NIOSH HEALTH HAZARD EVALUATION REPORT:

HETA #2002-0418-2912
Richards Industries
Cincinnati, Ohio

September 2003

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

PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Melissa Finley and Jeffrey Nemhauser, MD, of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Erin Snyder and Howard Lu, MD, of HETAB, DSHEFS. Analytical support was provided by Ardith Grote, Robert Streicher, and DataChem Laboratories, Inc. (Salt Lake City, Utah). Desktop publishing was performed by Robin Smith. Review and preparation for printing were performed by Penny Arthur.

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Highlights of the NIOSH Health Hazard Evaluation

Evaluation of Organic Solvents and Isocyanates During Paint Spraying Operations

In September 2002, the National Institute for Occupational Safety and Health (NIOSH) received a Health Hazard Evaluation (HHE) request from the management of Richards Industries, Cincinnati, Ohio, to evaluate health effects reported by employees of the Paint Department. NIOSH investigators conducted a site visit to Richards Industries on October 1, and again on October 8, 2002.

What NIOSH Did

- We collected personal breathing zone and area air samples in the Paint Department and surrounding areas, and measured the amount of organic solvents and isocyanates in those samples.

- We checked the ventilation in the paint booths, mixing area, and other areas around the Paint Department.

- We spoke confidentially with employees working in the Paint Department and in nearby areas about their jobs, their exposures to paints and solvents, and health effects that they believed were due to workplace exposures.

What NIOSH Found

- Results of air sampling showed that all measured chemicals were below recommended limits.

- The air flow (ventilation) in the paint booth was too low to adequately capture paint vapors.

- There was little air circulation near the paint mixing table.

- Some employees reported having breathing problems, headaches, and anxiety. We could not find cause(s) of these health conditions.

What Richards Industries Managers Can Do

- Increase the airflow into the paint booth and drying booth.

- Provide local ventilation in the mixing area to help remove the paint vapors.

- Provide employees with gloves, goggles, and clothing that protects against exposure to organic solvents and isocyanates.

What the Richards Industries Employees Can Do

- Use protective equipment during paint mixing and spraying.

- Stand upstream of air flow in the paint booth during spraying.

- Do not point pedestal fans into the paint booth.

- Do not eat, drink, or smoke in work areas.

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 #2002-0418-2912

Health Hazard Evaluation Report 2002-0418-2912
Richards Industries
Cincinnati, Ohio
September 2003

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SUMMARY

On September 20, 2002, the National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation (HHE) to be conducted at Richards Industries in Cincinnati, Ohio. The request centered on workers' exposures to paint, catalyst, and thinner during spray painting operations. On October 8, 2002, NIOSH investigators conducted an exposure assessment that included personal breathing zone (PBZ) and general area (GA) samples for methyl ethyl ketone (MEK), toluene-2,4-diisocyanate (TDI), and other volatile organic compounds (VOCs). Qualitative samples were collected with thermal desorption tubes to determine the appropriate VOCs for analysis. MEK and TDI were chosen for sampling because of their presence in paint components. The October 8 site visit also included a local exhaust ventilation (LEV) assessment of the paint booth using a velometer and smoke tubes and a medical survey of employees working in and around the Paint Department.

Based upon the samples collected with the thermal desorption tubes, the PBZ and GA samples were analyzed for toluene, butyl acetate, propylene glycol methyl ether acetate (PGMEA), cyclohexanone, limonene, and total hydrocarbons (reported as decane). Toluene ranged from 0.004 to 0.34 parts per million (ppm), butyl acetate ranged from 0.02 to 0.57 ppm, PGMEA ranged from 0.03 to 0.58 ppm, cyclohexanone ranged from trace to 0.59 ppm, limonene ranged from 0.02 to 0.07 ppm, and total hydrocarbons ranged from 0.28 to 0.37 ppm. The MEK results ranged from 0.15 to 31 ppm, and the TDI monomer results ranged from not detected to 0.06 parts per billion (ppb). All of these results were below applicable occupational exposure limits.

The ventilation assessment revealed that air flow into and out of the paint booth was below recommended standards. Air flow within the drying booth was inadequate, and the air over the mixing table was stagnant.

Employees in and around the Paint Department reported, during confidential medical interviews, that they had experienced a variety of health effects including headache, anxiety, and respiratory problems. They believed these health effects to be either related to or directly a result of workplace exposures. The cause(s) of the reported symptoms could not be determined by NIOSH investigators.

Although air sampling did not identify any over-exposures, ventilation within the Paint Department did not meet minimum airflow velocity requirements. Recommendations are provided to further reduce employees' exposures to these chemicals by improving ventilation and by the appropriate use of personal protective equipment.

Keywords: SIC Codes 3491 (Manufacturing Industrial Valves), paint booth, solvents, toluene, butyl acetate, propylene glycol methyl ether acetate, PGMEA, cyclohexanone, limonene, methyl ethyl ketone, MEK, 2,4-toluene diisocyanate, TDI, anxiety, shortness of breath, fatigue, headache, esophageal reflux disease.

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INTRODUCTION

In September 2002, the National Institute for Occupational Safety and Health (NIOSH) received a Health Hazard Evaluation (HHE) request from the management of Richards Industries, Cincinnati, Ohio. The request centered on workers' exposures to paints, solvents, and catalyst in the Paint Department. The HHE request did not identify workers outside this area as having health problems related to Paint Department exposures. According to the request, Paint Department employees had reported experiencing "anxiety, shortness of breath, fatigue, headache, and worsening of esophageal reflux disease" as a result of their workplace exposures and "withdrawl [sic] symptoms" after assuming new jobs within the company but outside of the Department. An initial site visit conducted on October 1, 2002, included a walk-through evaluation of the area of concern. NIOSH investigators returned to Richards Industries on October 8, 2002, to conduct personal breathing zone (PBZ) and general area (GA) air sampling for methyl ethyl ketone (MEK), volatile organic compounds (VOCs), and toluene diisocyanate (TDI). The October 8 site visit also included a local exhaust ventilation (LEV) assessment of the paint booth using a velometer and smoke tubes and a medical survey of employees working in and around the Paint Department. A NIOSH interim letter to the company (dated January 7, 2003), summarized industrial hygiene findings and initial recommendations of the survey which NIOSH investigators were told would be shared at a safety committee meeting at the plant. This final report contains the results of the air sampling and medical evaluations, discussions of sampling methods, a review of the potential health effects from the various chemicals to which Richards Industries employees are exposed, and recommendations.

