee whose rash began while working SS) had skin rashes at the time of this site visit. The rashes were photographed and reviewed, along with medical and occupational histories taken during the site visit, by the NIOSH medical officer and a NIOSH dermatologist who concluded that nine had potentially work-related skin rashes (6 LS, 2 SS, and the former SS worker).[19] A letter was sent to each of the 18 employees notifying them of the dermatologist's conclusions.

July/August 2001

Industrial Hygiene Evaluation

Solvent Air Concentrations

PBZ air sample results for MEK, toluene, acetone, hexane, and xylenes are summarized in Table 11. Ninety workers were monitored in five different areas of the plant including LS Reverse Build (24), LS Male Build (11), LS Final (11), LS Repair/LSJP/LS Join/JP Leak Test/Sprayer (27) and PL (17). The seventeen PL workers included one "cement sprayer" and one employee assigned to SS part-time. LS Repair, LSJP, and LS Join were combined for data analysis because the job tasks and materials used were similar. All results were well below relevant occupational exposure criteria. Inhalation exposures to MEK were higher in LSRB and LSMB than LSR/LSJP/LSJ/JP Leak Test/Sprayer and LSF; the lowest concentrations were in PL. This was expected as LSRB and LSMB workers used more cement, which contains MEK, than any other group. In the LSF and LSR/LSJP/LSJ/JP Leak Test/Sprayer, acetone exposures were highest because inspection and repair work requires cleaning, which is done mostly with acetone. Toluene, hexane, and xylene exposures were slightly higher in LSMB and LSRB than in other parts of the plant, which was likely the result of using more cement.

Comparing Solvent Air and End-of-Shift Urine Solvent/Metabolite Concentrations

Significant correlations were found between full-shift TWA air concentrations of MEK and EOS urine MEK ($r=0.81$, $p=<.01$), air toluene concentrations and EOS urine o-cresol ($r=0.54$, $p=<.01$), and air acetone concentrations and EOS urine acetone ($r=0.66$, $p=<.01$). No significant correlations were found between airborne toluene, n-hexane, and xylene concentrations and their corresponding urine concentrations of hippuric acid, 2,5-hexanedione, and methylhippuric acids ($r=0.05$, $p=0.64$; $r=-.09$, $p=0.43$; and $r=0.03$, $p=0.81$, respectively).

Assessing the Contributions of Airborne and Dermal Exposure to Body Burden

MEK concentrations in PBZ air and urine samples were used to approximate the contribution of inhalation exposure to overall MEK body burden to then estimate the contribution of dermal exposure. First, PBZ air concentrations were used in the following ACGIH model to estimate expected urine MEK concentrations (ACGIH MEK documentation for a BEI[5]):

MEK in urine (mg/L) = (320 + 9.4 MEK inhalation exposure (ppm))/ 1000

The estimated MEK urine concentrations were then divided by PBZ air MEK concentrations and multiplied by 100. The result is an estimated percent of MEK exposure accounted for by inhalation. When this model is applied to workers with urine MEK concentrations at or above the ACGIH BEI of 2.0 mg/L, inhalation exposures only account for 10%–30% of the overall urine MEK concentrations. Ten LS workers (eight LSRB and two LSMB) had urine MEK concentrations at or above the BEI despite PBZ air sampling results below exposure criteria, indicating a substantial dose via dermal absorption.

Eight LS workers participated in the dermal exposure evaluation; data results are provided in Table 12. Included in the table are PBZ and urine concentrations, and glove MEK breakthrough times. The table shows that over the work shift there was potential for an appreciable amount of MEK available for dermal absorption by either permeating (by gaseous diffusion) or penetrating (by cracks or holes) the neoprene/latex blend gloves. MEK was detected on the inside of all five workers' gloves, and breakthrough times ranged from 30 to 295 minutes. The eight participants wore gloves for the entire work shift.

Medical Evaluation

Demographics and Other Characteristics

Seventy-four of 138 (54%) LS and 18 of 19 (95%) PL workers participated in the baseline questionnaire and urine measurements, and 90 of the 92 completed the EOS questionnaire and biological sampling (72 [52%] LS and 18 [95%] PL workers). The number of LS and PL employees did not always add up to 90 for each analysis because of varying response rates on specific questionnaire items and occasional insufficient quantities of urine to complete all laboratory analyses for some participants. Demographic and medical characteristics are shown in Table 13 by job title.

To assess whether a meaningful difference in solvent exposure existed between workers who worked the weekend before the survey and those who did not, LS workers were grouped into those who worked Saturday and/or Sunday prior to the survey and LS workers who did not. Comparison of these two groups found no meaningful difference in baseline urine concentrations of solvents or their metabolites; therefore, all LS employees were combined into one group to compare with PL.

LS and PL employees were compared on various characteristics that could influence our findings regarding responses to symptom surveys, levels of exposure, and the relationship between environmental and biological measures. LS had a much higher percentage of female employees than PL (93% and 33%, respectively). There was no significant difference between PL and LS workers in current smoking status or ingestion of benzoic acid foods or beverages, either at baseline or EOS. PL employees had a significantly higher percentage of persons who drank alcohol in the prior 24 hours compared to LS employees ($p<0.01$) for both baseline and EOS measurements. There was no significant difference between PL and LS employees regarding hobbies using solvents in the 24 hours prior to baseline data collection, but a significantly higher number of PL employees than LS employees reported this activity during EOS surveys ($p=0.03$).

Biological Monitoring

Baseline Urine Levels

None of the PL workers and only seven (12%) of the LS workers had baseline urine MEK levels above the limit of detection (LOD). No significant difference was found between baseline urine concentrations of MEK for the LS and PL workers ($p=0.33$). This remained true when accounting for alcohol use in the prior 24 hours and for hobbies involving solvents in the prior 24 hours.

Baseline urine concentrations for hippuric acid and o-cresol did not significantly differ in LS and PL workers (p=0.91 and 0.13, respectively). This remained true when accounting for current smoking, alcohol use in the prior 24 hours, and ingesting foods/drinks containing benzoic acid in the prior 8 hours (hippuric acid only), and when eliminating the three participants with hobbies involving solvents.

Mean baseline 2,5-HD urine concentrations in LS were higher than in PL (1.38 mg/g creatinine vs.1.04 mg/g creatinine; p=0.05). A difference was found when taking into account alcohol use in the prior 24 hours. Those LS workers who drank alcohol 24 hours prior to the testing had lower hexanedione urine levels than those who did not drink (LS drinkers mean: 0.68; LS non-drinkers mean: 1.42); the opposite was true for PL workers (PL drinkers mean: 1.23; PL non-drinkers: 0.95). The effect of solvent exposure differed significantly between alcohol drinkers and nondrinkers (p=0.046).

The results of the baseline and EOS urine concentrations for acetone and methyl-hippuric acids were well below the BEI, with many workers having non-detectable levels. Urine results for these substances were not analyzed statistically because of these findings.

Comparing LS and PL EOS Urine Levels to the BEI

The number of employees with EOS urine solvent/metabolite concentrations at or above the BEI for MEK, o-cresol, hippuric acid, 2,5-HD, acetone, and methylhippuric acid is given in Table 14.

Ten of 62 (16%) LS workers had an EOS urine concentration of MEK at or above the BEI of 2 µg/mL. All PL employees had urinary MEK concentrations below the detectable limit of 0.2 µg/ml. Among LS employees (N=62), the median urinary MEK concentration was 0.45 µg/mL with a range between 0.1 and 7.2 µg/ml.

Seven of sixty-seven (10 %) of LS workers, but none of the PL workers, had an EOS o-cresol concentration at or above the BEI. The median EOS urine o-cresol concentrations among PL employees was 0.06 µg/mL (range 0.05–0.20) compared to 0.10 µg/mL (range 0.02–0.59) in LS employees (p<0.05).

Four LS (6%) and two PL (13%) workers had urine levels of hippuric acid at or above the BEI. The median EOS urine hippuric acid concentrations among PL workers was 270 mg/g creatinine (range: 60–2000) compared to 410 mg/g creatinine (range: 0–3300) among LS workers (p=0.40).

