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**HETA 97-0084-2669**  
**Woodward Governor Company**  
**Fort Collins, Colorado**

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## PREFACE

The Hazard Evaluations and Technical Assistance Branch of 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 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.

The Hazard Evaluations and Technical Assistance Branch 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 the National Institute for Occupational Safety and Health.

## ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Charles McCammon, Randy L. Tubbs, Beth Reh, and Chris Reh of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Steve Lee. Analytical support was provided by DataChem Laboratories. Desktop publishing was performed by Pat Lovell. Review and preparation for printing was performed by Penny Arthur.

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**Woodward Governor Company**  
**Fort Collins, Colorado**  
**December 1997**

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## SUMMARY

On January 13, 1997, the National Institute for Occupational Safety and Health (NIOSH) received a request from the safety director of the Woodward Governor Co., Fort Collins, Colorado, plant to conduct a health hazard evaluation (HHE). The request asked for assistance in documenting worker exposure to a wide variety of contaminants in production jobs including printed circuit board manufacturing, electrical product assembly, silk screening, spray painting, shipping, and mechanical production. The exposures of concern included isocyanates, inorganic acids, ammonia, solvents, lead, cutting fluids, and noise.

Woodward Governor has many plants around the world involved in the manufacture of engine control devices. The Fort Collins, Colorado, plant employs about 800 workers involved in a wide range of production jobs. An environmental survey was conducted on March 10-12, 1997, which included monitoring for noise, metal working fluids, solvents (toluene, xylene, propylene glycol monomethyl ether [PGME], and formaldehyde), lead, ammonia, inorganic acids (hydrochloric, nitric, sulfuric, and phosphoric acids), and isocyanates (toluene diisocyanate [TDI] and methylene diisocyanate [MDI] monomers and oligomers, and total reactive isocyanate groups [TRIGs]).

Personal, full-shift noise exposures and area spectral noise samples was measured over a two-day period mostly in the machining area. Average noise level (based on OSHA criteria) ranged from 69-83.1 dB(A). Based on NIOSH evaluation criteria, the noise levels ranged from 79.2-87.1 dB(A). Noise exposures did not exceed the OSHA personal exposure limit (PEL) or action level for up to a 10-hour shift. However, three jobs did exceed the NIOSH recommended exposure criteria (REL) for noise, two of them for 8-hour shifts or longer and one for a 9-hour shift.

Full-shift, personal samples for total particulate and 10-minute area samples using a real-time dust monitor were collected to determine worker exposure to metal working fluids (MWF). The personal samples ranged from 0.14 to 3.2 mg/m<sup>3</sup>. Two of the eight machine operators had total particulate concentrations in excess of the proposed NIOSH REL of 0.5 mg/m<sup>3</sup> (1.4 and 3.2 mg/m<sup>3</sup>).

Personal breathing zone air samples for toluene and xylene collected in the printed circuit board and machine area ranged from 0.01-1.5 ppm and 0.04-0.8 ppm, respectively. All were well below any evaluation criteria. Area air samples for PGME collected in the Photo Processor room ranged from 0.36-0.42 mg/m<sup>3</sup>, an order of magnitude below the REL/PEL. All four area air samples collected for formaldehyde in the Plating Room were below the analytical limit of detection.

Two personal air samples collected for lead during the cleaning of dross from the wave solder machine, were 15.1 and 28.3  $\mu\text{g}/\text{m}^3$  for the 15-minute operation. Two area air samples collected above the wave solder machine for lead, over the entire shift ranged, from 0.06-0.07  $\mu\text{g}/\text{m}^3$ .

Area and personal air samples collected for inorganic acid in the Plating Room, ranged from non-detectable ( $<0.01 \text{ mg}/\text{m}^3$ ) to a high of 0.12  $\text{mg}/\text{m}^3$  for nitric acid. None of the other acid concentrations exceeded the analytical limit of detection (equivalent air detection concentrations of  $<0.01 \text{ mg}/\text{m}^3$ ).

Area air sampling results for TDI during spray painting operations, ranged from 5.1-9.6  $\mu\text{g}/\text{m}^3$  for 2,4-TDI monomer, and 7.4-17.9  $\mu\text{g-NCO}/\text{m}^3$  for total reactive isocyanate groups (TRIGs). No 2,6-TDI monomer was detected. The low levels indicated that the spray booth was effectively containing the isocyanates. Area air samples collected for MDI during packaging operations found no MDI monomer, with oligomer concentrations ranging from none detected to 15.5  $\mu\text{g}/\text{m}^3$ . The TRIG concentrations were all below 9.8  $\mu\text{g-NCO}/\text{m}^3$ .

Air concentrations for solvents (toluene, xylene, propylene glycol monomethyl ether, and formaldehyde), lead, ammonia, inorganic acids (hydrochloric, nitric, sulfuric, and phosphoric acids), and isocyanates were all below the respective evaluation criteria. Three jobs in the machining area were found to exceed the NIOSH REL for noise. Two of the machine operators were exposed to concentrations above the proposed NIOSH REL for metal working fluids. Recommendations are included to help improve working conditions throughout the plant.

Keywords: SIC 3519 (Internal Combustion Engines, Not Elsewhere Classified), noise, isocyanates, metal working fluids, TDI, MDI, total reactive isocyanate groups, toluene, xylene, formaldehyde, inorganic acids, ammonia, lead

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## INTRODUCTION

On January 13, 1997, the National Institute for Occupational Safety and Health (NIOSH) received a request from the safety director of the Woodward Governor Co., Fort Collins, Colorado, plant to conduct a health hazard evaluation (HHE). The request was for assistance in documenting worker exposure to a wide variety of contaminants in production jobs including printed circuit board manufacturing, electrical production, silk screening, spray painting, shipping, and mechanical production. The exposures of concern included isocyanates, inorganic acids, ammonia, solvents, lead, cutting fluids, and noise.

## BACKGROUND

Woodward Governor has many plants around the world involved in the manufacture of engine control devices. The Fort Collins, Colorado, plant employs about 800 workers involved in a wide range of production jobs. The plant has a variety of production activities including printed circuit manufacturing, metal manufacturing, assembly, research and development, and shipping. Within each area, such as printed circuit board manufacturing, there are multiple operations such as the plating line, screen printing, imaging, board drilling, and circuit testing. Some departments support many areas, examples being sheet metal fabrication, the chemical laboratory, and shipping. Other major areas of concern include spray painting, metal working machines utilizing cutting fluids, and heat treating.

The machining area of the Woodward Governor plant covers approximately 33,500 square feet and contains about 95 machines. Just prior to the NIOSH survey, Woodward had renovated the machining area and relocated machines within the space. Each machine is self-contained and does not share its metal working fluid (MWF) with any other machines through any kind of central system. None of the machines contain local exhaust ventilation

(LEV), but many are partially or totally enclosed when operating. On the days of the site visit, there was no visible mist in the air, and, for the most part, the floors were not slippery from MWFs. The tables and surfaces were also relatively clean, and the machines appeared to be wiped down routinely. Although the Safety Director reported that production was below normal because many employees were not at work due to spring break at the local schools, the employees reported that the level of cleanliness and visibility during the site visit was typical.

The majority of machines use water-based MWFs, either a Blasocut® water-soluble oil or a Syntilo® synthetic fluid, but a few use one of two of Hansterfer's Hard Cut® straight oils. None of the MWF suppliers has onsite personnel at this plant; the plant's maintenance department is responsible for all MWF maintenance. Each individual operator is responsible for adding new fluid (make-up fluid) as needed based on the automatically monitored fluid concentrations, and they can also request a complete change-over of fluid from the maintenance department. The maintenance department also performs scheduled fluid change-overs, which vary by machine and fluid type. The machines that use straight oils are only changed-over once a year or on request, during which time the machine is drained, rinsed out, wiped out, and refilled with new fluid. The filters on these machines are changed only as needed.

The machines that use the water-based fluids are changed-over more frequently (depending on the machine, every one to several months), and this change-over involves pumping the fluid out of the machine, cleaning out the metal chips, rinsing, using a cleanser (Cimclean® 30) and brush, a final rinsing of the tanks and lines, wiping the inside and outside of the machine, and refilling it with new fluid. During this process the machine must be shut-down for two to eight hours (varies by size of the machine). The responsible maintenance person keeps the records of maintenance in his notebook and on updated stickers on each machine. The only machines without scheduled change-overs are the

Hitachi and Citizen lathes; the fluids in these machines are only changed upon operator request because the operators do not want any scheduled shut-downs.

A week before the site visit, a MWF recycling system was installed for the Blasocut® fluids. The fluids in the machines that use Blasocut® are scheduled to be recycled (emptied from the machine, recycled in the Blaser Swiss Lube filtration system, and returned to the machine) every three weeks by the night maintenance personnel. The total cleaning and change-over of fluids for these machines was anticipated to be every six months.

No additions are made by plant personnel to the MWFs except for the dilution water to the water-based fluids. No biocides are used except that the Blasocut® MWFs contain 0.5-1% corrosion and fungi inhibitors before dilution. Microbial contamination is not monitored in this plant, but it does not appear to be a significant problem. Maintenance personnel reported that machine operators do not need to request fluid change-overs because of odors from fluid spoilage, and no microbial growth was visible during the survey. The contamination is probably kept at low concentrations by the frequent cleaning and change-overs.

During the air sampling, informal conversations were held with the machine operators. It appears that respiratory problems were not a major health complaint in this area, but some workers reported experiencing upper airway irritation. Several workers also reported experiencing skin irritation and rashes (many of the workers were not wearing gloves).

Isocyanate-containing materials are used in two production areas at Woodward Governor: the paint shop located in the Multi-purpose Building, and the polyurethane foam packaging operation located in the shipping area of the Main Building. Spray painting is conducted in a side-draft paint booth, using a high volume, low pressure spray paint gun. Typically, parts are moved into the paint booth, and masking tape and plastic are applied to areas not

receiving paint. Most parts receive three coats of paint: one coat of a primer and two coats of polyurethane enamel paint. The polyurethane enamel paint is a two-component paint system; the first component contains the color and various solvents, and the second component (catalyst) is 40% 1-methoxy-2-propanol acetate and 60% toluene diisocyanate (TDI)-based polymer. The amount of free TDI in the catalyst is less than 0.4%. The painter dons a full-face, supplied-air respirator when painting in the paint booth. In addition, the worker wears coveralls and rubber boots.

Polyurethane foam is used as a foam-in-place system for packaging parts in cardboard boxes prior to shipment. The polyurethane foam is a two-component system, and part A contains 42% (by weight) 4,4'-diphenylmethane diisocyanate (MDI) and 55% MDI-based polyisocyanate. The foam is applied by a single worker at a foaming station. The worker places the part to be shipped in a cardboard box, and then uses a foaming gun to deliver uncured foam into the box. As the foam cures, it expands to fill the voids within the spaces between the box and the part. The foaming station is equipped with a local exhaust ventilation system which is designed to remove contaminants away from the worker applying the foam.

## METHODS

### Noise

A two-day noise survey was conducted at the Woodward Governor Company, following the renovation of the machining area's floor plan. During the walk-through survey, specific areas in the facility were identified by management officials as locations where noise was perceived to be a potential concern. Also, areas where employees were currently participating in the company's hearing conservation program were targeted for noise sampling. Both personal, full-shift noise exposures and area spectral noise samples were obtained over the two days.



To monitor noise exposures continuously, Quest® Electronics Model M-27 Noise Logging Dosimeters were worn by employees during the work shift. The dosimeters were attached to the employee's belt and a small remote microphone was fastened to the work uniform (facing forward) at a mid-point between the ear and outside the employee's shoulder. The dosimeters were worn for the entire work day, including the employees' breaks and the lunch period, if the employee remained at the facility. At the end of the workshift, the dosimeters were removed and paused to stop data collection. The information was downloaded to a personal computer with Quest® Electronics M-27 computer software for interpretation. The dosimeters were calibrated before and after the workshift according to the manufacturer's instructions.