BACKGROUND

Richards Industries, a company of approximately 150 employees, manufactures metal valves and steam traps for a broad range of industries. The company uses both raw casting and purchased components to produce finished products, which are made to order for the customer. Finished products may be painted or unpainted. Painted parts are washed, masked* (if necessary), painted, then moved to either a drying booth or to open areas within the Paint Department and allowed to dry for 24 hours.

The Paint Department employs two workers. On the day of sampling conducted by NIOSH, one employee (the painter) worked solely on mixing, spraying, and cleaning, while the other worked exclusively on preparing the parts (washing and masking). During the painting operations, the painter wore cloth coveralls and safety glasses. The worker responsible for preparing the parts wore safety glasses and cloth work gloves. Neither of the two employees working in the Paint Department was observed to wear a respirator during any painting operations.

During the mixing and painting operations surveyed by NIOSH, one polyurethane paint, an isocyanate-containing catalyst, and a thinner containing MEK (CAS No. 78-93-3) were used. Paint components included n-butyl acetate (CAS No. 123-86-4), 23% by weight; cyclohexanone (CAS No. 108-94-1), 21% by weight; MEK, 9% by weight; and toluene (CAS No. 109-88-3) 8% by weight. The catalyst contained 1-methoxy-2-propanol acetate (CAS No. 108-56-6) also known as propylene glycol methyl ether acetate (PGMEA), 40% by weight; toluene-2,4-diisocyanate (CAS No. 584-84-9), 0.3% by weight; and toluene diisocyanate polymer, 60% by weight. MEK was used to clean the spray gun, nozzles, and hoses.

The walk-in spray paint booth had a bank of nine dry filters connected to exhaust ventilation in the rear. The walk-in drying booth has ceiling exhaust ventilation that was connected to the paint booth ventilation system. There was no LEV for the rest of the paint area, including the mixing table and parts washer area. Two large pedestal fans were available for use by the workers to increase airflow into the Paint Department for their thermal comfort.

*Masking involves covering the orifices of a part to prevent them from being painted.

METHODS

A sampling protocol was developed by NIOSH investigators after observing the operations and reviewing Material Safety Data Sheets (MSDSs) of the chemicals used in these operations. Full-shift PBZ samples of MEK and VOCs were collected from two employees and GA air samples for VOCs, MEK, and TDI were collected from four locations within the Paint Department (on the mixing table, at the edge of the paint booth, near the parts washer, and on a desk approximately 20 feet away from the mixing table). Work practices were observed during the painting operations.

To better characterize the health effects experienced by employees working in and around the Paint Department, NIOSH investigators conducted confidential medical interviews with painters (former and current) and employees who worked within 50 feet of the paint and drying booths. Information regarding occupation, medical and work history, non-occupational exposures, and symptoms was collected.

Volatile Organic Compounds (VOCs)

Area air samples were collected using thermal desorption tubes to determine qualitatively the specific VOCs for quantitative analysis from the charcoal tubes. The thermal desorption tubes were attached by Tygon® (Norton, Akron, Ohio) tubing to sampling pumps calibrated at a flow rate of 50 cubic centimeters per minute (cc/min). Each thermal desorption tube contained three beds of sorbent material: the first section contained Carbopak Y, the second section contained Carbopak B, and the last section contained Carboxen 1003. The thermal desorption tubes were analyzed using a Perkin-Elmer ATD 400 automatic thermal desorption system equipped with a gas chromatograph with a mass selective detector (TD-GC-MSD). The sampling and analytical techniques for this method are in accordance with NIOSH method 2549-Volatile Organic Compounds (Screening).[1]

Full-shift PBZ and GA air samples were collected using charcoal tubes attached by Tygon® tubing to sampling pumps calibrated at a flow rate of 100 cc/min. Based on the thermal tube results, toluene, butyl acetate, propylene glycol methyl ether acetate (PGMEA), cyclohexanone, limonene, and total hydrocarbons (reported as decane) were quantitatively analyzed using a Hewlett-Packard (Palo Alto, California) Model 5890A gas chromatograph equipped with a flame ionization detector.

Methyl Ethyl Ketone (MEK)

Full-shift PBZ and GA air samples for MEK were collected using beaded charcoal sorbent tubes attached by Tygon® tubing to sampling pumps calibrated at a flow rate of 100 cc/min according to NIOSH method 2500- Methyl Ethyl Ketone.[1] Two 15-minute short-term samples were taken at a flow rate of 200 cc/min to collect MEK during the mixing operation. All samples were analyzed with a Hewlett-Packard Model 5890A gas chromatograph equipped with a flame ionization detector.

Toluene-2,4- Diisocyanate (TDI)

Area air samples for TDI were collected using midget impingers containing 15 milliliters (mL) of 1-(9-anthracenylmethyl) piperazine (MAP) in butyl benzoate. The impingers were connected with Tygon® tubing to sampling pumps calibrated at a flow rate of 1 liter per minute (LPM) according to NIOSH draft method 5525-Isocyanates, Total (MAP).[2] The solution was removed from the impingers immediately after sampling and transferred to 20 mL glass vials with Teflon®-lined caps. Bulk samples of all three paint components (paint, catalyst, and thinner) were also collected to aid in analysis. All samples were transported and stored in a cold environment prior to analysis. The samples were analyzed using pH-gradient high performance liquid chromatography (HPLC).