No EFC employees had EOS urine 2,5-HD concentrations at or above the BEI. Overall, levels ranged between 0.78 and 4.4 mg/g creatinine. The median EOS urine 2,5-HD concentrations among PL employees (N=16) was 1.50 mg/g creatinine, while the median concentrations among LS employees (N=62) was 1.90 mg/g creatinine (p=0.10).

All EOS urinary acetone and total methylhippuric acid concentrations were well below the BEI.

The blood toluene levels were all below the lowest level that our laboratory can measure, 0.08 milligrams per liter (mg/L). Because this concentration (0.08 mg/L) is above the BEI level of 0.05 mg/L, no conclusions can be drawn regarding these measurements.

Comparing the Change in LS and PL Urine Solvent/Metabolite Levels across the Work Shift

The difference between EOS and baseline urine concentrations for each solvent or metabolite was determined to assess the amount of solvent taken up by the workers during their work shift. (Some participants did not return an EOS urine sample, or there was insufficient urine quantity to analyze; these participants were not part of this analysis.) PL employees had no change between baseline and EOS urine MEK concentrations (N=12, p=0.99), while LS employees had a significant increase (N=50,

p<0.01). The cross-shift increase in urine MEK concentrations in LS employees was not affected by alcohol use or hobbies involving solvents.

The differences between baseline and EOS urine hippuric acid and o-cresol concentrations were not statistically significant in PL employees (N=15, p=0.1 and N=14, p=0.61, respectively), but EOS concentrations were significantly higher than baseline in LS employees (N=67, p<0.01 and N=66, p<0.01, respectively). These increases in cross-shift urine concentrations among LS employees persisted when considering the following factors: smoking, alcohol use, hobbies involving solvent use, and benzoic acid food/beverage ingestion (benzoic acid was only considered when analyzing hippuric acid levels).

Statistically significant increases were found in 2,5-HD concentrations from baseline to EOS for both the PL and LS employees (p<0.01 and p<0.01, respectively). This did not change after considering 24-hour prior alcohol use and prior exposure to hobbies with solvent use individually.

Questionnaire results

Baseline

Data from the baseline questionnaires found that LS employees had significantly higher odds of reporting the following symptoms in the month prior to this evaluation than PL employees: 1) feeling "high" from chemicals used at work (OR=∞[1]), 2) having memory problems (OR=7.33), 3) needing to keep notes to remember things (OR=6.10), 4) feeling dizzy or lightheaded (OR=5.13), 5) having frequent headaches (OR=4.80), 6) having difficulty concentrating (OR=4.49), and 7) feeling tired more easily (OR=3.97) (see Table 15). After adjusting for gender differences, the odds of reporting symptoms of feeling "high" from chemicals used at work and frequent headaches remained significantly higher in LS than PL employees, while the reporting of memory problems, difficulty concentrating, feeling dizzy or lightheaded, feeling tired more easily, and needing to keep notes to remember things were no longer statistically significant.

EOS

Data from the EOS biomonitoring symptom survey found that LS employees had significantly higher odds of reporting memory problems (OR=5.71, p=0.02) and headache (OR=5.00, p=0.01) than PL employees (Table 16). Upon controlling for gender, the odds remained higher in LS than PL employees, but neither remained statistically significant.

Comparing EOS MEK and o-cresol urine concentrations with EOS symptoms

The relationship between EOS symptoms and EOS measures of exposure to MEK and toluene was evaluated.

Workers with a urine MEK level at or above 1.0 µg/mL had a significantly greater chance of having symptoms of fatigue, incoordination, or muscle weakness (OR=4.95, p = 0.01; OR=5.88, p=0.01; OR=4.27, p=0.02, respectively). There were no men with an MEK level ≥ 1.0 µg/mL, so our analyses to control for age were restricted to women only. After adjusting for age, women with a urine MEK level ≥ 1.0 had a significantly greater odds of having symptoms of fatigue, incoordination, or symptoms of muscle weakness (OR=5.02, p=0.03; OR=4.67, p=0.03; OR=3.25, p=0.054, respectively). MEK urine levels ≥ 1.0 rather than 2.0, the BEI, were evaluated for two reasons: 1) determining a statistical significance was feasible because of the larger number of workers with MEK urine levels ≥ 1.0, and 2) an MEK urine concentration ≥ 1.0 could be considered an "action level" at which management needs to consider taking action to assess the risk before it is at a point of overexposure.

No significant relationship was found between EOS urine o-cresol levels and EOS symptoms

1 ∞ = infinity; this value was obtained because there were no PL employees with the symptom of feeling "high" from chemicals used at work

after considering age, gender, and current smoking status.

DISCUSSION

LS and SS workers at EFC use a number of solvents in the course of their daily work, including MEK, toluene, acetone, hexane, and xylene. Air concentrations of these solvents were all well below current exposure guidelines. The very low air concentrations of solvents in the PL department were most likely due to migration from adjacent areas where these compounds were being used. Although inhalation exposures were low when compared with the OELs, biological monitoring results revealed over-exposures to MEK and toluene in some LS workers (16% and 10%, respectively). Measured TWA air concentrations of MEK and toluene could not account for the amount of MEK and toluene metabolite (o-cresol) measured concurrently in LS participant urine samples. This is probably true for SS workers as well because their job tasks and work practices are similar. Dermal exposure is the most likely cause of the over-exposures found by biologic monitoring.

Urine levels of hippuric acid and o-cresol are both used as indicators of toluene exposure. Prior studies have found some reliability problems with both urine o-cresol and hippuric acid levels, but generally found o-cresol to be less susceptible to interference from genetic and environmental factors (i.e., alcohol use, dietary factors) than urine hippuric acid levels.[20, 21, 22] Our findings showed inconsistencies between these two indicators; two PL workers with minimal workplace toluene exposures had low EOS o-cresol urine concentrations but high (> BEI) EOS hippuric acid urine concentrations.

While most workers reported wearing protective gloves, workers typically wore their protective gloves for a full shift (480 minutes) and some even for a full week before changing them. Chemical breakthrough times for the gloves ranged from 30 minutes after the start of work to 295 minutes, indicating significant dermal exposure to solvents. Dermal exposures were likely due to inappropriate glove selection, the lack of glove change-out schedules, employee work practices (such as cleaning gloves with MEK), and inadequate housekeeping, i.e., uncured cement on exterior of containers and on working surfaces.

The prevalence of self-reported neurological symptoms was significantly greater in LS workers than in PL workers, suggesting an association with solvent exposure. Our findings agree with results from several studies investigating neurobehavioral effects of acute and chronic mixed-solvent exposure in various manufacturing settings.[23, 24, 25, 26, 27] Evidence from these studies also indicates that early manifestations of solvent toxicity are often characterized by subclinical symptoms, such as impaired test performance on tasks involving manual dexterity, visual memory, and mood, and do not present as obvious clinical disease.[24] Continued excessive exposure to solvents may lead to symptoms such as memory disturbances, impaired psychomotor function, impaired verbal abilities, and disturbances of mood, which may persist after exposure has ceased.[27] Acute, high-dose exposure to solvents generally are associated with temporary symptoms such as headache, dizziness or lightheadedness, feeling "high", nausea, loss of coordination, and blurry vision. Our data found a higher prevalence of these symptoms among solvent-exposed EFC workers.

There were four major limitations of this investigation. First, urine concentrations of solvents/metabolites may be affected by non-occupational exposures such as working with solvents in hobbies or cleaning products at home, dietary factors, alcohol use, and cigarette smoking. Our study minimized these effects by assessing cross-shift changes in the same individual and by controlling for these exposures in our analyses. Second, most symptoms of solvent exposure are common, non-specific symptoms (e.g., headache, dizziness, fatigue) that may be found in non-exposed individuals. Our study attempted to control for this problem by comparing the exposed group with a less

exposed group of workers. Third, the exposed group consisted of mostly women and the less exposed group consisted mostly of men. Studies have found that women generally report symptoms more frequently than men do.[28] The small number of men working in LS (six) precluded a thorough evaluation of this issue. Finally, exposure to mixtures of solvents may affect individual urine solvent measurements (one solvent may interfere with another solvent's metabolism or excretion) and symptom prevalence (the effect of a number of solvents may be additive).