## **Metal Working Fluids**

During the site visit, full-shift, personal breathing zone (PBZ) air samples were collected on eight machine operators. These air samples were collected on pre-weighed polyvinyl chloride filters using Gilian® high-flow air pumps at a flowrate of 2 liters per minute, and analyzed for total particulate concentrations following NIOSH Method No. 0500.<sup>1</sup>

Along with the PBZ air sampling, 10-minute general area samples were collected using a real-time particulate analyzer, the Grimm Model 1106 Dust Monitor (Labortechnik GmbH & CoKG, Ainring, Germany). The Grimm Dust Monitor is a light scattering aerosol spectrometer designed for real-time particulate measurement with particle size discrimination. Eight channels collect mass information for particle sizes of greater than 0.35, 0.5, 0.75, 1.0, 2.0, 3.5, 5.0, and 6.5 micrometers (µm). For each sampling location, data was integrated for one minute and stored sequentially on the Grimm data card over the entire sampling period. The collected particle mass and size information was downloaded to a laptop computer following the completion of the sampling day.

## **Solvents**

PBZ and area samples were collected for toluene and xylene on 150-milligram (mg) charcoal tubes at flowrates of 0.1-0.2 Lpm using Gilian LFS 113D personal sampling pumps. The samples were analyzed by gas chromatography according to NIOSH Analytical Method #1501.<sup>1</sup>

Air samples for propylene glycol monomethyl ether (PGME) were collected at 0.5 Lpm on 300-mg XAD-7 sampling tubes (SKC #226-57). The samples were analyzed by gas chromatography according to NIOSH Analytical Method #1403.<sup>1</sup>

Formaldehyde air samples were collected at 0.1 Lpm on 180-mg treated XAD-2 sampling tubes (SKC #226-118). The samples were analyzed by gas chromatography according to NIOSH Analytical Method #2541.<sup>1</sup>

## **Lead, Ammonia, and Inorganic Acids**

Lead air samples were collected at 2-3 Lpm on 37-millimeter mixed cellulose ester (MCE) membrane filters in polystyrene cassette holders. The filters were digested and analyzed by heated graphite atomic absorption according to NIOSH Analytical Method #7105.<sup>1</sup>

Air samples for ammonia were collected at 0.2 Lpm through a sampling train consisting of a MCE filter connected to a 300-mg, sulfuric acid washed silica gel tube (SKC #226-10-06). The samples were analyzed by automated visible spectroscopy according to NIOSH Analytical Method #6015.<sup>1</sup>

Air samples for hydrochloric, nitric, sulfuric and phosphoric acid were all collected on 600-mg, cleaned silica gel tubes. Analysis of the air samples for inorganic acids was by ion chromatography according to NIOSH Analytical Method #7903.<sup>1</sup>

## Isocyanates

Area air samples were collected for TDI, MDI, TDI-based oligomers, and MDI-based oligomers using NIOSH Method 5522.<sup>2</sup> This method utilizes a midjet impinger containing 20 milliliters of a derivatizing reagent consisting of tryptamine dissolved in dimethyl sulfoxide. Samples were collected by drawing air through the midjet impinger at a nominal flowrate of 1.0 liter per minute, using a calibrated sampling pump. Upon completion of the sampling, the impinger solutions were transferred into opaque glass vials, and shipped to the analytical laboratory. The samples were analyzed using high performance liquid chromatography, with both fluorescence and electrochemical detection.

The limits of detection (LOD) for this method are 1.0 micrograms per sample ( $\mu\text{g}/\text{sample}$ ) for TDI, and 0.5  $\mu\text{g}/\text{sample}$  for MDI. In addition, the limits of quantification (LOQ) were 3.5 and 1.7  $\mu\text{g}/\text{sample}$  for TDI and MDI, respectively. All peaks eluting from the HPLC's column after the TDI and MDI monomers, were summed and used for quantification of the corresponding oligomers. This quantification was based on the standard curves for the monomer species; thus, the laboratory does not report an LOD and LOQ for the TDI- and MDI-based oligomers. LODs and LOQs are values determined by the analytical procedure used to analyze the samples, and are not dependent on sample volume. Minimum detectable concentrations (MDCs) and minimum quantifiable concentrations (MQCs) are determined by dividing the LODs and LOQs by air sample volumes appropriate for the given set of samples. MDCs and MQCs for this survey can be found in Tables 8 and 9.

The total reactive isocyanate groups (TRIGs) in air can be determined using data from NIOSH Method 5522. First, the monomer and oligomer concentrations are summed to obtain the total weight of isocyanate-containing compounds in a given air sample. Next, the molecular weight of the isocyanate functional groups in the parent compound is divided by the molecular weight of the parent compound. This yields a constant that reflects the

percentage of a compound's molecular weight that is contributed by the TRIGs. For MDI and MDI-based oligomers the TRIG's constant is 0.34; for TDI and TDI-based oligomers the TRIG's constant is 0.48. Finally, the total weight of isocyanate-containing compounds in a given air sample is multiplied by the TRIGs constant, and the product is the concentration of TRIGs in air.

## 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 increase 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)<sup>3</sup>, (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®)<sup>4</sup>, and (3) the U.S. Department of Labor,

OSHA Permissible Exposure Limits (PELs).<sup>5</sup> In July 1992, the 11th Circuit Court of Appeals vacated the 1989 OSHA PEL Air Contaminants Standard. OSHA is currently enforcing the 1971 standards which are listed as transitional values in the current Code of Federal Regulations; however, some states operating their own OSHA approved job safety and health programs continue to enforce the 1989 limits. NIOSH encourages employers to follow the 1989 OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criterion. The OSHA PELs reflect the feasibility of controlling exposures in various industries where the agents are used, whereas NIOSH RELs are based primarily on concerns relating to the prevention of occupational disease. It should be noted when reviewing this report that employers are legally required to meet those levels specified by an OSHA standard and that the OSHA PELs included in this report reflect the 1971 values.

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 short-term exposure limits (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

## Noise

Noise-induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically.<sup>6</sup> While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise-induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 Hz (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher

frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components.<sup>7</sup>

The A-weighted decibel [dB(A)] is the preferred unit for measuring sound levels to assess worker noise exposures. The dB(A) scale is weighted to approximate the sensory response of the human ear to sound frequencies near the threshold of hearing. The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels which are audible to the human ear. Because the dB(A) scale is logarithmic, increases of 3 dB(A), 10 dB(A), and 20 dB(A) represent a doubling, tenfold increase, and 100-fold increase of sound energy, respectively. It should be noted that noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise (29 CFR 1910.95)<sup>8</sup> specifies a maximum permissible exposure limit (PEL) of 90 dB(A) for a duration of 8 hours per day. The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship, or exchange rate. This means that a person may be exposed to noise levels of 95 dB(A) for no more than 4 hours, to 100 dB(A) for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dB(A) is allowed by this exchange rate. NIOSH, in its Criteria for a Recommended Standard,<sup>9</sup> proposed an REL of 85 dB(A) for 8 hours, 5 dB less than the OSHA standard. The NIOSH 1972 criteria document also used a 5 dB time/intensity trading relationship in calculating exposure limits. However, in 1995, NIOSH changed its official

recommendation for an exchange rate of 5 dB to 3 dB.<sup>10</sup> The ACGIH also changed its TLV in 1994 to a more protective 85 dB(A) for an 8-hour exposure, with the stipulation that a 3 dB exchange rate be used to calculate time-varying noise exposures.<sup>3</sup> Thus, a worker can be exposed to 85 dB(A) for 8 hours, but to no more than 88 dB(A) for 4 hours or 91 dB(A) for 2 hours.

The duration and sound level intensities can be combined in order to calculate a worker's daily noise dose according to the formula:

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

where  $C_n$  indicates the total time of exposure at a specific noise level and  $T_n$  indicates the reference duration for that level as given in Table G-16a of the OSHA noise regulation.<sup>8</sup> During any 24-hour period, a worker is allowed up to 100% of his daily noise dose. Doses greater than 100% are in excess of the OSHA PEL.

The OSHA regulation has an additional action level (AL) of 85 dB(A); an employer shall administer a continuing, effective hearing conservation program when the TWA value exceeds the AL. The program must include monitoring, employee notification, observation, audiometric testing, hearing protectors, training, and record keeping. All of these requirements are included in 29 CFR 1910.95, paragraphs (c) through (o).

Finally, the OSHA noise standard states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dB(A), feasible engineering or administrative controls shall be implemented to reduce the workers' exposure levels. However, in 1983, a compliance memorandum (CPL 2-2.35) directed OSHA compliance officers not to cite employers for lack of engineering controls until workers' TWA levels exceed 100 dB(A), so long as the company has an effective hearing conservation program in place. Even in TWA levels in excess of 100 dB(A), compliance officers are to use their discretion in issuing fines for lack of engineering controls.

## Metal working Fluids

Metal working fluids (MWFs) are used for lubrication, cooling, and removal of metal chips during machining operations. Health effects that have been associated with exposure to MWFs include cancer, dermatitis, and respiratory health effects. There are four major types of MWFs – straight oils, water soluble oils, semi-synthetic, and synthetic – and the evaluation of the potential health hazard from exposure to MWFs would vary depending on which type is being used. Straight oils are evaluated as an oil mist exposure and consideration must be given to potential contaminants contained in the oils. The other three types are water-based MWFs, and several evaluations might be necessary, including total particulate (both size-selective gravimetric analysis and particle count), nitrosamines, ethanolamines, formaldehyde, specific biocides, volatile and non-volatile organic compounds, metals, endotoxins, and microbial contamination. The relevant health effects and the evaluation criteria for the total particulate sampling performed during this survey are described below.

## Respiratory Effects

MWF exposure has been associated with a variety of respiratory health effects, including irritant bronchitis, occupational asthma, and hypersensitivity pneumonitis.<sup>11,12</sup> Subclinical changes in pulmonary function tests and lipoid pneumonia have also been associated with MWF exposures.<sup>12</sup> One study documented significant associations of cross-shift decrements in forced expiratory volume in one second ( $FEV_1$ ) on Mondays and Fridays with inhalable aerosol concentrations ranging from 0.20 to 2.03 micrograms per cubic meter ( $mg/m^3$ ) of straight oil, soluble oil, and synthetic MWFs;<sup>13</sup> but, another concluded that there were no adverse respiratory effects from exposure to soluble oil MWFs and only tenuous adverse effects from exposure to straight oil MWFs based on respiratory symptoms prevalence and lung function tests.<sup>14</sup>

## **Irritant Bronchitis**

Occupational bronchitis is a common condition marked by the presence of a productive cough that is caused or aggravated by occupational exposures. "Chronic bronchitis is clinically defined as the presence of a productive cough for at least 3 months, over at least 2 years."<sup>15</sup> Gases (as fumes or smoke), solids (as dusts or particulates in smoke), and liquids (as mists, sprays or fogs) can all cause an irritant bronchitis. Properties such as the particle size, concentration, antigenicity, and solubility determine the effect. Symptoms of bronchitis include dyspnea (shortness of breath), chest tightness, and cough. Bronchitis can be associated with pulmonary function abnormalities such as airflow obstruction and gas exchange abnormalities.<sup>15</sup> The diagnosis is based upon a medical and occupational history, a physical exam, and laboratory tests such as pulmonary function tests (PFTs).

## **Occupational asthma**

Asthma is a clinical syndrome characterized by increased responsiveness of the trachea-bronchial tree to a variety of stimuli.<sup>16</sup> Symptoms of asthma include episodic wheezing, chest tightness, and dyspnea, or recurrent attacks of "bronchitis" with cough, sputum production, and rhinitis.<sup>17</sup> The primary physiologic manifestation of airway hyper-responsiveness is variable or reversible airflow obstruction, which may be demonstrated by significant changes in the PFTs [forced expiratory volume in 1 second (FEV<sub>1</sub>) or peak expiratory flowrate (PEFR)]. Airflow changes can occur spontaneously, with treatment, with a precipitating exposure, or with diagnostic maneuvers such as nonspecific inhalation challenge.

Many agents and processes have been associated with occupational asthma, and others continue to be recognized.<sup>17,18</sup> Many occupational exposures can also exacerbate the symptoms of non-occupational asthma. MWF has been found to be an important cause of occupational asthma, and accounted for 12% of all reported occupational asthma cases in Michigan in 1988 to 1992.<sup>19</sup>

NIOSH has developed an asthma surveillance case definition and recommended reporting guidelines. This definition and these guidelines are recommended for surveillance of work-related asthma by State health departments and regulatory agencies receiving reports of cases from physicians and other health-care providers. The following is the NIOSH surveillance case definition for occupational asthma:<sup>20</sup>

- A. A physician diagnosis of asthma; and
- B. An association between symptoms of asthma and work, and any one of the following:
  1. Workplace exposure to an agent or process previously associated with occupational asthma, or
  2. Significant work-related changes in PFTs (specifically the readings for FEV<sub>1</sub> or PEFR), or
  3. Significant work-related changes in airways responsiveness as measured by nonspecific inhalation challenge, or
  4. Positive response to inhalation provocation testing with an agent to which the patient is exposed to at work. Inhalation provocation testing with workplace substances is potentially dangerous and should be performed by experienced personnel in a hospital setting where resuscitation facilities are available and where frequent observations can be made over sufficient time to monitor for delayed reactions.