Ventilation

Velometer (thermoanemometer) measurements were made with the VelociCalc® (TSI, Inc., St. Paul, Minnesota) Plus Air Velocity Meter Model 8386A. This instrument measures air velocity in feet-per-minute (fpm). Nine measurements of the air velocity were taken in a grid pattern across the face, middle, and back of the spray paint booth and the results were averaged to obtain the mean velocity. Observations were also made of "smoke" released in various locations around the Paint Department, specifically in and around the paint booth, drying booth, and mixing table.

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),[3] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[4] and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[5] Employers are encouraged to follow the NIOSH RELs, the ACGIH TLVs, the OSHA limits, 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)]. Employers should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). However, an employer is still required by OSHA to protect their 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.

Volatile Organic Compounds

VOCs comprise a large class of carbon-containing chemicals that share common physical properties. VOCs have a sufficiently high vapor pressure to allow some of the compound to exist in the gaseous state at room temperature. Studies have measured wide variations in VOC concentrations in the workplace, as well as differences in the mixtures of chemicals present. Research suggests that the irritant potency of VOC mixtures can vary. While in some instances it may be useful to identify some of the individual chemicals that are present in a workplace environment, it has been the concentration of total volatile organic compounds (TVOC) that has previously been used to predict certain types of health effects.[6] The use of this TVOC indicator, however, has never been standardized.

Some researchers have linked measured levels of TVOC exposure with human responses (such as headache and irritation of the eyes, nose, and throat). OSHA has established an exposure criterion for mixtures of VOCs in the industrial environment. It should be emphasized that the highly variable nature of complex VOC mixtures can greatly affect their irritant potential. Considering the difficulty in interpreting TVOC measurements, caution should be used in attempting to associate specific health effects with measured TVOC concentrations. In this HHE, decane ($C_{10}H_{22}$) was used as a surrogate for TVOCs.

Mixtures

Synergistic action and potentiation are two phenomena whereby some chemical combinations result in adverse health effects in excess of what might be caused by any individual chemical exposure. Synergistic action describes a situation in which the toxic effects of two (or more) chemicals in combination significantly exceeds the individual toxic effects of those same chemicals. Potentiation may occur when one chemical makes another much more toxic; alone, the potentiating chemical may produce little or no toxicologic effect. Applying exposure criteria without considering the possible effects of synergism or potentiation may underestimate the true potential for impairment to a worker's health as a result of exposure to chemical mixtures.

In the absence of information to the contrary concurrent exposure to two or more hazardous substances acting on the same target organ system should be considered as an additive exposure (and not as synergistic action or potentiation). To measure the effect of an additive exposure on a particular organ system, each substance in the mixture is computed as a fraction of its own occupational health evaluation criterion. If the sum of these fractions exceeds 1, employee exposure to that particular mixture of substances is considered excessive. This concept has been described by the following formula:

$$C1/T1 + C2/T2 + ... + Cn/Tn$$

where *Cn* refers to the observed atmospheric concentration of an air contaminant and *Tn* to its corresponding occupational health exposure criterion.[4,5]

The relevant occupational health exposure criteria used to derive this formula were established not to safeguard against health effects unique to a substance but to prevent the "additive effect" of exposure to multiple substances with similar health effects. When evaluating worker exposure to substances with similar physiological effects, then, the combined effect of all substances, rather than that of any one individually, should be given primary consideration.

Toluene

Toluene is a colorless, aromatic organic liquid containing a six carbon ring (a benzene ring) with a methyl group (CH_3) substitution. It is found in paints and other coatings, and is used as a raw material in the synthesis of organic chemicals, dyes, detergents, and pharmaceuticals.

Inhalation and dermal absorption are the major routes of entry for occupational exposures. Toluene can cause acute irritation of the eyes, respiratory tract, and skin. Since it is a defatting solvent, repeated or prolonged skin contact will remove the natural lipids from the skin which can cause drying, fissuring, and dermatitis.[7,8] Studies have shown that subjects exposed to 100 ppm of toluene for six hours complained of eye and nose irritation, and in some cases, headache, dizziness, and a feeling of intoxication (narcosis).[9,10,11] No symptoms were noted for exposures to concentrations of less than 100 ppm in these studies. The main effects reported with excessive (inhalation) exposure to toluene are central nervous system depression and neurotoxicity.[7] There are a number of reports of neurological damage due to deliberate sniffing of toluene-based glues resulting in motor weakness, intention tremor, ataxia, and cerebellar and cerebral atrophy.[12] Recovery is complete following infrequent exposure episodes; however, permanent impairment may occur after repeated and prolonged glue-sniffing abuse. Exposures to extremely high concentrations of toluene may cause mental confusion, loss of coordination, and unconsciousness.[13,14]

Originally, there was a concern that toluene exposures could produce hematopoietic (blood cell) toxicity because of the benzene ring present in the molecular structure of toluene. However, toluene does not produce the severe injury to bone marrow characteristic of benzene exposure as early reports suggested. It is now believed that simultaneous exposure to benzene (present as a contaminant in the toluene) was responsible for the observed hematopoietic toxicity.[8,15]

The NIOSH REL for toluene is 100 ppm for up to a 10-hour TWA.[3] NIOSH has also set a recommended STEL of 150 ppm for a 15-minute sampling period. The ACGIH TLV is 50 ppm for an 8-hour exposure TWA with a skin notation, indicating that cutaneous exposure contributes to the overall absorbed inhalation dose and potential systemic effects.[4] The OSHA PEL for toluene is 200 ppm for an 8-hour TWA.[5]

Butyl Acetate

Butyl acetate is a colorless or yellowish organic liquid with a characteristic fruit-like odor that is typically used as a solvent for nitrocellulose, oils, fats, resins, waxes, and camphor and in the manufacture of lacquer and plastics.

Inhalation and dermal absorption are the major occupational routes of entry. Studies have shown that in humans, butyl acetate affected the throat at 200 ppm, caused severe throat irritation at 300 ppm, and eye and nose irritation at 300 ppm.[16] Since it is a defatting solvent, repeated or prolonged skin contact will remove the natural lipids from the skin which can cause drying, fissuring, and dermatitis. At high concentrations, this chemical causes narcosis in animals, and it is expected that severe exposure may cause the same effect in humans.