CONCLUSIONS

NIOSH investigators concluded that a health hazard from excessive exposure to MEK and toluene existed among EFC employees at the time of our evaluation. Overexposures to MEK and toluene were predominantly due to dermal absorption rather than inhalation.

RECOMMENDATIONS

What management can do

Engineering controls

1. Provide tools such as pliers for employees to grasp impregnated materials, and baskets that fit into resin containers so that employees can avoid reaching into solvent.

Administrative Controls

2. Education and training

- Emphasize that the *skin* is a major route of solvent entry into the body.
- Emphasize PPE limitations, including penetration of chemicals through gloves. Temperature and type of use affect glove breakthrough time; i.e., flexing and cleaning gloves with other solvents such as MEK leads to faster chemical penetration.[29]
- Develop proper glove change-out schedules. Consulting with a glove expert or glove manufacturing company will be helpful in determining change-out schedules.
- Educate employees about factors affecting skin integrity, such as temperature (too hot, excessive sweating, or too cold), humidity (too much or not enough, e.g., dry skin), water (too much or not enough hand washing), ultraviolet light (sunburn), and good personal hygiene, including use of skin care products such as creams, lotions, and ointments. Some soaps, skin cleansers, and moisturizers contain substances that are themselves irritants or known allergens (e.g., lanolin and fragrances) that may cause allergic contact dermatitis in sensitive individuals. Information regarding moisturizers, soaps, and skin cleansers should be included in the safety training curriculum.

3. Maintain good housekeeping practices, such as cleaning excess cement off working surfaces, to prevent dermal exposure.

4. Establish a medical surveillance program for solvent-exposed employees. Encourage employees to notify the Medical Department of work-related health concerns. The Medical Department should record these work-related health concerns in a health log and periodically review the logs to identify unrecognized work-related illnesses and injuries. Such a system should be coordinated with the industrial hygiene and other health and safety staff.

5. Remove employees with physician-diagnosed solvent-related health problems from occupational solvent exposure, and retain pay and benefits for these employees until the diagnosing physician determines they can return to work in the exposed job. The diagnosing physician should be trained in occupational medicine.

6. Cease taking annual chest x-rays for employees in the respirator program; this practice may lead to unnecessary and excessive

radiation exposure, and is not necessary to determine an employee's ability to wear a respirator.

PPE Controls

7. Select better gloves based on chemicals used. For the highest level of protection, barrier-type gloves, such as the 4H™ can be used; or for better dexterity (effective protection but shorter breakthrough time), double glove combinations can be used such as butyl rubber/polyvinyl alcohol. In either situation, a change-out schedule must be developed based on actual working conditions for various tasks.

8. Establish a comprehensive PPE program in accordance with OSHA regulations including written procedures; proper selection, inspection and maintenance; factors affecting quality of PPE; and change-out schedules. OSHA standard 29 CFR, part 1910, subpart I – Personal Protective Equipment, the American Society for Testing and Materials (ASTM F 1461) and the American National Standards Institute (ANSI/ISEA105-2000) provide good guidance.[30, 31,32]

What employees can do

1. Taking the following simple steps will reduce the amount of solvents entering the body:

- Do not eat, drink, chew gum, or smoke in areas where solvents are used.
- Do not take food, beverages, chewing gum, or cigarettes into areas where solvents are used.
- Always wash hands with soap and water before eating, drinking, or smoking, even if gloves were worn previously.
- Wash the face before eating, drinking, or smoking.
- Shower, wash hair, and change into clean clothes as soon after work as possible.

2. Prevent solvents from contacting the skin:

- Wear more highly protective gloves (i.e., the ones NIOSH recommended to EFC).
- Wear protective sleeves.
- Wear protective coveralls that can be removed if they are splashed.
- Wash solvent-contaminated skin as soon as possible with soap and water. Never use solvents to wash skin.
- Check for tears in gloves and exchange damaged gloves with for new gloves as soon as you notice the damage.
- Keep gloves out of temperature extremes and direct sunlight. Avoid cleaning gloves with solvents.

3. Maintain healthy skin:

- If your skin is dry, moisturize it. If your skin is "pruny" from too much glove use, use a cotton liner to absorb excess sweat. If your hands are dirty, clean them.

4. Employees should report health concerns to the plant Medical Department.

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Appendix A
Notification Letter

HETA 20000374
October 5, 2002

NAME2
Address2
Address3

Dear NAME2:

Thank you for participating in the National Institute for Occupational Safety and Health (NIOSH) health hazard evaluation at Engineered Fabric Corporation (EFC). During the week of July 30, 2001, we collected urine and blood samples to estimate how much solvent (toluene, methyl ethyl ketone, acetone, n-hexane, and xylene) was in your body. We included workers from the Large Spray Department (LSD) because of their heavy use of solvents and workers from the Plaster Department (PD) as a comparison group since solvents are not used in this area. This letter reports your own results and the overall results of workers tested at EFC. Information about the potential health effects from exposure to each solvent is also included.

I would like to thank you for your cooperation and patience and apologize for the tardiness of this information. Staff at NIOSH and at the laboratories that perform our sample analyses were overwhelmed with matters involving the World Trade Center and Pentagon attacks, and the anthrax contamination of government buildings, postal offices, and media offices. This resulted in a delay in getting the samples analyzed and interpreted, and the results passed on to you.

It is important to remember that the tests we did were part of a health hazard evaluation. The evaluation was conducted to give us an indication of the range of exposure to each of the solvents among employees from EFC. The test results presented in this letter, by themselves, are not meant to provide a medical diagnosis. If you want an interpretation of your test result with respect to your medical history and overall health, we encourage you to share this letter with your doctor. If you, your family, or your doctor have any questions about these results, please feel free to write me at the mailing address at the top of this letter or call me at (513) 841-4386.

Sincerely yours,

Loren C. Tapp, MD, MS
Medical Officer
Hazard Evaluations and Technical Assistance Branch
Division of Surveillance, Hazard Evaluations and Field Studies

Enclosure

What we did:

Pre-shift urine samples were collected on the first day of the evaluation (baseline). Post-shift urine samples were collected for half of the participants on the third day and the other half of participants on the fourth day of the evaluation. Morning urine and blood samples were also taken on the fifth day of the

evaluation. Urine and blood samples were analyzed for specific solvents (or metabolites of solvents) which were known to be used in the Large Spray Department. Participants included Large Spray employees (Reverse Build (LSRB), Male Build (LSMB), Repair (LSR), Final (LSF), Join (LSJ), LSJP, Preform, and Spray Combo) and employees from the Plaster Department (PD).

Explanation of testing:

Some solvents pass through the body unchanged, so we can measure these solvents directly, for example, MEK and acetone in urine, and toluene in blood. Other solvents are changed or broken down into metabolites of the solvent which are then excreted in the urine. We can then measure these urine metabolites, for example the metabolites of hexane, xylene, and toluene. We took into account that some metabolites are normally found in the urine in small amounts and are not due to workplace exposures.

We compared your results with the Biological Exposure Index (BEI) for each chemical. The BEI is a concentration below which nearly all workers should not experience adverse health effects. (For a more detailed explanation of BEIs, see the Appendices.)

Your Results (also see Table in the Appendices)

Please note:
"ND" means not detectable; the amount of substance was below the lowest level that the laboratory can measure.
"INS sample" means there was insufficient (not enough) amount of sample to measure substance.
"PS not col" means the post-shift sample was not collected.

Toluene (urine metabolites: hippuric acid and o-cresol)

Hippuric acid and o-cresol levels in the urine are used to give an indication of toluene exposure. Urine o-cresol levels have been shown to be more accurate and less susceptible to interference from background levels than urine hippuric acid levels.