Patterns of work-related disease association can vary. The following examples are patterns that may suggest an occupational etiology: symptoms of asthma develop after a worker starts a new job or after new materials are introduced on a job (a substantial period of time may elapse between initial exposure and development of symptoms); symptoms develop within minutes of specific activities or exposures at work; delayed symptoms occur several hours after exposure, such as during the evenings of workdays; symptoms occur less frequently or not at all on days away from work and on vacations;

symptoms occur more frequently on returning to work. Work-related changes in medication requirements may have similar patterns, also suggesting an occupational etiology.

Changes in nonspecific bronchial hyperactivity can be measured by serial inhalation challenge testing with methacholine or histamine. Increased bronchial reactivity (manifested by reaction to lower concentrations or methacholine or histamine) following exposure and decreased bronchial reactivity after a period away from work are evidence of work-relatedness.

### **Hypersensitivity pneumonitis (HP)**

HP associated with MWFs, termed “machine operator’s lung,” has been recently described.<sup>11</sup> This study strongly suggested that microbial antigens in the MWFs played a causative role in the HP cases.

HP, also called extrinsic allergic alveolitis, is a spectrum of granulomatous, interstitial lung diseases which occur because of repeated inhalation and sensitization to a wide variety of microbial agents (bacteria, fungi, amoebae), animal proteins, and low-molecular weight chemical antigens.<sup>21</sup> It is marked by a pneumonitis which is reversible if exposure to the antigen is stopped; continued exposure can lead to a chronic interstitial fibrosis or scarring of the lungs. Only limited data are available on the epidemiology of HP. The type of exposure (e.g., antigen concentration, particle size, and antigen solubility), as well as individual susceptibility and individual risk factors, all play a role in determining if an individual will develop HP. The time of onset of HP after initial exposure to an antigen may range from a period of weeks to years.

In general, HP is marked by nonspecific symptoms. Acute HP begins in the first 12 hours after exposure with cough, dyspnea, chest tightness, fevers, chills, malaise, and myalgias (muscle aches). The symptoms of the subacute and chronic forms of HP include cough, dyspnea, possible wheezing, loss of appetite, and weight loss. The diagnosis should be

considered in anyone with recurrent pneumonias or recurrent respiratory symptoms.

Making a definite diagnosis of HP can be very difficult. No single aspect of the patient’s history, symptoms, physical findings, or laboratory tests is diagnostic of HP. Rather, the diagnosis is based on all of these, with the specific etiology determined by the exposure history and appropriate antibody tests.

### **Skin Effects**

Contact with straight oil MWFs can cause “oil-acne,” or folliculitis,<sup>22,23,24,25</sup> a condition caused by clogging of the skin pores as a result of chemical irritation.<sup>22,23</sup> Bacterial infection may arise secondarily, but it does not play a primary role in folliculitis.<sup>23</sup> Treatment is often easy, and recurrence is prevented by the reduction of skin contact and the use of proper cleaning methods.<sup>23</sup>

Exposure to water-soluble MWFs most frequently causes dermatitis, or inflammation of the skin.<sup>22,23,24,25</sup>

There are two distinct types of skin reactions – a direct reaction, irritant contact dermatitis (ICD), and an allergic reaction, allergic contact dermatitis (ACD). A direct reaction occurs at the site of contact, while an allergic reaction occurs not only locally at the point of contact but also systemically resulting in dermatitis at distant sites. The type of rash and the degree of irritation may not be the same for different individuals. Some researchers believe that ICD comprises 80% of the eczematous skin reactions to MWFs, while others believe that only 50% is ICD and 50% is ACD.<sup>24,25</sup> It can be difficult to distinguish between ICD and ACD, because even if an individual is sensitized to a component of the MWF, it is usually impossible to know how much the allergy was responsible for the reaction and how large a role the irritancy of the MWF played preceding, accompanying, or following the sensitization.<sup>23</sup>

ICD results from contact with a skin-damaging chemical substance. Common primary irritants associated with MWFs are its overall alkalinity, solvents, surfactants (emulsifiers or wetting agents),

biocides, and microtrauma from the metallic filings. Strong hand washing detergents used to clean the skin are also primary irritants.<sup>24</sup> The potential role of microbial enzymes and metabolites (potential contaminants of MWF) in ICD cases has not yet been addressed.

ACD results from individual sensitization to a sensitizing agent, an allergen. This sensitization allergic reaction develops in genetically susceptible persons and depends on the time and amount of exposure to the allergen. Once an individual becomes sensitized, exposure to even a small amount of the allergen can result in a reaction. Since allergic reactions are specific to each individual, not every person exposed will have a reaction, and those who do might react with different symptoms and varying degrees of severity. It is postulated that ICD can lead to ACD by damaging the skin and allowing sensitizers to penetrate.<sup>24</sup> Agents that can be sensitizers in MWFs are metals (chrome, cobalt, nickel), rubber accelerators, corrosion inhibitors, coupling agents, emulsifiers, fragrance additives, and biocides.<sup>24,25</sup> As with ICD, the potential role of microbial contamination of MWFs in ACD cases has not yet been addressed.

### **Evaluation of Oil Mists and Particulates, not otherwise classified**

The evaluation criteria for oil mists are primarily based on studies conducted with a petroleum-based, white mineral oil with no additives.<sup>26,27</sup> Mineral oils, as well as other lubricating or cutting oils, can contain a complex mixture of aromatic, naphthenic, and straight- or branched-chain paraffinic hydrocarbons. The composition of a given oil depends upon the way in which the oil was processed and the degree to which it was processed. Many mineral oils in use today vary in composition and can contain various additives and impurities.

Mineral oil mist is of low toxicity.<sup>28</sup> Inhalation of mineral oil mist in high concentrations may cause pulmonary effects, although this has rarely been reported. A single case of lipoid pneumonitis suspected to have been caused by exposure to very

high concentrations of oil mist was reported in 1950; this occurred in a cash register serviceman whose heavy exposure occurred over 17 years of employment.<sup>29</sup> Early epidemiological studies linked cancers of the skin and scrotum with exposure to mineral oils.<sup>30</sup> These effects have been attributed to contaminants such as polycyclic aromatic hydrocarbons (PAHs) and/or additives with carcinogenic properties. The International Agency for Research on Cancer (IARC) determined that there is sufficient evidence for carcinogenicity to humans, based on epidemiologic studies of uncharacterized mineral oils containing additives and impurities; there is inadequate evidence for carcinogenicity to humans for highly refined oils.<sup>31</sup> Prolonged exposure to mineral oil mist may also cause dermatitis. Persons with pre-existing skin disorders may be more susceptible to these effects.

Environmental evaluation criteria for mineral oil mist have been established by ACGIH and OSHA at 5 milligrams per cubic meter ( $\text{mg}/\text{m}^3$ ) of air as an 8-hour TWA. This concentration was selected to minimize respiratory irritation and pulmonary effects. The NIOSH REL for MWF is also  $0.5 \text{ mg}/\text{m}^3$ , with a STEL of  $10 \text{ mg}/\text{m}^3$ . However, since the role of additives and oil fume from partial heat-decomposition have yet to be completely evaluated experimentally, NIOSH suggests that these criteria may not be applicable to all forms of oil mists.<sup>26</sup>

Water-soluble MWFs cannot be analyzed using the oil mist sampling method. Thus, a total mass measurement is made, knowing that the water soluble oil portion of the sample collected must be less than the total mass. This measurement is the same one that is used for particulates not otherwise regulated (PNOR), a generic criterion established for airborne particulates that do not have an established occupational health exposure criterion. Formerly referred to as nuisance dust, the preferred terminology for the non-specific particulate NIOSH REL and OSHA PEL is now "*particulates, not otherwise regulated,*" or "*not otherwise classified (n.o.c.)*" for the ACGIH TLV. The NIOSH REL for total particulate, n.o.r., is  $10.0 \text{ mg}/\text{m}^3$ . The OSHA

PEL for total particulate, n.o.r., is 15.0 mg/m<sup>3</sup> and 5.0 mg/m<sup>3</sup> for the respirable fraction, determined as 8-hour averages. The ACGIH recommended TLV for exposure to a particulate, n.o.c., is 10.0 mg/m<sup>3</sup> (total dust, 8-hour TWA). These are generic criteria for airborne dusts which do not produce significant organic disease or toxic effect when exposures are kept under reasonable control.<sup>32</sup> These criteria are not appropriate for aerosols that have a biologic effect and may not be appropriate for evaluating MWFs. At this time, there is no generic occupational exposure standard or guideline for MWFs, but NIOSH has a proposed REL for MWFs of 0.5 mg/m<sup>3</sup>.<sup>33</sup>

## Isocyanates

The unique feature common to all diisocyanates is that they consist of two -N=C=O (isocyanate) functional groups attached to an aromatic or aliphatic parent compound. Because of the highly unsaturated nature of the isocyanate functional group, the diisocyanates readily react with compounds containing active hydrogen atoms (nucleophiles). Thus, the diisocyanates readily react with water (humidity), alcohols, amines, etc.; the diisocyanates also react with themselves to form either dimers or trimers. When a diisocyanate species reacts with a primary, secondary, or tertiary alcohol, a carbamate (-NHCOO-) group is formed which is commonly referred to as a urethane. Reactions involving a diisocyanate species and a polyol result in the formation of cross-linked polymers; i.e. polyurethanes. Hence, they are used in surface coatings, polyurethane foams, adhesives, resins, elastomers, binders, and sealants. Many material safety data sheets (MSDS) use isocyanate-related terms interchangeably. For the purpose of this report, terms are defined as follows.

**Diisocyanates (Monomers):** The difunctional isocyanate species from which polyisocyanates and polyurethanes are derived. Common examples of monomeric isocyanates include 1,6-hexamethylene diisocyanate (HDI), 2,4-and/or 2,6-toluene diisocyanate (TDI),

4,4'-diphenylmethane diisocyanate (MDI), methylene bis(4-cyclohexylisocyanate (HMDI), isophorone diisocyanate (IPDI), and 1,5-naphthalene diisocyanate (NDI). Commercial-grade TDI is an 80:20 mixture of the 2,4- and 2,6- isomers of TDI, respectively.

**Polyisocyanates:** Species possessing free isocyanate groups and derived from monomeric isocyanates either by directly linking these monomeric units (a homopolymer) or by reacting these monomers with di- or polyfunctional alcohols or amines (a copolymer).

**Prepolymers:** Species possessing free isocyanate groups, prepared from the reaction of a polyol with an excess of di- or polyisocyanate<sup>34</sup>. Commercially available isocyanate products frequently contain prepolymers in lieu of more volatile isocyanate monomers.

**Oligomeric Isocyanates (Oligomers):** Relatively low molecular weight polyisocyanates.

**Intermediates:** Species possessing free isocyanate groups, formed during use of an isocyanate product by partial reaction of the isocyanate species with a polyol.

In general, the types of exposures encountered during the use of isocyanates (i.e., monomers, prepolymers, polyisocyanates, and oligomers) in the workplace are related to the vapor pressures of the individual compounds. The lower molecular weight isocyanates tend to volatilize at room temperature, creating a vapor inhalation hazard. Conversely, the higher molecular weight isocyanates do not readily volatilize at ambient temperatures, but are still an inhalation hazard if aerosolized or heated in the work environment. The latter is important since many reactions involving isocyanates are exothermic in nature, thus providing the heat for volatilization. To



reduce the vapor hazards associated with the lower molecular weight diisocyanates, prepolymer and polyisocyanate forms of these diisocyanates were developed and have replaced the monomers in many product formulations. An example is the biuret of HDI, which consists of three molecules of HDI monomer joined together to form a higher molecular weight oligomer having similar characteristics to those found in the monomer. Also, many MDI product formulations consist of a combination of MDI monomer and a MDI-based polyisocyanate (such as polymethylene polyphenyl isocyanate). Many prepolymer and polyisocyanate formulations contain a small fraction (usually less than 1%) of unreacted monomer.