The NIOSH REL[3], ACGIH TLV[4], and OSHA PEL[5] for butyl acetate is 150 ppm for an 8-hour TWA. These agencies have also set a STEL of 200 ppm for a 15-minute sampling period of this substance.

Propylene Glycol Methyl Ether Acetate (PGMEA)

Propylene glycol methyl ether acetate (PGMEA), also known as 1-methoxy-2-propanol acetate, is a colorless, hygroscopic (drawing moisture from the atmosphere) liquid. In industry, it is typically found in solvents, flow improvers, and coalescents in coating, painting, and printing ink industries.

This substance can be absorbed into the body by inhalation of its vapor or aerosol and by ingestion. PGMEA can cause acute irritation of the eyes and respiratory tract. Exposure at high levels may result in central nervous system depression. Since it is a defatting solvent, repeated or prolonged skin contact will remove the natural lipids from the skin, which can cause drying, fissuring, and dermatitis.[17]

There is currently no NIOSH REL, OSHA PEL, or ACGIH for PGMEA. However, the American Industrial Hygiene Association (AIHA) has proposed a Workplace Environmental Exposure Level (WEEL) of 100 ppm for an 8-hour TWA.[18] Also several European occupational regulatory agencies have an exposure limit of 50 ppm for this substance.[19]

Cyclohexanone

Cyclohexanone is a colorless liquid typically used as an industrial solvent, intermediate, and emulsifier for cellulose acetate resins, vinyl resins, rubber, and waxes; as a solvent-sealer for polyvinyl chloride; and as a coating solvent in audio- and videotape production.

Exposures can occur by inhalation of cyclohexanone vapor, through dermal contact with the liquid, and by ingestion. Both the liquid and its vapor irritates the eyes, the skin, and the respiratory tract. In human studies, exposure to 50 ppm was irritating to the throat, and exposure to 75 ppm resulted in more noticeable eye, nose, and throat irritation.[20] The liquid is a defatting agent, and prolonged or repeated skin contact may produce irritation, dermatitis, and skin sensitization.[20,21] Cyclohexanone produces lethargy and narcosis in animals. Exposures far above the occupational exposure level could cause a depressed level of consciousness in humans.

The NIOSH REL for cyclohexanone is 25 ppm for up to a 10-hour TWA.[3] NIOSH has also labeled this substance with a skin notation indicating the potential for dermal absorption; skin exposure should be prevented through good work practices and the use of gloves, coveralls, goggles, and other appropriate personal protective equipment. ACGIH has established a 20 ppm TLV for an 8-hour exposure level and a 50 ppm STEL for a 15-minute sampling period.[4] This ACGIH TLV (like the NIOSH REL) carries a skin notation, indicating that cutaneous exposures can add to the overall absorbed dose and may contribute to potential systemic effects. ACGIH has also appended an A3 notation to cyclohexanone, indicating that it is a confirmed animal carcinogen with unknown relevance to humans. The OSHA PEL for cyclohexanone is 50 ppm for an 8-hour TWA.[5]

Limonene

Limonene is a colorless organic liquid with a characteristic fruity odor that is primarily found in formulations of food and feed additives, flavorings, and in packaging materials. It may be absorbed into the body by inhalation, through the skin, and by ingestion. Limonene may slightly irritate the eyes and skin, and repeated or prolonged contact may cause skin sensitization if the substance has been oxidized.[22] There is currently no OSHA PEL, NIOSH REL, or ACGIH TLV established for limonene. However, the AIHA has proposed a WEEL of 30 ppm for an 8-hour TWA.[18]

Methyl Ethyl Ketone

MEK, a colorless, flammable organic solvent with a characteristic odor similar to acetone, is typically used as a solvent in the surface coating and synthetic resin industries.[15] Occupational exposure to MEK occurs primarily through inhalation. Short duration inhalation exposure to 100 ppm of MEK was reported to cause slight nose and throat irritation; 200 ppm caused mild eye irritation; and 300 ppm was associated with headaches and throat irritation as well as an objectionable odor.[7] Continued or prolonged skin contact with MEK liquid can cause dermatitis.[23] Exposure to high concentrations of MEK may cause central nervous system depression. Additional studies indicate that MEK by itself does not cause neurologic toxicity of the extremities (peripheral neuropathy), but may potentiate the toxic effects of substances known to cause peripheral neuropathy, such as n-hexane.[23,24,25] Studies have found little evidence supporting an association between MEK exposure and the development of cancer in humans or experimental animals.[20]

NIOSH[3], ACGIH[4], and OSHA[5] all have a 200 ppm full-shift inhalation criteria for MEK and a STEL of 300 ppm for 15 minutes.

Toluene-2,4- Diisocyanate (TDI)

TDI exists as a colorless to pale yellow liquid or in crystalline form. It has a pungent odor and is used in the production of polyurethane foams and plastics and in polyurethane paints and wire coatings. Literature, such as MSDSs, sometimes use isocyanate-related terms interchangeably. For the purposes of this report, monomer is the isocyanate isomer, e.g. 2,4-toluene diisocyanate or 2,6-toluene diisocyanate, and present as a component in the catalyst and as a vapor in air. Oligomer is the molecule linking monomers together and present as a component in the catalyst and as an aerosol in air.

TDI can be absorbed into the body by inhalation of its vapor and aerosol and by ingestion. The liquid, vapor, and aerosol of this substance can irritate the eyes, the skin, and the respiratory tract. Repeated or prolonged vapor inhalation may cause asthmatic reactions, chemical bronchitis, hypersensitivity pneumonitis (HP, a severe lung disease caused by isocyanates), and lung edema (fluid build-up in the lungs). Exposures far above the occupational exposure limit may result in death. The effects of exposure may be delayed and medical observation is indicated. Repeated or prolonged skin contact with the liquid and/or aerosol may result in sensitization.[7,26,27]

Based on the results of a limited number of laboratory studies, NIOSH has concluded that sufficient evidence exists to label TDI with a "Ca" notation indicating that is considered a potential carcinogen. Animal studies have demonstrated that commercial-grade TDI is carcinogenic in both rats and mice. It is important to note that no epidemiologic data exists that links occupational TDI exposure with elevated cancer rates in exposed workers.