Your levels of urine hippuric acid were mg/g creat milligram per gram (mg/g) creatinine on Day 1 (baseline) and mg/g creatmg/g creat mg/g creatinine on Day 3 or 4, which were:

__ below the BEI level
__ at or above the BEI, the level at which workers may experience certain health effects (see solvent health effects in Appendix II)

Your levels of urine o-cresol were ug/ml microgram per milliliter (ug/ml) on Day 1 (baseline) and ug/mlug/ml on Day 3 or 4, which were:

__ below the BEI level
__ at or above the BEI, the level at which workers may experience certain health effects (see solvent health effects in Appendix II)

Results in other EFC employees tested by NIOSH

Ninety-one EFC employees participated in the biological sampling; six of these workers had a level of hippuric acid at or above the BEI (three in LSR, two in PD, and one in LSRB). The range of results for urinary hippuric acid was non-detectable (ND) to 2870 mg/g creat.

Eight employees had levels of urine o-cresol at or above the BEI (four in LSRB, one in LSMB, one in LSF, one in LSJ, and one in PD). The range for levels of urinary o-cresol was ND to 0.59 ug/ml.

Toluene (blood)

The blood toluene levels were all below the lowest level that our laboratory can measure, 0.08 milligrams per liter (mg/L). This concentration (0.08 mg/L) is above the BEI level of 0.05mg/L, however. In other words, no conclusions can be drawn regarding these measurements.

MEK

The MEK levels in your urine were ug/ml ug/ml on Day 1 (baseline) and ug/mlug/ml ug/ml on Day 3 or 4, which were:

__ below the BEI level
__ at or above the BEI, the level at which workers may experience certain health effects (see solvent health effects in Appendix II)

Results in other EFC employees tested by NIOSH

Of the 91 EFC evaluation participants, 11 had levels at or above the BEI (8 in LSRB, 3 in LSMB). The urinary MEK concentrations ranged from non-detectable (ND) levels to 7.2 ug/ml.

n-Hexane (urine metabolite: 2,5-hexanedione)

The 2,5-hexanedione levels in your urine were mg/g creat mg/g creatinine on Day 1 (baseline) and mg/g creat mg/g creatinine on Day 5, which were:

X below the BEI level

Results in other EFC employees tested by NIOSH

No EFC employees had levels at or above the BEI. Overall, levels ranged between 0.12 and 4.4 mg/g creatinine.

Acetone

All urinary acetone concentrations of participants were well below the BEI level, ranging between non-detectable and 6.2 ug/ml. Healthy persons **not** exposed to acetone at work have acetone in their urine at levels ranging from 0.13 - 40.3 ug/ml.

Xylene (urine metabolite: methylhippuric acids)

The methylhippuric acids levels in your urine were mg/g creatinine on Day 1 (baseline) and mg/g creatinine on Day 3 or 4, which were:

X below the BEI level

Results in other EFC employees tested by NIOSH

All participants had urinary total methylhippuric acid levels below the BEI level. Methylhippuric acids are not present in appreciable quantities in urine specimens collected from occupationally unexposed persons. Levels ranged between non-detectable and 820 mg/g creatinine.

Overall Summary

Air sampling with personal breathing zone monitors in the LSD and PD revealed air levels of the solvents well below occupational exposure criteria. The biological samples, however, did show worker specimens (mostly LSD employees) that were above the BEI level for some of the solvents or their metabolites, suggesting the need for further evaluation of the worksite to reduce exposures. Inconsistencies between BEI levels (total body exposures) and airborne levels may indicate that an employee is receiving a significant exposure through a route other than inhalation. In particular, MEK and toluene concentrations measured in the urine suggested that skin exposure and skin absorption of the solvents was occurring.

Recommendations

What management can do:

The solvent concentrations we found in the employees' blood and urine samples at or above the BEI suggest the need for further evaluation of the worksite to reduce exposures. Levels at or above the BEI indicate solvent exposures are above the recommended limit and need to be reduced to avoid adverse health effects in the workforce.

We have already contacted the company and made recommendations about types of gloves that should be worn by the employees of EFC when working with solvents. Employee training about the importance of glove use and how to properly use them is also needed.

What employees can do:

If your individual results indicated that you were exposed to a solvent at or above the BEI level or you have had symptoms consistent with those listed in the appendices of this report, we recommend sharing this letter with your doctor.

Your employer has the responsibility for providing you with a safe work environment. However, there are a number of simple steps you can take to reduce the amount of solvents entering your body:

- Do not eat, drink, chew gum, or smoke in areas where solvents are used.
- Do not take food, beverages, chewing gum, or cigarettes into areas where solvents are used.
- Always wash your hands with soap and water before you eat, drink, or smoke—even if you were wearing gloves.
- Wash your face before you eat, drink, or smoke.
- Shower, wash your hair, and change into clean clothes as soon after work as possible.

For all employees of EFC who work with solvents, try to prevent solvents from contacting your skin:

- Wear more highly protective gloves (i.e., the ones NIOSH recommended to EFC)
- Wear protective sleeves
- Wear protective coveralls that can be removed if they are splashed

- Wash solvent-contaminated skin as soon as possible with soap and water

Final report

We will be issuing a final report to the union and the company in which we will be making further recommendations. This report will include the results of the air samples and biological samples. Individual results will be kept confidential. You will be able to see this report at work, since the company will be required to post it in a prominent place accessible to employees for a period of 30 calendar days. If you would like a copy of the final report, please contact us.

Your results, range of other EFC worker results, and comparison with BEI and background levels

Solvent	EFC code	Solvent or Metabolite tested[1]	Type of sample	Your Results[2]		EFC employee range of results	BEI Level	Background levels (amount of solvent found in general population)
				Baseline - Workday 1 (Monday)	Workday 3 or 4 (Wed or Thur)[3]			
Toluene	Robine	**Hippuric acid**	urine	mg/g creat	mg/g creat mg/g creat	0 - 2870 mg/g creatinine	1600 mg/g creatinine	500-1500 mg/g creatinine
Toluene	Robine	**o-Cresol**	urine	ug/ml	ug/ml ug/ml	0-0.59 ug/ml	0.5 ug/ml	<0.1 ug/ml
Toluene	Robine	**Toluene**	blood	ND	ND	all ND	0.05 mg/L	<0.015ug/ml
MEK	Mekol	**MEK**	urine	ug/ml	ug/ml ug/ml	ND-7.2 ug/ml	2ug/ml	NF[4]
Acetone	Actine	**Acetone**	urine	ug/ml	ug/ml ug/ml	ND - 6.2 ug/ml	50 ug/ml	0.13-40.3 ug/ml
n-Hexane	n-Hexane	**2,5-hexanedione**	urine	mg/g creat	mg/g creat	0.12 - 4.4 mg/g creat	5 mg/g creatinine	0.12-0.78 mg/L
Xylene	Arine	**methyl-hippuric acids**	urine			ND - 820 mg/ g creatinine	1500 mg/g creatinine	NF[5]

1 Some solvents are excreted unchanged in the urine and can be measured directly (e.g., MEK and acetone in urine, and toluene in blood). Other solvents are metabolized in the body and the solvent metabolite is excreted in the urine and measured (e.g., metabolites of hexane, xylene, and toluene).
2 INS sample = insufficient (not enough) amount of sample to measure substance.
PS not col = the post-shift sample was not collected.
ND = Not detectable
3 Post-shift urine samples for 2,5-hexanedione levels were taken Work Day 5 (Friday)
4 Not found in those who don't work with MEK
5 Not found in those who don’t work with xylene

Appendix B
Confined Space Letter

October 4, 2001
HETA 2000-0374

Bill Ritter
Section Manager
Engineered Fabric Company
669 Goodyear Avenue
Rockmart, Georgia 30153

Dear Mr. Ritter:

The purpose of this letter is to address our concerns regarding entry requirements into the fuel cells by Engineered Fabrics Corporation (EFC) employees. Workers are required to physically enter and work inside the fuel cells for various reasons such as joining, priming, cleaning, repairing, and applying grout. The solvents primarily used during these activities include methyl ethyl ketone (MEK), acetone, toluene, and n-hexane.