Isocyanates exist in many different physical forms in the workplace. Not only are workers potentially exposed to the unreacted monomer, prepolymer, polyisocyanate, and/or oligomer species found in a given product formulation, they can also be exposed to partially reacted isocyanate-containing intermediates formed during polyurethane production. In addition, isocyanate-containing mixtures of vapors and aerosols can be generated during the thermal degradation of polyurethane coatings and plastics. The capability to measure all isocyanate-containing substances in air, whether they are in monomer, prepolymer, polyisocyanate, oligomer, and/or intermediate forms, is important when assessing a worker's total airborne isocyanate exposure.

## Review of Health Effects Associated with Isocyanates

Exposure to isocyanates is irritating to the skin, mucous membranes, eyes, and respiratory tract.<sup>35,36</sup> 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).<sup>38,37,38</sup> Contact dermatitis can result in symptoms such as rash, itching, hives, and swelling of the extremities.<sup>37,40</sup> A worker suspected of having isocyanate-induced asthma/sensitization will exhibit the traditional symptoms of acute airway

obstruction, e.g., coughing, wheezing, shortness of breath, tightness in the chest, and nocturnal awakening.<sup>37,38</sup> An isocyanate-exposed worker may first develop an asthmatic condition (i.e., become sensitized) after a single (acute) exposure, but sensitization usually takes a few months to several years of exposure.<sup>17,37,39,39,40</sup> The asthmatic reaction may occur minutes after exposure (immediate), several hours after exposure (late), or a combination of both immediate and late components after exposure (dual).<sup>39,42</sup> The late asthmatic reaction is the most common, occurring in approximately 40% of isocyanate sensitized workers.<sup>41</sup> After sensitization, any exposure, even to levels below an occupational exposure limit or standard, can produce an asthmatic response which may be life threatening. Experience with isocyanates has shown that monomeric, prepolymeric and polyisocyanate species are capable of producing respiratory sensitization in exposed workers.<sup>42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58</sup> Since the intermediates may be chemically similar to these compounds, it is reasonable to assume that they may also produce this condition. Prevalence estimates for isocyanate-induced asthma in exposed worker populations vary considerably: from 5% to 10% in diisocyanate production facilities<sup>59</sup> to 25% in polyurethane production plants<sup>62,60</sup> and 30% in polyurethane seatcover operations<sup>61</sup>. The scientific literature contains a limited amount of animal data suggesting that dermal exposure to diisocyanates may produce respiratory sensitization.<sup>62,63,64,65</sup> This finding has not been tested in dermally exposed workers.

Hypersensitivity pneumonitis (HP) also has been described in workers exposed to isocyanates.<sup>66,67,68,69</sup> Currently, the prevalence of isocyanate-induced HP in the worker population is unknown, and is considered to be rare when compared to the prevalence rates for isocyanate-induced asthma.<sup>40</sup> Whereas asthma is an obstructive respiratory disease usually affecting the bronchi, HP is a restrictive respiratory disease affecting the lung parenchyma (bronchioles and alveoli). The initial symptoms associated with isocyanate-induced HP are flu-like, including shortness of breath, non-productive cough, fever, chills, sweats, malaise, and nausea.<sup>39,40</sup> After

the onset of HP, prolonged and/or repeated exposures may lead to an irreversible decline in pulmonary function and lung compliance, and to the development of diffuse interstitial fibrosis.<sup>39,40</sup> Early diagnosis is difficult since many aspects of HP, i.e., the flu-like symptoms and the changes in pulmonary function, are manifestations common to many other respiratory diseases and conditions.

A limited number of animal studies have demonstrated that commercial-grade TDI is carcinogenic in both rats and mice.<sup>70</sup> Statistically significant excesses of liver and pancreatic tumors were observed in male and female rats and female mice that received TDI by gavage (route of exposure via the digestive tract). In addition, a statistically non-significant excess in rare brain tumors were observed in male rats also treated with TDI by gavage. Also, commercial-grade TDI was found to have a dose-dependent mutagenic effect on two strains of *Salmonella typhimurium* in the presence of a metabolic activator (S-9 liver fractions from rats or hamsters treated with Aroclor 254).<sup>71</sup> Based on these animal and in vitro studies, NIOSH investigators concluded that sufficient evidence exists to classify TDI as a potential occupational carcinogen<sup>72</sup>. It is important to note that no epidemiologic data exists linking TDI exposure to elevated cancer rates in exposed workers.

The only effective intervention for workers with isocyanate-induced sensitization (asthma) or HP is cessation of all isocyanate exposure. This can be accomplished by removing the worker from the work environment where isocyanate exposure occurs, or by providing the worker with supplied-air respiratory protection and preventing any dermal exposures.

## Evaluation Criteria for Isocyanate Exposures

The ACGIH TLV for TDI is an 8-hour TWA exposure concentration of 36  $\mu\text{g}/\text{m}^3$ .<sup>4</sup> As previously discussed, NIOSH considers TDI to be a potential

workplace carcinogen, and recommends that exposures be reduced to the lowest feasible concentration.<sup>74</sup> The NIOSH REL and ACGIH TLV for MDI are 50  $\mu\text{g}/\text{m}^3$  (for up to a 10-hour TWA exposure concentration) and 51  $\mu\text{g}/\text{m}^3$  (8-hour TWA exposure concentration), respectively.<sup>3,4</sup> OSHA does not have an 8-hr PEL for either TDI or MDI.<sup>5</sup>

NIOSH, OSHA, and ACGIH have exposure criteria for the evaluation of short-term or transient exposures to diisocyanates.<sup>3,5</sup> The ACGIH has a short-term exposure limit (STEL) for TDI of 140  $\mu\text{g}/\text{m}^3$ , and OSHA has a TDI ceiling limit of 140  $\mu\text{g}/\text{m}^3$ . Both NIOSH and OSHA have ceiling limits for MDI of 200  $\mu\text{g}/\text{m}^3$ . The NIOSH ceiling limit (based on a 10-minute TWA) and the ACGIH STEL (based on a 15-minute TWA) are limits that should not be exceeded during the work-day. The OSHA ceiling limit is a concentration that should never be exceeded during a workday.

Currently, there are no U.S. standards for TDI- and MDI-based oligomers (including prepolymers, polyisocyanates, and intermediates). The United Kingdom's Health and Safety Executive (UK-HSE) has taken a different approach, i.e., developed a non-specific standard based on the TRIGs in a volume of air<sup>73</sup>. The UK-HSE standards for TRIGs in air are an 8-hour, TWA exposure of 20 micrograms of isocyanate groups per cubic meter of air ( $\mu\text{g-NCO}/\text{m}^3$ ), and a ceiling limit of 70  $\mu\text{g-NCO}/\text{m}^3$ . The method for determining the TRIG concentrations using air sampling techniques is described in the section titled "Methods."

## Solvents

### Toluene

Toluene is a colorless, aromatic organic liquid containing a six carbon ring (a benzene ring) with a methyl group (CH<sub>3</sub>) substitution. It is a typical solvent found in paints and other coatings, and used as a raw material in the synthesis of organic chemicals, dyes, detergents, and pharmaceuticals. It is also an ingredient of gasoline, ranging from 5% to 22%.<sup>74,75</sup> A previous NIOSH evaluation found toluene content of gasoline ranging from 2.4% to 12%, with exposure levels from none detected to 0.56 ppm.<sup>76</sup>

Inhalation and skin absorption are the major occupational routes of entry. 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.<sup>77,78</sup>

The main effects reported with excessive (inhalation) exposure to toluene are CNS depression and neurotoxicity.<sup>38</sup> 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).<sup>79,80,81</sup> No symptoms were noted below 100 ppm in these studies. There are a number of reports of neurological damage due to deliberate sniffing of toluene-based glues resulting in motor weakness, intention tremor, ataxia, as well as cerebellar and cerebral atrophy.<sup>82</sup> Recovery is complete following infrequent episodes, however, permanent impairment may occur after repeated and prolonged glue-sniffing abuse. Exposure to extremely high concentrations of toluene may cause mental confusion, loss of coordination, and unconsciousness.<sup>83,84</sup>

Originally, there was a concern that toluene exposures produced hematopoietic 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 toxicity.<sup>39,85</sup>

The NIOSH REL for toluene is 100 ppm for an 8-hour TWA. NIOSH has also established a recommended STEL of 150 ppm for a 15-minute sampling period. The OSHA PEL for toluene is 200 ppm for an 8-hour TWA. The recently adopted ACGIH TLV is 50 ppm for an 8-hour exposure level. This ACGIH TLV carries a skin notation, indicating that cutaneous exposure contributes to the overall absorbed inhalation dose and potential systemic effects.

### Xylene

Xylene is a colorless, flammable organic liquid with a molecular structure consisting of a benzene ring with two hydroxyl (OH) substitutions. Xylene is used in paints and other coatings, as a raw material in the synthesis of organic chemicals, dyes, and pharmaceuticals, and it is an ingredient of gasoline and many petroleum solvents.<sup>46</sup>

The vapor of xylene has irritant effects on the skin and mucous membranes, including the eyes and respiratory tract. This irritation may cause itching, redness, inflammation, and discomfort. Repeated or prolonged skin contact may cause erythema, drying, and defatting which may lead to the formation of vesicles. At high concentrations, repeated exposure to xylene may cause reversible damage to the eyes.<sup>38</sup>

Acute xylene inhalation exposure may cause headache, dizziness, incoordination, drowsiness, and unconsciousness.<sup>86</sup> Previous studies have shown that concentrations from 60 to 350 ppm may cause giddiness, anorexia, and vomiting.<sup>38</sup> At high concentrations, exposure to xylene has a narcotic effect on the CNS, and minor reversible effects on the liver and kidneys.<sup>38,87</sup>

Historical accounts of hematopoietic toxicity as a result of xylene exposure are likely due to the high

concentration of benzene contamination in xylene prior to 1940.<sup>47,88</sup> These effects previously reported are no longer associated with contemporary xylene exposure.<sup>47,49</sup>

The current OSHA PEL, NIOSH REL, and ACGIH TLV for xylene are 100 ppm over an 8-hour TWA. In addition, OSHA and NIOSH have published STELs for xylene of 150 ppm averaged over 15 minutes.

## Formaldehyde

Formaldehyde is a colorless gas with a strong odor. Exposure can occur through inhalation and skin absorption. The acute effects associated with formaldehyde are irritation of the eyes and respiratory tract and sensitization of the skin. The first symptoms associated with formaldehyde exposure, at concentrations ranging from 0.1 to 5 parts per million (ppm), are burning of the eyes, tearing, and general irritation of the upper respiratory tract. There is variation among individuals, in terms of their tolerance and susceptibility to acute exposures of the compound.<sup>89</sup>

In two separate studies, formaldehyde has induced a rare form of nasal cancer in rodents. Formaldehyde exposure has been identified as a possible causative factor in cancer of the upper respiratory tract in a proportionate mortality study of workers in the garment industry.<sup>90</sup> NIOSH has identified formaldehyde as a suspected human carcinogen and recommends that exposures be reduced to the lowest feasible concentration. The OSHA PEL is 0.75 ppm as an 8-hour TWA and 2 ppm as a STEL.<sup>91</sup> ACGIH has designated formaldehyde to be a suspected human carcinogen and therefore, recommends that worker exposure by all routes should be carefully controlled to levels "as low as reasonably achievable" below the TLV.<sup>3</sup> ACGIH has established a ceiling limit of 0.3 ppm.

*Note: NIOSH testimony to DOL on May 5, 1986, stated the following: "Since NIOSH is not aware of any data that describe a safe exposure concentration to a carcinogen NIOSH recommends*

*that occupational exposure to formaldehyde be controlled to the lowest feasible concentration; 0.1 ppm in air by collection of an air sample for any 15-minute period as described in NIOSH analytical method 3500 which is the lowest reliably quantifiable concentration at the present time." NIOSH also lists a PEL for formaldehyde of 0.016 ppm for up to a 10-hour TWA exposure (again using NIOSH analytical method 3500 and indicating that this is the lowest reliably quantifiable concentration at the present time. Investigators should be aware that formaldehyde levels can currently be measured below 0.016 ppm. It may be appropriate to refrain from using numerical limits and instead state that concentrations should be the lowest feasible (in some situations, this may be limited by the ambient background concentration).*

## Propylene Glycol Monomethyl Ether (PGME)

PGME is a colorless liquid with a sweet ether-like odor. It is a common solvent used in coatings, cellulose, dyes, inks, and stains. PGME has a fairly low systemic toxicity but the odor is found to be objectionable at higher concentrations (causing nausea) and it causes severe eye and skin irritation. Possible chronic effects include liver and kidney damage.<sup>83</sup> Both NIOSH and ACGIH have recommended exposure limits of 100 ppm as a TWA and 150 ppm as a STEL.<sup>3,4</sup> OSHA currently does not have a standard for PGME.