NIOSH has set an REL of 0.005 ppm as a TWA for up to a 10-hour workday, with a ceiling concentration of 0.02 ppm for any 10-minute period.[3] The ACGIH TLV for toluene-2,4- or 2,6-diisocyanate is 0.005 ppm for an 8-hour exposure level.[4] ACGIH has also set a recommended STEL of 0.02 ppm for a 15-minute sampling period. This ACGIH TLV carries a "sensitizer" notation indicating the potential for the agent to produce sensitization as confirmed by human or animal data, and an A4 notation, indicating that it is a substance that may be carcinogenic to humans but which cannot be fully assessed at this time due to a lack of data. In contrast with the NIOSH position, ACGIH has determined that neither *in vitro* nor animal studies provide indications of carcinogenicity that are sufficient to classify the agent. The OSHA PEL for toluene-2,4-diisocyanate is 0.02 ppm for a ceiling limit that must not be exceeded during any part of the workday.[5]

NIOSH recommends both preplacement and periodic medical surveillance programs for all workers potentially exposed to diisocyanates.[28] Preplacement examinations should consist of detailed medical and work histories with emphasis on pre-existing respiratory and/or allergic conditions, a directed physical examination focusing on the respiratory tract, a baseline pulmonary function test to measure Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV_1) values, and a judgment on the worker's ability to wear a supplied-air respirator.** Workers should also undergo an annual medical screening examination in order to update their medical and work histories, and to document FVC and FEV_1 values. NIOSH further recommends that employers conduct exposure monitoring campaigns every 6 months.[28] Worker exposure should be determined for each operation in each work area, and should be measured whenever there are changes in the process or engineering controls.

The only effective control for workers with diisocyanate-induced asthma or HP is to eliminate all diisocyanate exposure. This can be accomplished by removing the worker from the work environment where diisocyanate exposure occurs, or by providing the worker with supplied-air respiratory protection.

Ventilation

According to OSHA regulations, all paint spraying areas must be provided with mechanical ventilation adequate to remove flammable vapors, mists, or powders to a safe location and to confine and control combustible residues so that life is not endangered. Mechanical ventilation must be kept in operation at all times during spraying operations and for a

**FVC is the total amount of air a person can force out of their lungs after breathing in as deeply as they can; FEV1 is the amount of air a person can force out of their lungs in one second.

sufficient time thereafter to allow vapors from coated articles and finishing material residues to be fully exhausted. OSHA regulations also require that in order to prevent the accumulation of explosive vapors, freshly spray painted articles must be allowed to dry in spaces provided with adequate ventilation.[29]

OSHA regulations require a minimum maintained face velocity (the velocity of air at the booth opening) of between 75 and 125 fpm for a walk-in, air spray paint booth.[30] ACGIH recommends a flow of 100 cubic feet per minute (cfm) per square foot of booth cross section for walk-in paint booths.[31]

RESULTS

Industrial Hygiene Evaluation

All samples collected by NIOSH on the day of the survey (toluene, butyl acetate, PGMEA, cyclohexanone, limonene, MEK, and TDI) were well below any pertinent occupational exposure criteria. The Limits of Detection (LOD), Limits of Quantification (LOQ), Minimum Detectable Concentrations (MDC), and Minimum Quantifiable Concentrations (MQC) for this study along with their respective sample volumes are shown in Table 1. Occupational exposure limits from OSHA, NIOSH, and ACGIH are included in Tables 2 through 4.

Volatile Organic Compounds

Charcoal tube air samples were quantitatively analyzed for toluene, butyl acetate, PGMEA, cyclohexanone, limonene, and total hydrocarbons (as decane). All results revealed individual concentrations to be well below applicable occupational evaluation criteria (Table 2).

The results of calculating the exposure to a mixture of solvents revealed that the sum did not exceed unity (1.0). The equation used is shown below where *C* refers to the observed atmospheric concentration of an air contaminant and *T* to its corresponding occupational health exposure criterion.

[Toluene (*C/T*) = 0.34/200] + [Butyl acetate (*C/T*) = 0.57/150] + [PGMEA (*C/T*) = 0.58/100] + [Cyclohexanone (*C/T*) = 1.0/50] + [Limonene (*C/T*) = 0.07/30] + [MEK (*C/T*) = 5.6/200] = 0.062

This finding is consistent with exposures to a chemical mixture at a level well below that which is considered excessive.

Methyl Ethyl Ketone

All samples for MEK were well below any occupational exposure criteria. These results are summarized in Table 3.

Toluene-2,4- Diisocyanate

The results of TDI sampling are shown in Table 4. One sample (collected at the paint booth) yielded a chromatographic pattern that closely matched the isocyanate bulk material and indicated exposure primarily to the spray aerosol. A second sample (collected at the parts washer) showed very low levels of monomer and oligomer and a ratio of monomer/oligomer that was much higher than that of the bulk, possibly indicating higher vapor exposure in this sample. A third sample (collected at the mixing table) showed only a trace of isocyanate.

Ventilation – Paint Booth

The ventilation assessment of the paint booth showed an average face velocity of 55 fpm and an average flow of 2860 cfm. This is below the ventilation guidelines established by OSHA and the recommendations of ACGIH. Figure 1 shows the results of the velocity measurements.

Use of ventilation smoke tubes revealed that areas of extremely low air velocity, or “dead spaces,” existed at the edge of the paint booth. NIOSH investigators also observed parts racks extending beyond the confines of the spray paint booth. This situation is not desirable since the booth is less efficient in capturing materials sprayed near the edge of or outside the booth. Moreover, the large pedestal fans, when turned on and placed facing into the booth, disrupted the desired pattern of air flow thereby worsening and not improving ventilation efficiency.