In a letter you sent to me, you indicated that the entry procedures have been evaluated and you consider them to meet the Occupational Safety and Health Administration's (OSHA) regulatory requirements for a confined space.[2] As you know, we have expressed our concerns previously about this issue. During our onsite surveys, NIOSH investigators observed different practices for tank entry than those described in your letter. For instance, employees are unable to complete their work on some of the F-18 fuel cells while wearing the supplied air hoods because they cannot physically reach some of the tighter fitting areas of the cell. We also noted that employees could be in some of the cells without the knowledge of other personnel.

Discussions with one of the authors of OSHA's confined space standard indicate that EFC may be in violation of meeting the standard's requirements.[3] Regardless of whether or not a space meets the definition of an alternative confined space, sampling must be done **prior to each entry** into the space. Additionally, signs must be posted indicating that the fuel cells are confined spaces.

RECOMMENDATIONS

EFC should thoroughly review these issues with OSHA to ensure compliance by calling Mr. Sherman Williamson at 202-693-2255. Mr. Williamson is considered to be an expert on OSHA's confined space standard.

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2 Code of Federal Regulations [1997]. 29 CFR 1910.146. Washington, DC: U.S. Government Printing Office, Federal Register.

3 Williamson, Sherman [2001] Telephone conversation on August 22, 2001 between A. Weber, AFO, NIOSH, CDC and S. Williamson, Washington, DC, OSHA.

Atmospheric testing should be done prior to each entry into a fuel cell.

Labeling and posting in the fuel cell departments should be done to notify employees that they are working
in confined spaces.

Employees should not be working in the cells without the knowledge of other personnel.

CLOSING

We believe that our concerns regarding the fuel cells justify immediate attention on your part. I have enclosed a copy of information we received using OSHA's Confined Space Advisor in terms of entry into the EFC fuel cells. If you have any questions, please call me at (404) 639-0444.

Sincerely,

Angela M. Weber, M.S.
Industrial Hygienist
Atlanta Field Office

cc:
OSHA Region IV
Employee Requesters
United Food and Commercial Workers, Union President

TABLES

ENGINEERED FABRICS CORPORATION, INC.

HETA 2000-0374

Table 1
Workplace Exposure Limits for EFC Solvents Evaluated
Engineered Fabrics Corporation
HETA 2000-0374-2998

Exposure Limits		MEK	Toluene	Acetone	n-Hexane	Xylenes
OSHA	PEL	200 ppm*	200 ppm	1000 ppm	500 ppm	100 ppm
	ceiling	—	300 ppm	—	—	—
NIOSH	REL	200 ppm	100 ppm	250 ppm	50 ppm	100 ppm
	STEL	300 ppm	150 ppm	—	—	150 ppm
ACGIH	TLV	200 ppm	50 ppm	500 ppm	50 ppm	100 ppm
	STEL	300 ppm	—	750 ppm	—	150 ppm
ACGIH BEI	Urine	2 ug/mL**	1600 mg/g creat*** as hippuric acid 0.5 ug/mL as o-cresol	50 ug/mL	5 mg/g creat as 'total' 2,5-hexanedione (with hydrolysis)****	1500 mg/g creat as total methylhippuric acids
	Blood	—	0.05 mg/L	—	—	—

* parts per million
** micrograms per milliliter
*** milligrams of compound per gram creatinine
**** BEI used at time of data analysis; current BEI is 0.4 ug/mL as 'free' 2,5-hexanedione (without hydrolysis)

Table 2
Personal Breathing Zone Sample Results for Large Spray Fuel Cell Department
Engineered Fabrics Corporation
HETA 2000-0374-2998
February 28, 2001

		Sampling Times				MEK Concentration parts per million (ppm)		Acetone Concentration (ppm)		Toluene Concentration (ppm)	
Sample Number	Location/Task	Start	Stop	Duration (min)	Volume (liters)	TWA	Sampling Period TWA	TWA	Sampling Period TWA	TWA	Sampling Period TWA
9637-8 9637-19	LS Pre-Form	6:46 11:46	11:45 14:57	299 191	15.1 9.7	15 98	47	6 7	6	1.2 3.0	1.9
9637-14 9637-17	LS Male Build	6:51 11:47	11:47 15.03	296 196	14.8 9.8	37 97	61	5 7	5	2.0 5.4	3.3
9637-13 9637-23	LS Male Build	6:53 12:35	11:49 14:52	296 137	15.0 6.9	59 98	71	6 9	7	5.5 6.9	5.9
9637-10 9637-24	LS Male Build	7:00 11:48	11:48 14:48	288 180	14.3 9.0	59 132	87	14 56	30	4.1 9.2	6.0
9637-11 9637-26	LS Reverse Build	7:01 11:38	11:37 15:03	276 205	13.8 10.2	42 50	45	10 20	14	0.8 6.5	3.2
9637-4 9637-29	LS Reverse Build	6:56 12:58	11:40 14:55	284 117	14.2 5.8	36 30	34	3 3	3	1.2 1.6	1.3
9637-12 9637-16	LS Reverse Build	6:49 11:35	11:34 14:43	285 188	14.2 9.3	46 58	51	5 4	5	3.4 3.1	3.3
9637-1 9637-22	LS Reverse Build	6:58 11:44	11:43 14:51	285 187	14.2 9.3	20 84	45	9 14	11	1.1 3.4	2.0
9637-7 9637-21	LS Join	7:12 11:28	11:26 14:48	254 200	12.8 10.0	218 51	144	4 7	5	2.5 1.2	1.9
9637-3 9637-30	LS Repair	7:33 12:03	11:29 14:29	236 146	11.8 7.3	16 74	38	8 13	10	0.2 2.0	0.9
9637-5 9637-18	LS Repair	7:27 12:14	11:33 14:35	246 141	12.3 7.0	4 8	5	7 54	24	0.2 0.4	0.3
9637-6 9637-20	LS Repair	7:30 11:58	11:42 14:33	252 155	12.6 7.8	3 19	9	14 60	32	0.2 0.2	0.2
9637-2 9637-27	LS Final	7:25 12:00	11:37 14:47	252 167	12.2 8.1	8 5	7	65 120	87	0.3 0.3	0.3
9637-15 9637-28	LS Final	7:31 12:07	11:48 14:34	257 147	12.9 7.4	3 5	4	32 13	25	0.2 0.3	0.2
9637-9 9637-25	LS Leak Test	7:33 11:59	9:15 14:56	102 177	5.0 8.7	4 4	4	11 11	11	0.2 0.2	0.2
ACGIH TLV-TWA						**200**		**500**		**50**	
NIOSH REL-TWA						**200**		**250**		**100**	
OSHA PEL-TWA						**200**		**1000**		**200**	

Table 3
Personal Breathing Zone Sample Results for Large Spray Fuel Cell Department
Engineered Fabrics Corporation
HETA 2000-0374-2998
March 1, 2001