## Lead

Lead is ubiquitous in U.S. urban environments due to the widespread use of lead compounds in industry, gasoline, and paints during the past century. Exposure to lead occurs via inhalation of dust and fume, and ingestion through contact with lead-contaminated hands, food, cigarettes, and clothing. Absorbed lead accumulates in the body in the soft tissues and bones. Lead is stored in bones for decades, and may cause health effects long after exposure as it is slowly released in the body.

Symptoms of lead exposure include weakness, excessive tiredness, irritability, constipation, anorexia, abdominal discomfort (colic), fine tremors, and "wrist drop."<sup>92,93,38</sup> Overexposure to lead may also result in damage to the kidneys, anemia, high blood pressure, infertility and reduced sex drive in both sexes, and impotence. An individual's blood lead level (BLL) is a good indication of recent exposure to, and current absorption of lead.<sup>94</sup> The frequency and severity of symptoms associated with lead exposure generally increase with the BLL.

Under the OSHA general industry lead standard (29 CFR 1910.1025), the PEL for airborne exposure to lead is 50  $\mu\text{g}/\text{m}^3$  (8-hour TWA).<sup>95</sup> The standard requires lowering the PEL for shifts exceeding 8 hours, medical monitoring for employees exposed to airborne lead at or above the action level of 30  $\mu\text{g}/\text{m}^3$  (8-hour TWA), medical removal of employees whose average BLL is 50  $\mu\text{g}/\text{dL}$  or greater, and economic protection for medically removed workers. Medically removed workers cannot return to jobs involving lead exposure until their BLL is below 40  $\mu\text{g}/\text{dL}$ . The OSHA interim final rule for lead in the construction industry (29 CFR 1926.62) provides an equivalent level of protection to construction workers. ACGIH has proposed a TLV for lead of 50  $\mu\text{g}/\text{m}^3$  (8-hour TWA), with worker BLLs to be controlled to at or below 20  $\mu\text{g}/\text{dL}$ , and designation of lead as an animal carcinogen.<sup>3</sup>

## Ammonia

Ammonia is a severe irritant of the eyes, respiratory tract and skin. It may cause coughing, burning, and tearing of the eyes; runny nose; chest pain; cessation of respiration; and death. Symptoms may be delayed in onset. Exposure of the eyes to high gas concentrations may produce temporary blindness and severe eye damage. Exposure of the skin to high concentrations of the gas may cause burning and blistering. Repeated exposure to ammonia gas may cause chronic irritation of the eyes and upper respiratory tract.<sup>38,96</sup> The NIOSH REL for ammonia is 25 ppm for a 10-hour TWA. The NIOSH STEL for ammonia is 35 ppm. ACGIH has set limits of 25 ppm or as an 8-hour TWA and a STEL of 35 ppm. The OSHA PEL for ammonia is 50 ppm for an 8-hour TWA.

## Inorganic Acids: Hydrochloric, Nitric, Sulfuric, and Phosphoric Acids

Inorganic acids are primary irritants and are corrosive in high concentrations. Inorganic acids will cause chemical burns when in contact with the skin and mucous membranes, and are a particular hazard if contact with the eye should occur.<sup>97</sup> Vapors and mists are respiratory tract irritants. Discoloration or erosion of the teeth may also occur in exposed workers. Ingestion of inorganic acids will result in severe throat and stomach destruction. The following table lists the inorganic acids evaluated, and their corresponding health effects.

Chemical	NIOSH REL	Principle Health Effects <sup>98,99</sup>
Hydrochloric acid	5 ppm (Ceiling)	Corrosive to skin, eyes and mucous membranes, respiratory tract irritant.
Nitric acid	2 ppm (TWA) 4 ppm (STEL)	Corrosive to skin and other tissue, pneumonitis, pulmonary edema. May liberate gaseous oxides of nitrogen
Phosphoric acid	1 mg/m <sup>3</sup> (TWA) 3 mg/m <sup>3</sup> (STEL)	Eye, respiratory tract, skin irritant. Concentrated solutions can cause severe burns.
Hydrofluoric acid	3 ppm (TWA) 6 ppm (STEL)	Severe and painful burns on contact. Inhalation may result in delayed pulmonary edema.
Sulfuric acid	1 mg/m <sup>3</sup> (TWA)	Corrosive to skin and other tissue, respiratory irritation and dental erosion. Potential human carcinogen.

As with the other inorganic acids, skin contact with concentrated HF will result in marked tissue destruction. However, undissociated HF will readily penetrate skin and deep tissue where the corrosive fluoride ion can cause necrosis of soft tissues and decalcification of bone, resulting in excruciating pain.<sup>38</sup> Due to this property, contact with dilute solutions, or minor exposures, can result in delayed reactions which eventually turn out to be severe burns. This process of tissue destruction and HF neutralization, unlike other acids, is prolonged for days.<sup>38</sup>

## RESULTS

### Noise

During the survey period, use of hearing protection devices (HPDs) was observed in many areas of the facility. Boxes of ear plugs (Howard Leight MAX<sup>®</sup> and Howard Leight MAX Lites<sup>®</sup>) were seen on tables and benches in different departments. Also, ear muffs were used in the paint booth in the training building. Use of ear plugs varied from proper insertion with the plug completely in the ear canal to improper fit where a large portion of the plug was outside the ear canal. The condition of the ear muffs also varied from “acceptable,” to situations where cushions and bands needed replacement.

Most of the personal noise samples were collected on the first survey day. Based on these data, it was determined that the noise exposures were not excessive and that a second day of retesting the entire facility was not warranted. Instead, areas that had a potential for high levels of noise, the Sheet Metal Area, and the Drilling and Routing Department (not tested on the first day because of computer problems that reduced production) were selected for personal sampling on the second day of the survey.

The dosimeters collect data such that both the 5-dB and 3-dB exchange rates are calculated for the same noise exposures and they report both values. Thus, all of the relevant noise evaluation criteria can be compared with the same data samples. The dosimeter results are summarized in Table 1. Fourteen samples were collected on the two survey days, 10 on the first day and 4 on the second day. A microphone became disconnected on day two for approximately three hours on a worker in the Sheet Metal area so that this sample was removed from further analysis. Nearly all of the employees who wore dosimeters reported that the sampling day was typical with no excessive noisy or quiet periods.

Inspection of the L<sub>avg</sub> data (5-dB exchange rate) in the table reveals that none of the surveyed jobs has a noise exposure greater than the OSHA action level of 85 dB(A). Even if the average noise data is extrapolated to extended shifts of 9 or 10 hours, the

percent dose values are less than 50%. In all but one instance, the powder paint area, the doses are much less than the OSHA action level. When the 3-dB exchange rate data ( $L_{eq}$ ) are examined, the NIOSH REL is sometimes exceeded. Specifically, the employee working in the tumbler area of Department 595, the Heat Treat Department worker, and the powder paint employee have noise doses that exceed 100%. The excessive exposures were measured for all three shift lengths in the tumbler and powder paint areas, but only for the extended shifts in the Heat Treat Department.

The dosimeter placed on the powder paint employee had the microphone cord come unattached for a short period of the sample. Thus, 83 minutes of sampling time had an erroneously low noise level that decreased the  $L_{avg}$  value. The actual noise exposure was very likely higher than reported, and may have exceeded the OSHA action level. The real-time plot of the exposure levels for this employee are shown in Figure 1. The graph shows that for the morning period, many noise levels are at or above 85 dB(A). When the individual data points are analyzed, 37% (124 of 339 minutes) of the noise values are greater than 85 dB(A).

One of the highest continuous noise exposures measured at Woodward Governor Company was a router mounted on a table in an enclosed corner of the Drill and Router Department. The personal dosimeter data show a seven minute period where the exposures were 97 dB(A) while the employee routed the edges of circuit boards in the enclosed area (Figure 2). The employee did wear ear muffs during the operation. A comparison of the noise levels for the employee who used the router with the other Drill and Router Department employee who was wearing a dosimeter shows that the enclosure reduced exposures from 97 to 77 dB(A).

During the survey period, other noise events were noticed by the NIOSH investigators. In the Circuit Board Plating Department, the two automated dip lines have warning signals to alert the employee that circuit boards need to be removed from or placed on the line. The line on the north side of the room uses

a buzzer, while the other line uses a shrill tone to signal the worker. This latter signal was very annoying to the NIOSH investigator, a feeling reiterated by the employee working in the room. However, the employee also noted that the signals were necessary to complete the work and that he needed to be alerted to each line separately, meaning that the signals have to be distinguishable from each other. Another area in the facility where a particular noise event occurred was in Sheet Metal Fabrication. The material-holding tables and bins are made of metal. When employees return unused material to storage, a metal-to-metal contact is made which results in a loud banging sound.

## Metal working Fluids

The personal breathing zone (PBZ) total particulate air sampling results are displayed in Table 2. Although the general machining area did not have any visible MWF mist in the air, two operators had PBZ exposures higher than the proposed NIOSH REL of  $0.5 \text{ mg/m}^3$ . One of these was the operator of machine 425, angular grinding. The high exposure was not surprising since this machine was old and has no enclosures. The other high exposure was to the operator of machine 440, process drawing. This machine was totally enclosed and this high exposure was not expected. It could be a result of the operator opening the access door while the machining process was running, or from residual aerosol in the machine that escaped when the access door was opened. If the first case is found to be true, then the operator should modify the work practices. If the second case is found to be true, then local exhaust ventilation should be added to this machine.

During the afternoon, general area (GA) air samples were collected using a GRIMM at the six MWF machines where a PBZ was being collected. These results are displayed in Table 3 and Figure 3. The real-time monitoring results cannot be directly compared with the PBZ samples because they were only collected over a 10-minute period and because the GRIMM measures the particle mass indirectly using the refractive index of the particle. Since the particles are water-based, the filter sampling will

loose much of the particle mass due to evaporation, and therefore would be expected to be somewhat lower than the measurements collected using the GRIMM. These GRIMM measurements were useful for providing some direct feed-back about particulate concentrations on the day of the sampling, and also for providing some information about the distribution of particle size (Figure 3). Not enough sampling data were collected to make any statistically significant conclusions about particle size, but the data suggest that much of the exposure is in the respirable range.

## Solvents

The results of air samples for toluene and xylene are summarized in Table 4. The sample from the silk screening area was very low (0.01-0.2 ppm) and documents the positive effect of replacing the old toluene-based screen cleaner with the citrus-based cleaner. It was thought that the toluene levels in the Conformal Coating area would be high, but they were found to be 1/5 to 1/10th the concentration of recommended exposure criteria. Air samples from the Mechanical Assembly area where workers complained of solvent odors, contained very little toluene or xylene. However, a large peak of an unknown chemical was noted during analysis. This unknown peak was probably related to one of the other solvents used in the adhesive.

Two air samples were collected for propylene glycol monomethyl ether (PGME), in the Photo Processor room and one in the office of the person who operates the Photo Processor. Both of these samples were low, the processor concentration being 0.42 mg/m<sup>3</sup> and the office sample being 0.36 mg/m<sup>3</sup> (OSHA PEL and NIOSH REL are 360 mg/m<sup>3</sup> for a TWA).

Four air samples were collected for formaldehyde in the Plating Room: two were personal samples on the Plating Room Operators (one while the worker added fresh formaldehyde solution), and two were area samples collected directly above and between tanks #22 and #23. All samples were below the limit of detection for the analytical method (0.4 micrograms/sample). With the sample volumes

collected in this study, the effective detection limit for formaldehyde is <0.1 ppm.

## Lead, Ammonia, and Inorganic Acids

The sample results for airborne lead are summarized in Table 5. All samples are below the OSHA PEL of 50 µg/m<sup>3</sup>. The samples collected early in the morning during dress cleaning of the wave solder machine averaged 28.3 µg/m<sup>3</sup> on the worker conducting the cleaning and 15.1 µg/m<sup>3</sup> for the helper. These levels are at or near the OSHA action limit for lead (25 µg/m<sup>3</sup>), but the exposures lasted for only 10-15 minutes. Both workers wore respirators and gloves during this job.