Ventilation – Drying Booth & Mixing Table

Ventilation smoke tubes revealed that the drying booth was not under negative pressure relative to the surrounding paint area (air was moving out of the booth and then captured by the general ventilation in the area). General room ventilation was not adequate to effectively capture vapors from drying materials. An area of stagnant air was identified above the mixing table and no LEV for this area was provided.

Workplace Observations

During this evaluation, NIOSH investigators spoke with Paint Department employees to gain information about typical work practices. This information is summarized below along with observations made by NIOSH investigators of the workplace and work practices on the day of the survey.

- Paint Department employees reported the occasional use of half-mask and full-face air-purifying respirators (3M® and Wilson®) equipped with organic vapor/P100 filter combination cartridges. On the day of sampling, neither of the two employees working in the Paint Department wore a respirator during the painting operations. Thus, on an irregular basis, painters may voluntarily wear negative pressure air-purifying respirators with combined organic vapor and particulate cartridges.

- Use of respiratory protection is not required by the company and Richards Industries does not have a formal respirator program. Respirators currently in use in the Paint Department are not being properly maintained or properly stored by workers.

- Some workers wear cotton coveralls, safety glasses, and occasionally nitrile gloves when painting or handling solvents. Gloves were not worn by the painter while painting on the day of the survey. Similarly, neither gloves nor eye protection were worn by the employee responsible for cleaning spray guns, nozzles, and hoses with MEK. Workers reported that the nitrile gloves provided by the company are degraded by the MEK, so they are not worn. During the NIOSH evaluation, skin contact with solvents was observed.

- Containers supplying the painting materials to the spray gun were located on the outside wall of the booth. These containers were not kept closed during the spraying and at the time of the site visit, NIOSH investigators observed the containers being spilled twice.

- Cleaning of the spray gun, nozzles, and hoses with MEK occurred outside the paint booth (in an open area of the department). Waste MEK was sprayed into a 55-gallon drum.

Medical Evaluation

A total of six employees voluntarily participated in the medical survey. Three were painters (past and present) and three others worked within a 50 foot radius of the Paint Department. All surveyed employees were male. The mean length of employment was 9 years. They all reported 40-hour work weeks and two reported that they occasionally worked overtime for up to 14 additional hours per week.

Painters

NIOSH investigators interviewed three Richards Industries employees who either work currently or had worked in the Paint Department. At the time of the NIOSH site visit, the current painter had worked in this position for approximately one month. The other two employees had worked as painters for two to three years but had since been promoted or reassigned to other jobs within the company. Two of the three painters reported that workplace exposures had resulted in their developing shortness of breath that improved during periods spent away from painting (that is, weekends and holidays). One of the former painters experienced a reaggravation of his respiratory symptoms during a temporary reassignment to the Paint Department. None of the workers reported eye or skin irritation.

The three painters had purchased for themselves dual cartridge (P100/organic vapor), half-face negative pressure air-purifying respirators for use during work. These respirators were and are used by the painters on a voluntary basis. The interviewed employees stated that they had not undergone formal fit-testing; nor had they received formal training concerning respirator usage. Currently, painters at Richards Industries change their respirator cartridges every three to four weeks. At the time of the site survey, however, these employees described periodically experiencing a sweet, metallic taste in their mouths prior to changing out the respirator cartridges. This may be an indication of respirator cartridge failure and thus, solvent and isocyanate exposure.

Although never fit-tested, all three employees described the fit-check process used prior to donning their masks. One employee had facial hair in a distribution that would likely interfere with fit-testing and the seal of the respirator to his face. Since this employee did not wear a respirator on the sampling day, it is unknown if he maintains his facial hair when he does opt to use respiratory protection.

The current painter reported wearing his respirator on a "regular basis," whereas the former painters used their respiratory protection on a somewhat less regular basis. Two of the three interviewed employees noted that their health effects were more pronounced in the absence of respirator use. The painters reported a variety of health effects that they believed to be either related or due to their exposures while spray painting. These included a worsening of gastro-esophageal reflux disease, post-nasal drip, headaches, and elevated blood pressure. In addition, all three painters reported some level of stress and anxiety related to the performance of their job. Specifically, the workers mentioned "being on edge," and also feeling nervous and depressed.

Workers Employed In the Vicinity of the Paint Department

NIOSH investigators also interviewed three persons who worked adjacent to the paint department. Two persons had worked near the paint department since the paint booth was moved to this area of the plant two years previously. The third individual had worked near the paint department for approximately seven months.

One of the three had not noticed any odors associated with the Paint Department and did not describe any health complaints. The other two employees reported the presence of strong paint odors in the afternoons when the spray paint guns are usually cleaned. Both of these employees associated having headaches and dizziness with exposure to paint odors. In addition, one employee, with a reported history of asthma, also described having had episodes of wheezing, shortness of breath, and chest tightness. The employees who experienced health effects when exposed to paint odors, reported that their health effects typically resolved shortly after odor dissipation or when leaving the area. Neither employee complained of eye, nose or throat irritation.

DISCUSSION

None of the air samples collected by NIOSH for VOCs, MEK, or TDI yielded results that exceeded occupational exposure limits. However, one employee interviewed reported respiratory symptoms that could potentially be related to workplace exposures to substances in use within the Paint Department. In particular, this person reported a work-related exacerbation of pre-existing asthma. Therefore, steps taken to further reduce employee exposures to these chemicals may be beneficial. Additionally, since many of these chemicals have low odor thresholds (meaning they can be smelled at low concentrations), employees may associate the smell of the chemical with the onset of health problems.