		Sampling Times				MEK Concentration (ppm)*		Acetone Concentration (ppm)		Toluene Concentration (ppm)	
Sample Number	Location/Task	Start	Stop	Duration (min)	Volume (liters)	TWA	Sampling Period TWA	TWA	Sampling Period TWA	TWA	Sampling Period TWA
9637-91 9637-61	LS Pre-Form	6:50 11:28	11:28 14:55	278 207	14.0 10.4	29.1 35.8	32.0	14.7 14.9	14.8	3.03 2.79	2.93
9637-40 9637-65	LS Male Build	7:04 11:28	11:21 14:52	257 204	12.9 10.2	29.0 119.5	69.1	4.9 6.6	5.6	2.88 5.71	4.13
9637-88 9637-67	LS Male Build	7:00 11:24	11:24 14:58	264 214	13.1 10.6	22.5 57.4	38.1	6.7 63.4	32.1	1.71 7.48	4.29
9637-94 9637-80	LS Spray Booth	6:53 11:12	11:12 14:58	259 226	12.9 11.3	15.2 27.6	21.0	2.8 4.1	3.4	1.37 2.06	1.69
9637-89 9637-83	LS Reverse Build	6:51 11:02	11:02 14:52	251 230	12.6 11.5	26.9 41.1	33.7	11.7 15.3	13.4	1.32 1.51	1.41
9637-53 9637-85	LS Reverse Build	6:48 11:06	11:06 14:54	258 228	12.8 11.4	81.8 71.7	77.0	7.2 4.4	5.9	4.53 3.96	4.27
9637-82 9637-81	LS Reverse Build	6:58 11:08	11:08 14:53	250 225	12.4 11.2	41.0 60.7	50.3	5.4 4.5	5.0	1.27 6.16	3.59
9637-93 9637-64	LS Join	6:55 11:13	11:12 14:53	257 220	12.8 11.0	14.0 30.2	21.5	3.6 1.9	2.8	0.78 1.03	0.89
9637-86 9637-69	LS Outside Repair	6:57 11:15	11:14 14:54	257 219	12.9 11.0	9.5 0.7	5.4	238.7 36.4	145.6	0.13 0.07	0.10
9637-37 9637-60	LS Breakout	7:11 11:21	11:20 14:53	249 212	12.4 10.6	11.5 20.2	15.5	3.4 3.6	3.5	1.00 1.27	1.12
9637-84	LS Repair	7:34	14:56	442	22.1	6.7	6.7	34.2	34.2	0.50	0.50
9637-87	LS Repair	7:35	14:54	439	21.9	15.0	15.0	28.8	28.8	0.41	0.41
9637-90	LS Final	7:20	14:49	449	22.4	4.2	4.2	14.3	14.3	0.42	0.42
9637-79	LS Leak Test	7:25	14:51	446	21.6	22.0	22.0	13.4	13.4	0.30	0.30
ACGIH TLV-TWA							**200**		**500**		**50**
NIOSH REL-TWA							**200**		**250**		**100**
OSHA PEL-TWA							**200**		**1000**		**200**

*parts per million

Table 4
Personal Breathing Zone Sample Results for Small Spray Fuel Cell Department
Engineered Fabrics Corporation
HETA 2000-0374-2998

February 28, 2001

		Sampling Times				MEK Concentration parts per million (ppm)		Acetone Concentration (ppm)		Toluene Concentration (ppm)	
Sample Number	Location/Task	Start	Stop	Duration (min)	Volume (liters)	TWA	Sampling Period TWA	TWA	Sampling Period TWA	TWA	Sampling Period TWA
9637-45	SS Build/Swabbing	6:45	11:34	289	14.5	28.0	49.9	12.5	15.5	3.47	5.74
9637-32		11:35	14:53	198	9.9	81.9		19.9		9.06	
9637-49	SS Build/Swabbing	6:55	11:33	278	13.9	36.5	48.4	11.5	12.2	4.18	5.34
9637-41		11:34	14:51	197	9.9	65.3		13.2		6.98	
9637-52	SS Repair/Final	6:50	11:27	277	13.8	12.3	15.2	42.7	99.2	1.05	1.21
9637-54	Clean	11:28	14:54	206	10.3	19.1		155.8		1.44	
9637-38	SS Repair	6:40	11:30	290	14.5	12.6	16.4	14.8	16.8	1.20	1.65
9637-55		11:31	14:56	205	10.3	21.8		19.6		2.29	
ACGIH TLV-TWA							**200**		**500**		**50**
NIOSH REL-TWA							**200**		**250**		**100**
OSHA PEL-TWA							**200**		**1000**		**200**

March 1, 2001

		Sampling Times				MEK Concentration parts per million (ppm)		Acetone Concentration (ppm)		Toluene Concentration (ppm)	
Sample Number	Location/Task	Start	Stop	Duration (min)	Volume (liters)	TWA	Sampling Period TWA	TWA	Sampling Period TWA	TWA	Sampling Period TWA
9637-35	SS Spray Booth	7:04	11:26	262	13.2	18.5	19.4	11.8	11.5	2.20	2.37
9637-97		11:26	14:49	203	10.2	20.5		11.1		2.58	
9637-44	SS Build/Corner	6:56	11:25	269	13.5	24.4	28.1	14.1	17.7	3.15	4.24
9637-33	Patch	11:25	14:51	206	10.3	32.9		22.5		5.66	
9637-31	SS Repair/Stencil	7:05	11:32	257	13.4	12.7	11.7	17.6	12.2	1.08	0.95
9637-50		11:32	14:48	196	9.8	10.4		4.7		0.77	
9637-39	Return Goods Repair	7:21	14:41	440	21.9	12.2	12.2	3.6	3.6	0.84	0.84
9637-96	Return Goods Repair	7:24	14:44	440	21.7	18.7	18.7	5.4	5.4	0.63	0.63
ACGIH TLV-TWA							**200**		**500**		**50**
NIOSH REL-TWA							**200**		**250**		**100**
OSHA PEL-TWA							**200**		**1000**		**200**

Table 5
Personal Breathing Zone Sample Results for Plaster Department
Engineered Fabrics Corporation
HETA 2000-0374-2998

February 28, 2001

		Sampling Times				MEK Concentration (ppm)*		Acetone Concentration (ppm)		Toluene Concentration (ppm)	
Sample Number	Location/Task	Start	Stop	Duration (min)	Volume (liters)	TWA	Sampling Period TWA	TWA	Sampling Period TWA	TWA	Sampling Period TWA
9637-51	Plaster/Finishing	7:09	14:54	465	23.3	0.5	0.5	0.3	0.3	0.05	0.05
9637-48	Plaster/Finishing	7:06	14:51	465	23.2	0.8	0.8	0.7	0.7	0.15	0.15
9637-56	Plaster/Pouring Molds	7:19	14:49	450	22.6	0.4	0.4	0.3	0.3	0.08	0.08
ACGIH TLV-TWA						**200**		**500**		**50**	
NIOSH REL-TWA						**200**		**250**		**100**	
OSHA PEL-TWA						**200**		**1000**		**200**	

*parts per million

March 1, 2001

		Sampling Times				MEK Concentration (ppm)*		Acetone Concentration (ppm)		Toluene Concentration (ppm)	
Sample Number	Location/Task	Start	Stop	Duration (min)	Volume (liters)	TWA	Sampling Period TWA	TWA	Sampling Period TWA	TWA	Sampling Period TWA
9637-46	Plaster/Pouring Molds	6:41	14:40	479	24.3	0.3	0.3	0.3	0.3	0.05	0.05
9637-92	Plaster/Finishing	6:46	14:36	470	23.6	0.3	0.3	0.6	0.6	0.05	0.05
9637-36	Plaster/Sugar Sprayer	6:54	14:42	468	23.4	0.7	0.7	1.3	1.3	0.11	0.11
ACGIH TLV-TWA						**200**		**500**		**50**	
NIOSH REL-TWA						**200**		**250**		**100**	
OSHA PEL-TWA						**200**		**1000**		**200**	

*parts per million

Table 6
Summary of Personal Breathing Zone Samples for MEK, Acetone and Toluene in Large Spray, Small Spray, and Plaster Department
Engineered Fabrics Corporation
HETA 2000-0374-2998
February 28–March 1, 2001

Location	MEK (ppm)*	Acetone (ppm)	Toluene (ppm)
Large Spray Dept. N=29	Range: 4 – 144 Median: 34	Range: 3 – 146 Median: 11	Range: 0.1 – 6 Median: 1.4
Small Spray Dept. N=9	Range: 12 – 50 Median: 19	Range: 4 – 99 Median: 12	Range: 1 – 6 Median: 2
Plaster Dept. N=6	Range: 0.3 – 0.8 Median: 0.5	Range: 0.3 – 1.3 Median: 0.6	Range: 0.1 – 0.2 Median: 0.1