The air samples for ammonia are summarized in Table 6. All these samples, both area and personal, were well below the OSHA and NIOSH criteria of 25 ppm. This included a short-term sample on a worker involved in cleaning the Chem Cat (Ultra Etch). This worker's short-term exposure was only 1.5 ppm, well below the recommended STEL of 35 ppm.

Air samples collected for inorganic acids throughout the Plating Area are summarized in Table 7. All these samples are at or near the detection limit for the analytical method and as such are well below the OSHA/NIOSH criteria.

## Carbon Monoxide

Carbon monoxide (CO) was monitored throughout the main building area and also throughout the Multipurpose Building and the Pilot Building (particularly the Boiler Room). In all but one area, only trace levels of 1-2 ppm were found (OSHA PEL is 50 ppm as a TWA, NIOSH REL is 35 ppm as a TWA). In the Heat Treating Room where numerous gas-fired burners operate, levels of 8-14 ppm were found. There are open flame burners in this area which contributed the most to the CO concentrations. When product exited from a heat treating machine, brief pulses of CO in the 15-20 ppm range were



measured. It is unknown if conditions in the winter vary with the amount of exhausted air in the general area, but it would be wise to measure again at that time. Complaints had been received by maintenance workers about the conditions above the ceiling (under the roof) directly above the heat treating machine. There is a catwalk in this space which passes directly above the heat treating machines. The temperature was quite warm in this area and the CO concentrations ranged from 15-20 ppm, which are below any of the exposure criteria. Again, it would be advisable to measure the concentrations during the winter period to determine if conditions vary.

## Isocyanates

The data from the TDI monomer and oligomer air sampling are presented in Table 8. During the NIOSH air sampling, a single worker conducted two painting sessions. A large hydraulic unit was spray painted during the first session, and 4 metal panels were painted during the second session. The airborne concentrations measured within the spray paint booth ranged from 5.1 to 9.6  $\mu\text{g}/\text{m}^3$  for 2,4-TDI monomer, and 7.4 to 17.9  $\mu\text{g-NCO}/\text{m}^3$  for TRIGs. No 2,6-TDI was detected in any of the air samples. In addition, an air sample collected outside the paint booth did not detect any TDI monomers or oligomers. Considering this, the TRIG concentration was not calculated for this air sample. These data indicate that area isocyanate levels within the paint booth are low, especially when compared to the ACGIH TLV for TDI and the UK-HSE standard for TRIGs. The low levels measured within the booth, coupled with the fact that TDI or TRIGs were not detected in the sample collected outside of the booth, indicate that the booth is effectively containing the isocyanate-containing compounds. The worker performing the spray painting wears a full-face, supplied-air respirator, and did receive annual respirator training and fit testing. This, combined with the booth, are effective in protecting the painters from hazardous inhalation exposures to isocyanate-containing substances. The NIOSH investigator did observe that the worker had

uncovered arms, which increases the likelihood of dermal isocyanate exposures.

Table 9 contains the data from the MDI monomer and oligomer air sampling conducted during the foam packaging operation. A total of 12 units were packaged during the NIOSH air sampling. MDI monomer was not detected in any of the area air samples, and the MDI oligomer samples ranged from none detected to 15.5  $\mu\text{g}/\text{m}^3$ . In fact, only 1 of the 6 area air samples did not detect any MDI oligomer; the other 5 area air samples had MDI oligomer concentrations ranging from 13.4 to 15.5  $\mu\text{g}/\text{m}^3$ . In Table 9, most of the TRIG measurements are preceded by a “less than” (<) sign. Since no MDI monomer was detected in these air samples, the MDC was used in the TRIG calculation. Thus, the TRIG calculation represents the maximum TRIG concentration that could be measured during this survey, and the actual TRIG concentration may be lower than that shown in Table 9. The TRIG concentrations were all below 9.8  $\mu\text{g-NCO}/\text{m}^3$ . The area air samples probably provide a reasonable estimate of the worker’s exposures when applying the foam; the worker is stationary during this task and the air sampling devices were near the worker. Thus, the worker is probably exposed to trace levels of MDI monomer, and low levels of MDI oligomer and TRIG when performing this task.

## DISCUSSION AND CONCLUSIONS

### Noise

During the surveyed period, the noise exposures did not exceed the OSHA PEL or action level for up to a 10-hour work shift. However, three jobs did exceed the NIOSH REL for noise; two of them for 8-hour shifts or longer and one for a 9-hour shift or longer. Thus, there are potentially hazardous noise exposures in a few areas of the Woodward Governor Company. Employees who work in these areas need to wear HPDs until the noise sources are identified and the noise reduced through engineering controls.

Also, the length of time the employees spend in the area can be reduced as an administrative control to the noise.

The NIOSH evaluation is limited in scope. Only a one day noise survey was conducted in the noisier areas of the facility. Before hearing conservation programs are reduced or eliminated, the company needs to conduct further noise monitoring to verify these findings. Additional noise dosimetry should be done on employees who are at or above the evaluation criteria which were identified in the NIOSH evaluation. If the dosimetry confirms that most of the exposures are below the criteria, then a complete noise mapping of the manufacturing area should be undertaken. The noise map, which is a profile of the noise levels in and around each machine and in each department, will provide the relevant data needed to compare future noise levels if work processes or plant layout change. It also documents the occupational noise exposures to which employees could be subjected.

Many employees were wearing HPDs in the work area, but not wearing the devices correctly or were using ear muffs that were in need of maintenance or repair. Also, the noise reduction rating (NRR) of the ear plugs range from 30-33 dB. These are large NRR values, representing some of the highest achievable levels of protection, if they are worn correctly. The measured noise levels in the manufacturing area do not warrant the use of the maximum achievable protection available. For employees who do wear HPDs in their occupation, annual monitoring of their hearing is recommended by NIOSH.<sup>9</sup> Woodward Governor Company currently follows this practice and it should be continued.

## Solvents

None of the solvent exposures measured approached any of the exposure criteria. A strong solvent odor was noticed in the Mechanical Assembly area where workers applied an adhesive to various parts. A solvent peak was noticed from the air samples collected in this area (not toluene or xylene). The

chemical was not able to be identified. The lab hoods used in this area were not working well. Hood #3643 had an average face velocity of 17 feet per minute (fpm) and hood #6644 had an average of 32 fpm. These hoods should be operating in the range of 100-150 fpm. The optimal sash height was not marked on these hoods and workers tended to keep the sashes open fully.

Solvent odors in the Conformal Coating room were noticeable and it was thought the exposures might be significant. However, the levels were well below the exposure criteria. The touch-up booth in this area was not working well and smoke tests showed that the airflow pattern was up into the worker's breathing zone before being exhausted. Improved containment and higher exhaust volumes should correct the airflow problems in the booth.

Airborne formaldehyde concentrations in the Plating Room were quite low, during normal operations directly above the baths and during the addition of fresh formaldehyde solution. PGME air concentrations in the Photo Processor Room and in the Operator's office were quite low, on the order of about 1/1000 the exposure criteria.

## Lead, Ammonia, and Inorganic Acids

The only measurable airborne concentrations of lead (28.3 and 15.1  $\mu\text{g}/\text{m}^3$ ) were found during the dross cleaning on the wave solder machine in Electrical Assembly. Although the concentrations were below the OSHA TWA PEL, it is recommended that workers conducting this cleaning continue to wear respirators. It is likely the exposure will vary from time to time, depending on the work practices of the individuals. Therefore, it would be safer to continue the use of respirators to insure worker protection.

The airborne concentrations of lead above the solder pot in the Electrical Assembly area were very low. However this was a simulated test with the pot at normal temperature and the local exhaust system operating. No one was using the pot so there was no

disturbance of the lead vapors. Workers reported that they do not always turn on the local exhaust system. This would significantly change the potential for lead fume exposure.

Lead contamination was readily apparent around the solder pot, on the table near the wave solder machine where the dross cleaning was conducted, around individuals who were doing hand soldering of the circuit boards, and in the Mechanical Assembly area where the lead hammers were used. Employees handling lead need to be trained on the proper cleaning of contaminated surfaces. Water alone does not fully clean surfaces of lead contamination since lead is not soluble in water. A mild solution of sodium phosphate will help remove the lead on surfaces. Employees were also observed eating and drinking in these contaminated areas. Because lead dust can easily contaminate food and beverages, eating and drinking should be restricted in any areas where lead is used. This includes the wave solder area, in Electrical Assembly, and where the lead hammers are used.

Ammonia exposures were all well below the various evaluation criteria, including samples collected on a worker during the cleaning of the Ultra Etch machine in the Plating area. While the ammonia odor was quite noticeable during the cleaning, the exposures were about 1/30th the STEL. The worker used a household type vacuum to clean the blue powder out of the Ultra Etch machine. This fine powder was then exiting out the exhaust of the vacuum. Although the worker was not near the vacuum exhaust, the fine dust was very irritating. A more efficient vacuum, with a HEPA filter, is recommended for this job. Other ammonia concentrations throughout the Plating Line remained low, including samples collected directly above the ammonia tank in the Plating Line.

All the air samples for nitric and sulfuric acid were low, all but one below the limit of detection (1 µg/sample) for the analytical method. This included samples collected in the Water Treatment area below the Plating Line when a source of local exhaust ventilation was turned off. The Water

Treatment Operator wanted to redirect a small amount of the exhaust ventilation in the Water Treatment area but wanted to insure that airborne levels of ammonia and acids did not rise as a result of this loss of ventilation. The amount of ventilation was quite small relative to the space and had no impact on the already low concentrations of both ammonia and acids.

## Isocyanates

Although MDI monomer and oligomer concentrations were low, the design of the local exhaust system for the packaging area could use some improvement. During the sampling, airflow measurements were obtained from the local exhaust ventilation system for the foam packaging station. As shown in Figure 4, the plenum at the workstation was divided into 9 equal sections, and a centerline air velocity measurement was taken at each section. These measurements were used to calculate an average linear velocity for the hood of 900 feet per minute (fpm), and a volumetric flowrate of 5820 cubic feet per minute.

The following equation<sup>100</sup> is used to design a local exhaust ventilation system to effectively capture contaminants and remove them from the worker's breathing zone:

$$Q = V(10X^2 + A)$$

where:

Q = volumetric flowrate in cfm

V = airflow velocity in fpm at distance X from the hood, or the minimum hood-induced air velocity necessary to capture and convey a contaminant into the hood.

X = straight-line distance in feet from center of hood to the contaminant source

A = area of hood opening in square-feet

In this case, the area of the hood opening was 6.47 square-feet, and the distance from the hood to the foaming area (contaminant source) was approximately 20 inches. The ACGIH recommends a minimum hood-induced air velocity (V) of 200 fpm when performing “intermittent container filling” involving the release of a “contaminant of high toxicity.”<sup>100</sup> This results in a minimum design volumetric flowrate of 6850 cfm for the current local exhaust ventilation system at the foam packaging station. As noted in Figure 4, the air velocity measurements on the right side of the hood are lower than those in the center and left side of the hood. There was observable blockage (hardened foam) in the right side of the hood, which may be restricting airflow and reducing capture velocity. Removing the blockage may increase volumetric flowrate to the above 6850 cfm; otherwise, other steps should be taken to increase the volumetric flowrate of this hood.

## RECOMMENDATIONS

### Noise

1. A complete noise map of the manufacturing area is needed. The noise map should show the measured noise levels superimposed on a floor plan of the facility. The map can be posted so that employees can visualize the areas where precautions need to be taken to protect themselves from occupational noise exposures. The noise map should be updated on a regular basis (perhaps annually) or whenever processes or equipment change or when employees begin to complain of louder than normal conditions. The data from all of the maps should be retained for historical purposes to document employees’ potential exposures to noise.

2. Any areas identified by the noise map that begin to approach the OSHA action level of 85 dB(A) should be further measured with personal noise dosimetry to decide if the employees need to be included in the company’s hearing conservation program. Periodic monitoring of the people who fall near the action level should be included in the

monitoring portion of the hearing conservation program.

3. Training of employees in the use and maintenance of hearing protection devices needs to be formalized by the company. Many employees were observed wearing ear plugs incorrectly with much of the plug sticking out of the ear. Some ear muffs were found to have cushions that were brittle, torn, or covered with splattered paints which need to be replaced. A good rule of thumb for the periodic replacement of ear muff cushions is every six months or less if recommended by the manufacturer of the device.