The levels of TDI measured in this facility were well below the NIOSH REL and no interviewed employees reported symptoms consistent with sensitization to TDI or TDI-induced asthma. To minimize the potential for worker sensitization to TDI, and because of the carcinogenic potential of TDI and its isomers, Richards Industries should, nonetheless, work to reduce TDI exposures to their lowest feasible level using appropriate engineering controls and work practices.[32]

As described above, painters at Richards Industries report intermittently wearing negative pressure air-purifying respirators with combined particulate and organic vapor cartridges. NIOSH recommends that respiratory protection be used for worker protection only when engineering controls are not technically feasible, during the interim while the controls are being installed or repaired, or when an emergency and other temporary situations arise.[33] Respirators are the least preferred method of worker protection from air contaminants for two reasons: (1) an effective respiratory protection program must be implemented to increase the reliability of the protection and (2) the cooperation of the workers to adhere to the elements of the program is critical for respirators to afford adequate protection. If employees continue to wear cartridge respirators voluntarily, certain elements of the respiratory protection program are still necessary, as outlined by OSHA. When respirators are used voluntarily the employer need only establish those respirator program elements necessary to assure the respirator itself is not a hazard. The employer is required to provide Appendix D of the standard to respirator users, ensure the individual(s) is medically able to wear the respirator, and that it is kept clean, maintained and stored properly. OSHA requirements relevant to voluntary use of respirators are described in the OSHA regulation 29 CFR 1910.134.[34]

Further efforts should be taken to protect workers from dermal exposures to the compounds with which they work. Skin contact can be a significant route of exposure to solvents, and contact dermatitis of the hands and forearms can be a problem for workers exposed to these chemicals. NIOSH recommends that efforts should be taken to prevent dermal exposures to isocyanate-containing compounds since this route of exposure has also been linked with adverse health effects. The current glove program was found to be ineffective because of the lack of worker training, failure to enforce the use of protective gloves, and the use of gloves made of an inappropriate material for the solvents of concern. The nitrile gloves provided by the company are not effective in protecting against dermal exposures to toluene, butyl acetate, cyclohexanone; only somewhat effective in protecting against PGMEA and TDI; and are readily degraded by MEK. Butyl rubber gloves, coveralls, and either eye goggles or face shield to protect skin and eyes from volatile compounds are recommended. A face shield or eye goggles would be more effective than eye glasses in protecting the eyes from contact with the solvent liquid (in the event of a splash or spill during mixing). For the nature of the operations at this facility, butyl rubber gloves are effective in protecting against dermal exposure to MEK, TDI, butyl acetate, cyclohexanone, and compounds similar to PGMEA.

CONCLUSIONS

Air sampling revealed very low exposures to substances in use at the plant. The area air sampling for TDI suggests that spray painters are exposed to isocyanates, but at very low concentrations (well below the OSHA PEL). Although measured solvent concentrations were below recommended exposure limits, symptoms potentially consistent with solvent exposures were reported. These included respiratory symptoms, headaches, and dizziness. No isocyanate-related asthma was found.

Interviews with workers revealed that the symptoms reported were consistent with, but not specific for, agents in the plant. Since no excessive exposures were found, the cause(s) of the reported symptoms cannot be determined; it is possible that some of the reported symptoms may be related to work.

Despite the low concentrations of chemicals we found from air sampling, NIOSH recommends that further measures to minimize exposures should be taken. Some controls are in place, but improvements can be made to further reduce exposures. Ventilation of the paint booth, drying booth, and mixing table need to be improved. Work practices during paint spraying and clean-up could be improved. Proper use of PPE, such as respirators (when used voluntarily), coveralls, gloves, and goggles or face shield, need to be implemented and enforced.

Recommendations are provided below to increase the level of protection for workers in the Paint Department.

RECOMMENDATIONS

Traditional industrial hygiene practice dictates that the following hierarchy of controls, in decreasing order of desirability and effectiveness, be implemented to minimize occupational exposures and protect worker health:

- Eliminate the toxic substance from the workplace.
- Substitute a less toxic substance for a more toxic substance.
- Install engineering controls designed to reduce exposure.
- Use administrative controls to reduce exposure.
- Use personal protective equipment to reduce exposure.

Engineering Controls

- Increase the face velocity of the spray paint booth to between 75 and 125 fpm and the flow rate to between 3875 and 6458 cfm. The ventilation equipment should be checked for adequate performance at least every three months.
- Install a system to monitor ventilation system performance since disposable particulate filters can become obstructed with debris over time and can reduce airflow. A common technique is the installation of a manometer across the filter bank which can monitor air flow in the booth and indicate when filters need to be changed.
- Reduce the size of the parts racks to allow more effective capture of the paint spray; or as an alternative, enlarge the booth. Since booth depth is critical (spray rebound may escape from shallow booths), sufficient space must be provided to permit airflow on all sides of the object, to provide room to work, and to enable air to enter the booth in a smooth, controlled manner.
- Increase the exhaust ventilation of the drying booth to maintain a negative pressure in relation to the surrounding areas.
- Provide local exhaust ventilation for the mixing table and parts washer area.

Administrative Controls (Work Practices)

- Workers should remain upstream of the parts being painted. Placing parts on a turntable can help facilitate easy access to all sides of an object and extension arms on spray guns can enable employees to paint hard to reach cavities.
- Avoid directing air flow from the pedestal fans into the paint booth.
- Allow all painted parts to dry in a ventilated booth.
- Keep paint containers tightly closed.[29]
- Clean the spray gun, nozzles, and hoses in ventilated areas. OSHA requires that the cleaning of spray nozzles and auxiliary equipment take place inside a spray booth with functioning ventilation.[29]
- Properly dispose of used rags. OSHA requires that (1) approved metal waste cans be provided wherever rags or waste are impregnated with finishing material, (2) all such rags or waste be deposited into the approved waste cans immediately after use, and (3) waste can contents be properly disposed of at least once daily or at the end of each shift.[29]
- Restrict eating and drinking in the area of the paint operation.
- Use the minimum air pressure of the spray gun needed to accomplish a given task. Excessive air pressure generally results in increased dispersion of the paint and a decreased effectiveness of available ventilation.
- Establish a respiratory protection program for voluntary respirator use.
- Establish a TDI medical monitoring program for the early detection and prevention of the acute and chronic effects of exposure to isocyanates.[28] The

workers' physicians should be given information about the adverse health effects of exposure to isocyanates and an individual workers' potential for exposure.

Personal Protective Equipment

- Provide butyl rubber gloves for dermal protection to painters when solvents or paints are being mixed or applied.
- Provide face shield or eye goggles for eye protection to painters when solvents are being mixed.