*parts per million

Table 7
HMDI Concentrations during Various Work Activities
Engineered Fabrics Corporation
HETA 2000-0374-2998
February 28 – March 1, 2001

Work Activity and Location	Sample Type*	Elapsed Sample Time**	Sample Volume***	HMDI****
Spray application of cement in large spray booth	PBZ	31	46.5	131.2
Spray application of cement in small spray booth	PBZ	47	70.5	27.2
Hand-brush application of cement, joint sealing in large spray area	PBZ	5	7.5	<8.0
Hand-brush application of cement in small spray area–Sample 1	PBZ	25	37.5	<1.4
Hand-brush application of cement in small spray area–Sample 2	PBZ	15	22.5	<2.3
Hand-brush application of cement, reverse build-female–Sample 1	AAS	325	487.5	0.4
Hand-brush application of cement, reverse build-female–Sample 2	AAS	310	465.0	0.5
Hand-brush application of cement, reverse build-male–Sample 1	AAS	296	444.0	1.9
Hand-brush application of cement, reverse build-male–Sample 2	AAS	298	447.0	0.5
Reactor charging with HMDI in mixing building	PBZ	14	21.0	<2.9
Batch catching in mixing building	PBZ	22	33.0	<1.8

*PBZ - personal breathing zone air sample, AAS - area air sample.
**Elapsed sample time is in minutes.
***Sample volumes are in liters of air.
****HMDI concentrations are in micrograms per cubic meter of air ($\mu g/m^3$). If a concentration is preceded by a "less than" symbol (<), this indicates that HMDI was not detected in the sample, and the number is the minimum detectable concentration for that sample.

Table 8
Characteristics of Large Spray, Small Spray, and Plaster Department Workers
Engineered Fabrics Corporation
HETA 2000-0374-2998
February 28–March 1, 2001

	Large Spray	Small Spray	Plaster
Participants by job type:	124	18	19
% Female	85%	72%	21%
Average age in years (range)	39.6 (18–61)	43.2 (20–58)	42.8 (19–61)
Average years worked at plant (range)	3.9 (0.25–32)	11.6 (0.33–28)	12.5 (0.33–33)
Current smoker	35%	44%	47%
Handle solvents outside of work (including nail polish & remover)	33%	17%	11%
Had ≥ 1 alcoholic drink in past month	24%	11%	37%
Average number of alcoholic drinks per month (range)	1.7 (0–48)	0.4 (0–6)	7.0 (0–99)

Table 9
Reported Glove and Barrier Cream Use Among Large Spray, Small Spray, and Plaster Workers
Engineered Fabrics Corporation
HETA 2000-0374-2998
February 28–March 1, 2001

		Large Spray N=123* # (%)	Small Spray N=17** # (%)	Plaster N=19*** # (%)
Use barrier cream		45 (38%)	1 (6%)	3 (19%)
Wear gloves at work		123 (100%)	16 (94%)	11 (58%)
Primary type of gloves:				
	Neoprene/latex	85 (69%)	13 (72%)	3 (16%)
	Latex	10 (8%)	4 (22%)	5 (26%)
	Nitrile	13 (10%)	0	0
	Multiple types	16 (13%)	0	1 (5%)
	Cotton	0	0	1 (5%)
	Other	0	0	1 (5%)
Number of pairs of primary gloves used per day	**1**	72 (58%)	12 (67%)	9 (50%)
	2	38 (31%)	3 (17%)	1 (6%)
	3	10 (8%)	1 (6%)	0
	≥ 4	4 (3%)	1 (6%)	0
Re-use gloves:		97 (79%)	10 (56%)	10 (59%)
Wear second set of gloves under primary gloves		30 (26%)	5 (29%)	3 (17%)
Of those who wore secondary gloves, type of secondary gloves:	**Cotton**	16 (53%)	3 (60%)	2 (67%)
	Neoprene/latex	5 (17%)	2 (40%)	1 (33%)
	Latex	3 (10%)	0	0
	Nitrile	1 (3%)	0	0
	Multiple types	4 (13%)	0	0
	Other	1 (3%)	0	0

* Actual N for LS ranged between 117 and 124.
** Actual N for SS ranged between 17 and 18.
*** Actual N for PL ranged between 16 and 19.

Table 10
Reported Work-related Symptoms in Previous Six Months among Large Spray, Small Spray, and Plaster Employees
Engineered Fabrics Corporation
HETA 2000-0374-2998
February 2001

Work-Related Symptoms:	Large Spray* # (%)	Small Spray** # (%)	Plaster*** # (%)
eye, nose, throat irritation	43 (35%)	4 (25%)	1 (6%)
frequent headache	36 (30%)	7 (47%)	2 (12%)
dizziness/light-headedness	32 (26%)	4 (29%)	2 (11%)
unusual fatigue or drowsiness	41 (34%)	6 (43%)	3 (16%)
nausea or upset stomach	19 (16%)	3 (21%)	0
blurred or double vision	13 (11%)	0	0
difficulty with memory or concentration	14 (11%)	5 (33%)	0
loss of coordination	9 (7%)	1 (6%)	0
Need to step away from work area for fresh air:			
Frequently	12 (10%)	1 (6%)	0
Occasionally	53 (44%)	7 (41%)	3 (16%)
Rarely	14 (12%)	4 (24%)	2 (11%)
Never	42 (35%)	5 (29%)	14 (74%)

*Actual N for LS ranged between 119–122**.**
** Actual N for SS ranged between 14–17.
*** Actual N for PL ranged between 16–19.

Table 11
Personal Breathing Zone Samples of EFC Employees by Job Type
Engineered Fabrics Corporation
HETA 2000-0374-2998
August 1–2, 2001

Job Category	Summary Descriptions	Full-shift TWA concentrations (ppm)*				
		MEK	Toluene	Acetone	Hexane	Xylenes
Plaster (N=17)	Mean, Median (SD)**	1.9, 0.5 (5.5)	0.4, 0.1 (1.1)	0.8, 0.8 (0.8)	0.2, 0.2 (0.1)	0.01, 0.00 (0.01)
	Min, Max	0.1, 23.0	0.02, 4.7	0.1, 3.4	0.003, 0.4	0.00, 0.03
Total LS (N=73)	Mean, Median (SD)	21.2, 17.0 (19.7)	1.6, 1.4 (1.5)	13.7, 4.4 (33.1)	0.8, 0.3 (1.3)	0.23, 0.02 (0.97)
	Min, Max	0.1, 98.9	0.1, 7.5	0.3, 222.9	0.02, 7.1	0.00, 7.33
LS Male Build (N=11)	Mean, Median (SD)	26.8, 23.7 (26.8)	2.5, 1.9 (1.8)	2.9, 2.6 (1.5)	2.4, 1.8 (2.2)	0.2, 0.2 (0.15)
	Min, Max	0.1, 98.9	1.2, 7.5	1.5, 6.7	0.6, 7.1	0.04, 0.52
LS Reverse Build (N=24)	Mean, Median (SD)	34.7, 28.0 (18.3)	2.4, 2.2 (1.1)	4.2, 3.6 (3.0)	0.7, 0.3 (1.3)	0.6, 0.05 (1.65)
	Min, Max	11.8, 88.7	0.4, 4.6	1.2, 13.6	0.0, 5.9	ND***, 7.33
LS Repair, LSJP, LS Join**** (N=27)	Mean, Median (SD)	12.2, 6.5 (12.0)	1.0, 0.4 (1.4)	16.6, 4.6 (42.1)	0.4, 0.3 (0.4)	0.02, ND (0.06)
	Min, Max	2.0, 41.1	0.1, 6.7	0.3, 222.9	0.0, 1.8	ND, 0.24
LS Final (N=11)	Mean, Median (SD)	8.1, 4.0 (6.3)	0.3, 0.3 (0.1)	38.2, 16.2 (47.4)	0.2, 0.1 (0.2)	0.0, ND (0.002)
	Min, Max	2.3, 19.7	0.2, 0.6	5.2, 147.0	0.04, 0.7	ND, 0.01
ACGIH	TLV	200	50	500	50	100
NIOSH	REL	200	100	250	50	100
OSHA	PEL	200	200	1000	500	100