4. The types of HPDs offered to employees needs to be examined. The two ear plugs seen in the facility offer much attenuation capability. Workers can be overprotected by ear plugs. The well-fitted ear plug with an NRR of 30 dB reduces both the ambient noises plus any signals that the employees must hear to do their jobs. Signals include conversation along with machine sounds and warning signals. Because the manufacturing areas of Woodward Governor Company do not have much hazardous noise, the attenuation needed to reduce exposures to a safe, tolerable, and comfortable level is small. HPDs that are more comfortable or allow workers to hear necessary signals should be sought by the company.

5. Employees who wear HPDs on the job should have annual audiometric testing. This is currently practiced by the Medical Department and should be continued. However, the employees who do not meet the requirements stipulated in the regulations of 29 CFR 1910.95 should not be included in the company’s formal hearing conservation program. The practice of audiometric testing and recurrent training of employees in the matters of noise and its effects and the proper use of HPDs can be included in a wellness program which the Medical Department already has in place. Feedback from the Safety Department as to the noise exposure levels particular employees face will dictate in which program these employees should be placed. This should be a dynamic endeavor that allows employees to move back and forth between

programs whenever their documented noise exposure change.

6. The shrill sounding warning signal in the Circuit Board Plating Department should be changed to a less annoying sound. Perhaps both signals could be buzzers, but have one sound for a continuous burst and the other have a series of short bursts. These signals should be easily distinguishable to the employee and be less annoying.

7. Metal-on-metal contacts in the Sheet Metal Fabrication area should be eliminated to help reduce the noise impacts associated with this activity. The sound-deadening materials seen on the tumblers in the machining areas of the facility can be used on the material handling devices found in this area. This type of noise control should also be considered in other areas of the company where this kind of noise is produced when metal bangs into other pieces of metal.

## **Metal working Fluids**

1. There appears to be relatively good maintenance of the MWFs in this plant. Unfortunately, the maintenance person who is responsible for all the water-based fluids will be leaving and the management system is largely unwritten. Thus, a detailed written maintenance program needs to be developed and the record-keeping needs to be improved. According to maintenance personnel, Woodward Governor has a long-term plan to install a computer system to coordinate all maintenance schedules and records. It would be ideal if this could be installed in the near future so that the MWF maintenance program does not dissolve when the current employee responsible for it leaves. One of the most important factors in preventing health effects from MWF exposures is having good machine fluid maintenance.

2. Two of the PBZ air samples were above the proposed NIOSH REL of  $0.5 \text{ mg/m}^3$ , and these exposures need to be controlled by enclosing the operations, modifying work practices, and, if exposures are still high, adding local exhaust

ventilation. Although most of the PBZ air samples were low and MWF mist was not visible in the machining area, more particulate sampling should be conducted to characterize the machines that were not operating during this survey. For concentrations above the proposed NIOSH REL, the actions suggested earlier in the Results section of the report should be taken to try to reduce the exposures. To ensure that exposures are being maintained below  $0.5 \text{ mg/m}^3$ , air sampling should be performed routinely (such as quarterly or semi-annually) throughout the machining area and also whenever there is a process or ventilation change. Although there is no OSHA PEL for water-based MWFs, OSHA is currently assessing the economic feasibility of proposing a PEL of  $0.5 \text{ mg/m}^3$ , so compliance with this exposure limit may eventually be legally required.

3. Most of the machines were not running while employees added or removed parts, but many employees were not wearing gloves to protect their skin. MWFs are associated with dermal health effects and therefore skin contact should be prevented through the use of personal protective equipment (PPE). Since some employees did report that skin problems were occurring, Woodward Governor should consider implementing a policy requiring hand and forearm protection except in specific situations where glove use is a safety hazard. The specific type of rubber should be recommended by the fluid manufacturer since MWFs are so varied, but cotton gloves and shirt sleeves should never be used for protection because they will absorb the MWF and hold it against the skin, which will increase exposure and irritation.

4. Woodward Governor should consider implementing a symptoms surveillance program that encourages employees to report any symptoms that occur at work or might be work-related. These data should be collected and stored systematically so that the safety department could use them for early identification of potential problems and for targeting areas that might need exposure monitoring or engineering controls.

## Isocyanates

1. NIOSH recommends that whenever there is a potential for exposure to diisocyanates, including concentrations below the NIOSH RELs, that the employer provide the worker with supplied-air respiratory protection. Air-purifying respirators are not recommended since diisocyanates have poor odor warning properties. Currently, the painters are provided with and use supplied-air respirators, but the worker at the foaming station is not provided with any respiratory protection.

2. The volumetric airflow for the hood at the foam packaging station should be increased to 6850 cfm. The hood should be inspected before every packaging operation to determine if the hood and duct are blocked or the airflow restricted. In addition, contaminant capture can be improved through the installation of flanges. A flange is a surface or shield which is located at and parallel to the hood face, and provides a barrier to unwanted airflow from behind the hood. A common rule of thumb is that the width of the flange should equal the square root of the hood area (A).<sup>100</sup>

3. All efforts should be taken to prevent dermal exposures to isocyanate-containing substances. The employer should provide protective clothing, gloves, and footwear that is impervious to isocyanate-containing compounds. The protective clothing should either be disposed or laundered after each use (e.g. at the end of the work shift). The gloves should be elbow-length, and made of a isocyanate-resistant material, such as butyl rubber, nitrile rubber, polyvinyl alcohol, or polyvinyl chloride. Face-shields and aprons should be used whenever there is a possibility of a splash or a spill of liquids containing isocyanate-containing materials. The open points at the interface between different forms of protective clothing, e.g. the opening which forms between the sleeve of a protective suit and a glove, should be sealed to prevent exposure through the interface. A common and effective method for sealing these interfaces is to use duct tape to join the two different forms of protective clothing.

4. The employer should provide workers with appropriate training on the inhalation and dermal exposure hazards associated with isocyanate-containing materials, and on the proper use of personal protective equipment associated with protection from these exposures.

5. NIOSH recommends both preplacement and periodic medical surveillance programs for all workers potentially exposed to diisocyanates. The preplacement examinations should consist of detailed medical and work histories with emphasis on pre-existing respiratory and/or allergic conditions, a physical examination that centers on the respiratory tract, a baseline pulmonary function test that measures FEV1 and FVC, and a judgement on the worker's ability to wear a supplied-air respirator. Workers should be provided with annual examinations which update the medical and work histories, and measure the worker's FEV1 and FVC.

6. NIOSH recommends that employers conduct industrial hygiene surveys on all workers potentially exposed to the isocyanates. These surveys should contain both inhalation and dermal exposure evaluations, and should be conducted on an annual basis or when there are changes in the process or engineering controls. A sufficient number of samples should be collected to characterize each employee's exposure, and to characterize isocyanate emissions from a given process, operation, machine, etc. These surveys should encompass both routine (e.g. normal operations and scheduled maintenance) and non-routine (e.g. repair activities associated with breakdowns or malfunctions) work activities. Task-oriented exposure assessments should be used to determine the isocyanate exposure levels associated with specific tasks within an operation or shift.

7. All medical and industrial hygiene records should be kept by the employer for a time period of no less than 30 years.

## Other

1. A more efficient vacuum cleaner should be used when cleaning the Ultra Etch machine in the Plating Area. The current vacuum created a cloud of very irritating blue dust (containing ammonia). A High Efficiency Particulate Aerosol (HEPA) vacuum would be acceptable.
2. No eating or drinking should be allowed in many of the work areas of the plant where lead soldering is conducted and other chemical exposures may occur. This includes the Electrical Assembly area, the Shipping Department, and the Paint Shop. The issue of eating and drinking at the workstation should be re-evaluated throughout the entire plant.
3. Sodium phosphate solution (or something similar) should be used to help clean lead from contaminated surfaces. Most surfaces are currently either dry cleaned or cleaned with water.
4. Employees involved with soldering or others with the potential for exposure to lead should be warned to wash their hands prior to eating, drinking, or smoking. This message should be part of the employee Hazard Communication training and signs should be posted to help remind them.
5. The lab hoods in the Mechanical Sub Assembly area (NW corner of the Main Building) should be fixed to operate within acceptable face velocities (about 100 fpm) and the hoods should be on a periodic testing schedule. The touch-up hood in the Conformal Coating room also needs to be fixed so that solvent vapors do not rise up into the worker's face.
6. The respirator program in the painting areas need to be re-evaluated. Respirators were stored on open hooks or otherwise outside storage bags, they were not worn properly, not cleaned after use, nor were cartridges replaced on a regular basis. Supervisor of these Departments should have the responsibility to insure that all aspects of the respirator programs are followed by the employees.

7. Filter maintenance on the spray booths was not specified nor was a log kept. A manahelic gauge could be installed to monitor the pressure drop across the filters to determine when the filters need to be changed.

8. The exhaust system on the silk screening press was effective only about 14-16 inches away from the exhaust slot. The exhaust effectiveness was severely reduced by the turbulence cause by the air intake above the press. Any side enclosures that could be added would also increase the effectiveness of the exhaust ventilation. This exhaust ventilation is used to control the small amount of ink solvents and the citrus-based cleaner currently being used so the effective operation is not imperative.

## REFERENCES

1. NIOSH [1994]. NIOSH Manual of Analytical Methods. 4<sup>th</sup> Edition. Cincinnati, Ohio: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-113, 1994.
2. NIOSH [1994]: Method 5522, isocyanates. In: Eller PM, Cassinelli ME, eds. *NIOSH Manual of Analytical Methods*, 4th ed. Cincinnati, OH: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-113.
3. NIOSH [1992]. Recommendations for occupational safety and health: compendium of policy documents and statements. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 92-100.
4. ACGIH [1995]. 1995-1996 threshold limit values for chemical substances and physical

agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

5. Code of Federal Regulations [1989]. 29 CFR 1910.1000. Washington, DC: U.S. Government Printing Office, Federal Register.

6. Ward WD [1986]. Anatomy & physiology of the ear: normal and damaged hearing. Chapter 5. In: Berger EH, Ward WD, Morrill JC, Royster LH, eds. Noise & hearing conservation manual. 4th ed. Akron, OH: American Industrial Hygiene Association, pp 177-195.

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

8. Code of Federal Regulations [1992]. OSHA. 29 CFR 1910.95. Washington, DC: U.S. Government Printing Office, Federal Register.

9. NIOSH [1972] Criteria for a recommended standard: occupational exposure to noise. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 73-11001.

10. Niemeier RW [1995]. Memorandum of April 13, 1995, from R.W. Niemeier, Division of Standards Development and Technology Transfer, to NIOSH Division Directors, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Public Health Service, U.S. Department of Health and Human Services, 1995.

11. Bernstein DI, Lummus L, Santilli G, Siskosky J, Bernstein IL [1995]. Machine Operator's Lung. Chest. 106:636-641.

12. Sprince N, Thorne PS, Cullen MR [1994]. Oils and related petroleum derivatives. In Textbook of Clinical Occupational and Environmental Medicine. Rosenstock L and Cullen MR (eds.). Philadelphia: W.B. Saunders Company.

13. Kennedy S, et al. [1989]. Acute pulmonary responses among automobile workers exposed to aerosols of machining fluids. American Journal of Industrial Medicine. 15:627-641.

14. Ameille J, et al. [1995]. Respiratory symptoms, ventilatory impairment, and bronchial reactivity in oil mist-exposed automobile workers. American Journal of Industrial Medicine. 27:247-256.

15. Barnhart S [1994]. Irritant Bronchitis. In Textbook of Clinical Occupational and Environmental Medicine. Rosenstock L and Cullen MR (eds.). Philadelphia: W.B. Saunders Company.

16. American Thoracic Society [1987]. Standards for the Diagnosis and Care of Patients with Chronic Obstructive Pulmonary Disease (COPD) and Asthma. American Review of Respiratory Diseases. 136:225-244.

17. Chan-Yeung M, Lam S [1986]. Occupational Asthma. American Review of Respiratory Diseases. 133(4): 686-703.

18. Salvaggio JE, Taylor G, Weill H [1986]. Occupational Asthma and Rhinitis. In Occupational Respiratory Diseases. Merchant JA (ed.). Cincinnati, OH: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health. DHHS (NIOSH) Publication No. 86-102.

19. Reilly MJ, Rosenman KD, Watt FC, et al. [1994]. Surveillance of occupational asthma – Michigan and New Jersey 1988-1992. MMWR. 43(SS1):9-17.