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Table 1
Analytical Limits for Air Sample Analysis
October 8, 2002
Richards Industries
HETA 2002-0418-2912

Analyte	LOD (mg/sample)	LOQ (mg/sample)	Volume (L)	MDC (ppm)	MQC (ppm)
Toluene	0.0004	0.001	44.6	0.002	0.006
Butyl Acetate	0.0003	0.0009	44.6	0.001	0.004
PGMEA	0.001	0.004	44.6	0.004	0.02
Cyclohexanone	0.0005	0.002	44.6	0.003	0.01
Limonene	0.0002	0.0007	44.6	0.0008	0.003

Decane	0.002	0.006	44.6	0.008	0.02
MEK	0.0008	0.003	44.9	0.006	0.02

Analyte	LOD (ng/sample)	LOQ (ng/sample)	Volume (L)	MDC (ppb)	MQC (ppb)
2,6-TDI (monomer)	6	19	398	0.002	0.007
2,4-TDI (monomer)	6	19	398	0.002	0.007
TDI oligomer	6	19	398	0.002	0.007

LOD = Limit of Detection
LOQ = Limit of Quantitation
MDC = Minimum Detectable Concentration
MQC = Minimum Quantifiable Concentration
mg = milligram
ng = nanogram (1,000,000 milligrams)
L = liter
ppm = parts per million
ppb = parts per billion

The limits of detection (LOD) describe the amount of substance below which it cannot be detected on the sample. The limits of quantification (LOQ) describe an amount of substance above the LOD, but not enough to quantify accurately. The LOD and LOQ are values determined by the analytical procedure used to analyze the samples, and are not dependent on sample volume. Minimum detectable concentrations (MDCs) are the minimum detectable air concentration and are determined by dividing the LODs by air sample volumes appropriate for the given set of samples. Minimum quantifiable concentrations (MQCs) are determined by dividing the LOQs by air sample volumes for the given set of samples, and reflect a concentration above the MDC but not enough to quantify accurately. In determining the MDC and MQC for this study, the NIOSH industrial hygienists used the highest sample volumes from the area air sampling data and from the PBZ air sampling data for each type of sample.

Table 2
Results of VOC Sampling
October 8, 2002
Richards Industries, Inc.
HETA 2002-0418-2912

Sample Type	Person/ Location	Sample Volume (L)	Concentration (ppm)					
			Toluene	Butyl Acetate	PGMEA	Cyclohexanone	Limonene	Total VOC (Decane)
PBZ	**Painter 1**	44.6	0.34	0.57	0.58	1.0	0.04	0.37
PBZ	**Painter 2**	42.4	0.20	0.34	0.36	0.59	0.04	0.32
Area	**Paint Booth**	24.1	0.05	0.11	0.13	0.12	0.07	0.34
Area	**Mixing Table**	33.0	0.22	0.25	0.11	0.36	0.02	0.36
Area	**Parts Washer**	33.6	0.16	0.34	0.37	0.54	0.06	0.33
Area	**Desk**	32.0	0.004	0.02	0.03	trace	0.02	0.28

Occupational Exposure Limits

OSHA PEL[1]	200	150	None	50	None	None
NIOSH REL[2]	100	150	None	25	None	None
ACGIH TLV[3]	50	150	None	25	None	None
Other (AIHA WEEL[4])			100		30	

1-Occupational Safety and Health Administration Permissible Exposure Limit
2- National Institute for Occupational Safety and Health Recommended Exposure Limit
3- American Conference of Governmental Industrial Hygienists Threshold Limit Value
4-American Industrial Hygiene Association Workplace Environmental Exposure Level
PBZ = personal breathing zone
trace = detected value was between MDC (0.003 ppm) and MQC (0.01 ppm)

Table 3
Results of MEK Sampling
October 8, 2002
Richards Industries, Inc.
HETA 2002-0418-2912

Sample Type	Label/ Location	TWA Sample Volume (L)	TWA (ppm)	STEL Sample Volume (L)	STEL (ppm)
PBZ	**Sample 1**	43.1	2.3	3.0	11
PBZ	**Sample 2**	44.9	4.6	2.2	31
Area	**Paint Booth**	33.5	4.5		
Area	**Mixing Table**	32.6	5.6		
Area	**Parts Washer**	33.7	0.96		
Area	**Desk**	32.2	0.15		
Occupational Exposure Limits					
OSHA PEL			200		300
NIOSH REL			200		300
ACGIH TLV			200		300

Table 4
Results of TDI Sampling
October 8, 2002
Richards Industries, Inc.
HETA 2002-0418-2912

Location	Sample Volume (L)	Concentration (ppb) 2,6-TDI	2,4-TDI	TDI oligomer (monomer equivalent)
Paint Booth	385	0.06	0.04	1
Mixing Table	387	trace	ND	trace
Parts Washer	375	0.01	trace	0.03
Desk	370	ND	ND	ND
Conference Room	398	ND	ND	ND

Occupational Exposure Limits

	2,6-TDI	2,4-TDI	TDI oligomer
OSHA PEL	--	20 (C)	--
NIOSH REL	--	5	--
ACGIH TLV	5	5	--

trace = detected value was between the MDC (0.002 ppb) and MQC (0.007 ppb)
ND = not detected- sample was below the LOD (6 ng)
C = Ceiling level (Concentration which should not be exceeded)

Figure 1
Results of Velocity Measurements
October 8, 2002
Richards Industries, Inc.
HETA 2002-0418-2912

Booth Face

70	100	80
40	80	55
20	50	4

Average Face Velocity = 55 fpm
Recommended Target (OSHA) = 75-125 fpm

Average Flow Rate = 2860 cubic feet per minute (cfm)
Recommended Target (OSHA) = 3875-6458 cfm

Booth Middle

5	60	75
10	70	50
65	60	45

Booth Rear

35	95	55
15	90	70
55	50	45

All measurements are in feet per minute (fpm).
Booth depth = 60"
Booth height = 80"
Booth width = 93"

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