*parts per million
**SD – standard deviation
***ND – not detected; given a value of half the limit of detection for statistical analyses (e.g., for xylene, nd=0.00045)
****This job category also included JP Leak Test/Sprayer

Table 12
Dermal Exposure Assessment Results of Large Spray Employees
Engineered Fabrics Corporation
HETA 2000-0374-2998
July/August 2001

Sample Number	Location	Full-shift TWA MEK PBZ (ppm)	MEK Glove breakthrough-time* (min)	End-of-Shift MEK Urine (µg/mL)
LS-9728-32	LSRB	43.9	30–95	7.20
LS-9728-65	LSRB	40.0	No color change**	5.20
LS-9728-57	LSRB	47.0	30–85	3.40
LS-9728-74	LSMB	38.3	No color change	2.30
LS-9728-34	LSRB	88.7	150–200	1.60
LS-9728-69	LSMB	36.1	Sample lost	1.40
LS-9728-60	LSRB	42.5	30–60	0.98
LS-9728-24	LSRB	69.7	265–295	NA

*Breakthrough times are based on colorimetric indicator.
**Although no color change was observed on the indicator, excessive sweating may have affected results.
NA = sample not available; urine sample volume was insufficient for analysis

Table 13
Characteristics Reported by Large Spray and Plaster Workers on Baseline Biological Monitoring Survey
Engineered Fabrics Corporation
HETA 2000-0374-2998
July/August 2001

	Large Spray N=74 Number (%)	Plaster N=18 Number (%)
Age (years)	Average = 41 (range 20-62)	Average = 40 (range 20-62)
Female	69 (93%)	6 (33%)
Diabetic	4 (5%)	0
High blood pressure	23 (31%)	6 (33%)
Prior severe head injury	10 (14%)	1 (6%)
Taking any medications	52 (70%)	8 (44%)
Current smoker	24 (32%)	7 (39%)
Alcohol in past 24 hours	4 (5%)	6 (33%)
Worked on Saturday	52 (70%)	1 (6%)
Worked on Sunday (out of 72 responses)	8 of 56 (14%)	0 of 16
Ingested food/drink containing benzoic acid in past 8 hours	28 (38%)	7 (39%)
Exposed to solvents outside of work in past 24 hours	1 (1%)	2 (11%)

Table 14
Comparing End-of-Shift (EOS) urine concentrations with BEI Levels by Job Title
Engineered Fabrics Corporation
HETA 2000-0374-2998
July/August 2001

Solvent or urinary metabolite	EOS urine concentration Average/Median (Range)		Significant difference between LS and PL	Number of employees with urine concentrations ≥ BEI	
	LS N=65*	PL N=15**	p value	LS	PL
Hippuric acid [BEI: 1600mg/g creatinine]	521/410 (0–3300)	502/270 (60–2000)	0.40	4	2
o-cresol [BEI: 0.5 ug/ml]	0.19/0.10 (0.02–0.59)	0.09/0.06 (0.05–0.2)	<0.05	7	0
MEK [BEI: 2.0 ug/ml]	1.07/0.45 (0.1–7.2)	0.1/0.10 (all 0.1)	<0.01	10	0
2,5-hexanedione [BEI: 5 mg/g creatinine]	1.94/1.90 (0.8–4.4)	1.65/1.50 (1.0–2.7)	0.10	0	0
Acetone [BEI: 50 ug/ml]	1.53/1.30 (0.15–6.10)	0.66/0.55 (0.15–1.9)	<0.01	0	0
Methylhippuric acid [BEI: 1500 mg/g creatinine	28.96/0 (0–820)	8.67/0 (0–100)	0.73	0	0

*Actual N for LS EOS urine concentrations ranged from 62 – 67.
**Actual N for PL EOS urine concentrations ranged from 12 – 16.

Table 15
Reported Symptoms in Month Prior to Baseline Biological Monitoring Survey by Job Title
Engineered Fabrics Corporation
HETA 2000-0374-2998
July/August 2001

Have you had the following symptom(s) in the month prior?	Large Spray, N=74 Number (%)	Plaster, N=18 Number (%)	Odds Ratio	P Value
Feel high at work	31 (42%)	0	Inf*	0.01
Memory problems	44 (59%)	3 (17%)	7.33	0.01
Need for notes to remember	32 (43%)	2 (11%)	6.10	0.01
Dizzy or lightheaded	44 (59%)	4 (22%)	5.13	0.01
Frequent headache	48 (65%)	5 (28%)	4.80	0.01
Poor concentration	35 (47%)	3 (17%)	4.49	0.02
Tires more easily	53 (72%)	7 (39%)	3.97	0.01
Relatives noticing memory problem	30 (41%)	3 (17%)	3.41	0.06
Sleeping more often	33 (45%)	4 (22%)	2.89	0.08
Irritability	49 (66%)	8 (44%)	2.45	0.09
Numbness or tingling in fingers	16 (22%)	1 (6%)	4.69	0.18
Confused or disoriented	15 (20%)	1 (6%)	4.32	0.18
Problems falling asleep	33 (45%)	5 (29%)	1.93	0.25
Weakness in legs or feet	18 (24%)	2 (11%)	2.57	0.34
Tolerance to alcohol has decreased	8 (11%)	0	Inf*	0.35
Difficulty moving fingers	21 (28%)	3 (17%)	1.98	0.38
Problems with balance or incoordination	19 (26%)	3 (17%)	1.73	0.55
Depression	34 (46%)	7 (39%)	1.34	0.59
Difficulty understanding what is read	6 (8%)	2 (11%)	0.72	0.65
Numbness or tingling in toes	13 (18%)	2 (11%)	1.70	0.73
Weakness in arms or hands	18 (24%)	3 (17%)	1.61	0.75
Heart palpitations	17 (23%)	3 (17%)	1.49	0.75
Difficulty driving home from work	19 (26%)	4 (22%)	1.23	0.99
Seizures	0	0	NA	NA

* Infinity; denominator equaled zero

Table 16
Reported Symptoms Experienced During the Workweek on Post-shift Biological Monitoring Survey by Job Title
Engineered Fabrics Corporation
HETA 2000-0374-2998
July/August 2001

Symptom during prior work week:	Large Spray N=72 Number (%)	Plaster N=18 Number (%)	Odds Ratio	P Value
Fatigue	48 (68%)	8 (44%)	2.61	0.07
Irritability	37 (51%)	6 (33%)	2.11	0.17
Headache	36 (50%)	3 (17%)	5.00	0.01*
Memory problems	30 (42%)	2 (11%)	5.71	0.02*
Lightheadedness	23 (32%)	3 (17%)	2.35	0.20
Difficulty concentrating	21 (29%)	2 (11%)	3.29	0.14
Weakness in muscles	15 (21%)	2 (11%)	2.11	0.51
Feeling uncoordinated	11 (15%)	0	Inf**	0.11
Confused	10 (14%)	1 (6%)	2.74	0.45

*Indicates statistically significant difference between Large Spray and Plaster workers
* Infinity; denominator equaled zero

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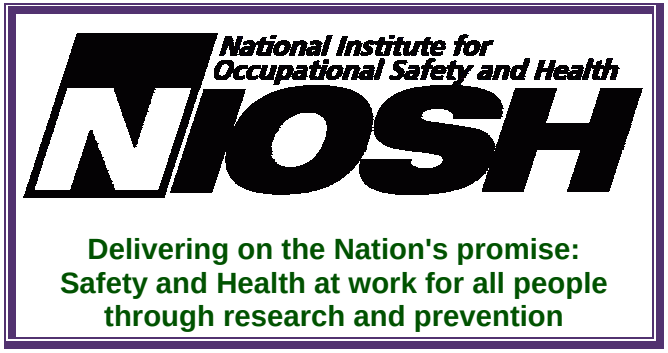

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