20. Hoffman RE, Rosenman KD, Watt F [1990]. Occupational Disease Surveillance: Occupational Asthma. *MMWR*. 39(7):119-123.
21. Rose C [1994]. Hypersensitivity Pneumonitis. In *Textbook of Clinical Occupational and Environmental Medicine*. Rosenstock L and Cullen MR (eds.). Philadelphia: W.B. Saunders Company.
22. Kipling MD [1977]. Health hazards from cutting fluids. *Tribology international*. February, pp. 41-46.
23. Rycroft RJG [1990]. Petroleum and petroleum derivatives. In *Occupational Skin Disease*. 2nd ed. Adams R (ed.). Philadelphia: W.B. Saunders Company. pp. 486-502.
24. Alomor A [1994]. Occupational skin disease from cutting fluids. In *Dermatologic Clinics*. Taylor J (ed.). Philadelphia: W.B. Saunders Company. Vol. 12, No. 3. pp. 537-546.
25. Zugerman C [1986]. Cutting fluids: their use and effects on the skin. *Occupational Medicine State of the Art Review*. 1(2):245-258.
26. NIOSH [1988]. NIOSH testimony on the Occupational Safety and Health Administration's proposed rule on air contaminants, August 1, 1988, OSHA Docket No. H-020. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.
27. Wagner WD, Wright PG, Stokinger HE [1964]. Inhalation toxicology of oil mists I: chronic effects of white mineral oil. *Am Ind Hyg Assoc J* 25:158-168.
28. Hathaway GJ, Proctor NH, Hughes JP, Fischman ML [1991]. *Chemical hazards of the workplace*. 3rd ed. New York, NY: Van Nostrand Reinhold.
29. Proudfit JP, Van Ordstrand HS [1950]. Chronic lipid pneumonia following occupational exposure. *AMA Arch Ind Hyg Occup Med* 1:105-111.
30. IARC [1982]. *Monographs on the evaluation of the carcinogenic risk of chemicals to humans: chemicals, industrial processes and industries associated with cancer in humans*. Suppl. 4. Lyon, France: World Health Organization, International Agency for Research on Cancer, pp 227-228.
31. IARC [1987]. *Monographs on the evaluation of the carcinogenic risk of chemicals to humans, overall evaluations of carcinogenicity: an updating of IARC monographs vols. 1 to 42*. Suppl. 7. Lyon, France: World Health Organization, International Agency for Research on Cancer, pp 252-254.
32. ACGIH [1986]. *Documentation of threshold limit values and biological exposure indices for chemical substances and physical agents*. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.
33. NIOSH [1996]. *Draft proposal: Criteria for a recommended standard: Occupational exposures to metalworking fluid*, February, 1996. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.
34. Woods G [1987]. *The ICI Polyurethanes Book*. New York, NY: ICI Polyurethanes and John Wiley & Sons. Inc.
35. NIOSH [1978]. *Criteria for a recommended standard: occupational exposure to diisocyanates*. DHEW (NIOSH) Publication No. 78-215. Cincinnati, OH: U.S. Dept. of Health, Education, and Welfare, Public Health Service, Center for Disease Control, NIOSH.
36. NIOSH [1990]. *Pocket guide to chemical hazards*. DHHS (NIOSH) Publication No. 90-117.

Cincinnati, OH: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, NIOSH.

37. NIOSH [1986]. Occupational respiratory diseases. DHHS (NIOSH) Publication No. 86-102. Cincinnati, OH: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, NIOSH.

38. Levy BS, Wegman DH (editors) [1988]. *Occupational Health: Recognizing and Preventing Work-Related Diseases*. Second Edition. Boston/Toronto: Little, Brown and Company.

39. Porter CV, Higgins RL, Scheel LD [1975]. A retrospective study of clinical, physiologic, and immunologic changes in workers exposed to toluene diisocyanate. *American Industrial Hygiene Association Journal* 36: 159-168.

40. NIOSH [1981]. Technical report: respiratory and immunologic evaluation of isocyanate exposure in a new manufacturing plant. DHHS (NIOSH) Publication No. 81-125. Cincinnati, OH: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, NIOSH.

41. McKay RT, Brooks SM [1981]. Toluene diisocyanate (TDI): biochemical and physiologic studies. *American Review of Respiratory Disease* 123: 132.

42. Harries M, Burge S, Samson M, Taylor A, Pepys J [1979]. Isocyanate asthma: respiratory symptoms due to 1,5-naphthylene di-isocyanate. *Thorax* 34: 762-766.

43. Woolrich PF [1982]. Toxicology, industrial hygiene and medical control of TDI, MDI, and PMPPi. *American Industrial Hygiene Association Journal* 43: 89-98.

44. Mobay Corporation [1983]. Health & safety information for MDI, diphenylmethane

diisocyanate, monomeric, polymeric, modified. Pittsburgh, PA: Mobay Corporation.

45. Berlin L, Hjortsberg U, Wass U [1981]. Life-threatening pulmonary reaction to car paint containing a prepolymerized isocyanate. *Scandinavian Journal of Work, Environment and Health* 7: 310-312.

46. Zammit-Tabona M, Sherkin M, Kijek K, Chan H, Chan-Yeung M [1983]. Asthma caused by diphenylmethane diisocyanate in foundry workers. *American Review of Respiratory Disease* 128: 226-230.

47. Chang KC, Karol MH [1984]. Diphenylmethane diisocyanate (MDI)-induced asthma: evaluation of immunologic responses and application of an animal model of isocyanate sensitivity. *Clinical Allergy* 14: 329-339.

48. Seguin P, Allard A, Cartier A, Malo JL [1987]. Prevalence of occupational asthma in spray painters exposed to several types of isocyanates, including polymethylene polyphenyl isocyanate. *Journal of Occupational Medicine* 29: 340-344.

49. Nielsen J, Sungo C, Winroth G, Hallberg T, Skerfving S [1985]. Systemic reactions associated with polyisocyanate exposure. *Scandinavian Journal of Work, Environment and Health* 11: 51-54.

50. Alexandersson R, Gustafsson P, Hedenstierna G, Rosen G [1986]. Exposure to naphthalene-diisocyanate in a rubber plant: symptoms and lung function. *Archives of Environmental Health* 41: 85-89.

51. Mapp CE, Chiesura-Corona P, DeMarzo N, Fabbri L [1988]. Persistent asthma due to isocyanates. *American Review of Respiratory Disease* 137: 1326-1329.

52. Liss GM, Bernstein DI, Moller DR, Gallagher JS, Stephenson RL, Bernstein IL [1988]. Pulmonary and immunologic evaluation

of foundry workers exposed to methylene diphenyldiisocyanate (MDI). *Journal of Allergy and Clinical Immunology* 82: 55-61.

53. Keskinen H, Tupasela O, Tiikkainen U, Nordman H [1988]. Experiences of specific IgE in asthma due to diisocyanates. *Clinical Allergy* 18: 597-604.

54. Cartier A, Grammar L, Malo JL, Lagier F, Ghezzi H, Harris K, Patterson R [1989]. Specific serum antibodies against isocyanates: association with occupational asthma. *Journal of Allergy and Clinical Immunology* 84: 507-514.

55. Mobay Corporation [1991]. Hexamethylene diisocyanate based polyisocyanates, health and safety information. Pittsburgh, PA: Mobay Corporation.

56. Vandenplas O, Cartier A, Lesage J, Perrault G, Grammar LC, Malo JL [1992]. Occupational asthma caused by a prepolymer but not the monomer of toluene diisocyanate (TDI). *Journal of Allergy and Clinical Immunology* 89:1183-1188.

57. Vandenplas O, Cartier A, Lesage J, Cloutier Y, Perrault G, Grammar LC, Shaughnessy MA, Malo JL [1992]. Prepolymers of hexamethylene diisocyanate as a cause of occupational asthma. *Journal of Allergy and Clinical Immunology* 91: 850-861.

58. Baur X, Marek W, Ammon J, Czuppon AB, Marczynski B, Raulf-Heimsoth M, Roemmelt H, Fruhmant G [1994]. Respiratory and other hazards of isocyanates. *International Archives of Occupational and Environmental Health* 66: 141-152.

59. Weill H [1979]. Epidemiologic and medical-legal aspects of occupational asthma. *The Journal of Allergy and Clinical Immunology* 64: 662-664.

60. Adams WGF [1975]. Long-term effects on the health of men engaged in the manufacture

of tolylene diisocyanate. *British Journal of Industrial Medicine* 32: 72-78.

61. White WG, Sugden E, Morris MJ, Zapata E [1980]. Isocyanate-induced asthma in a car factory. *Lancet* i: 756-760.

62. Karol MH, Hauth BA, Riley EJ, Magreni CM [1981]. Dermal contact with toluene diisocyanate (TDI) produces respiratory tract hypersensitivity in guinea pigs. *Toxicology and Applied Pharmacology* 58: 221-230.

63. Erjefalt I, Persson CGA [1992]. Increased sensitivity to toluene diisocyanate (TDI) in airways previously exposed to low doses of TDI. *Clinical and Experimental Allergy* 22: 854-862.

64. Rattray NJ, Bothman PA, Hext PM, Woodcock DR, Fielding I, Dearman RJ, Kimber I [1994]. Induction of respiratory hypersensitivity to diphenylmethane-4,4'-diisocyanate (MDI) in guinea pigs. Influence of route of exposure. *Toxicology* 88: 15-30.

65. Bickis U [1994]. Investigation of dermally induced airway hyperreactivity to toluene diisocyanate in guinea pigs. Ph.D. Dissertation, Department of Pharmacology and Toxicology, Queens University, Kingston, Ontario, Canada.

66. Baur X, Dewair M, Rommelt H [1984]. Acute airway obstruction followed by hypersensitivity pneumonitis in an isocyanate (MDI) worker. *Journal of Occupational Medicine* 26: 285-287.

67. Yoshizawa Y, Ohtsuka M, Noguchi K, Uchida Y, Suko M, Hasegawa S [1989]. Hypersensitivity pneumonitis induced by toluene diisocyanate: sequelae of continuous exposure. *Annals of Internal Medicine* 110: 31-34.

68. Selden AI, Belin L, Wass U [1989]. Isocyanate exposure and hypersensitivity pneumonitis - report of a probable case and prevalence of specific immunoglobulin G

antibodies among exposed individuals. *Scandinavian Journal of Work, Environment and Health* 15: 234-237.

69. Vanderplas O, Malo JL, Dugas M, Cartier A, Desjardins A, Levesque J, Shaughnessy MA, Grammar LC [1993]. Hypersensitivity pneumonitis-like reaction among workers exposed to diphenylmethane diisocyanate (MDI). *American Review of Respiratory Disease* 147: 338-346.

70. NTP [1986]. NTP technical report on the toxicology and carcinogenesis studies of commercial grade 2,4(80%)- and 2,6(20%)-toluene diisocyanate (CAS No. 26471-62-5) in F344/N rats and B6C3F1 mice (gavage studies). NTP TR 328, NIH Publication No. 88-2584. Research Triangle Park, NC: U.S. Dept. of Health and Human Services, Public Health Service, National Institutes of Health, National Toxicology Program.

71. Andersen M, Binderup ML, Kiel P, Larsen H, Maxild J [1980]. Mutagenic action of isocyanates used in the production of polyurethanes. *Scandinavian Journal of Work, Environment and Health* 6:221-226.

72. NIOSH [1989]. Current intelligence bulletin 53: toluene diisocyanate (TDI) and toluenediamine (TDA), evidence of carcinogenicity. DHHS (NIOSH) Publication No. 90-101. Cincinnati, Ohio: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control, NIOSH.

73. Silk SJ, Hardy HL [1983]. Control limits for isocyanates. *Annals of Occupational Hygiene* 27: 333-339.

74. WHO [1989]. IARC monographs on the evaluation of carcinogenic risks to humans: occupational exposures to the petroleum refining; crude oil and major petroleum fuels. *World Health Organization* 45:159-201. 1-8 March 1988.

75. ENVIRON Corporation [1990]. Summary report on individual and population exposures to gasoline. Arlington, VA: ENVIRON Corporation. November 28.

76. NIOSH [1992]. Health hazard evaluation report: American Petroleum Institute, Washington, D.C. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, NIOSH Report No. 88-304-2326.

77. Proctor NH, Hughes JP, Fischman ML [1989]. Chemical hazards of the workplace. 2nd ed. Philadelphia, PA: Van Nostrand Reinhold.

78. NIOSH [1973]. Criteria for a recommended standard: occupational exposure to toluene. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 73-11023.

79. WHO [1981]. Recommended health-based limits in occupational exposure to select organic solvents. Geneva: World Health Organization, Technical Report Series No. 664.

80. Benignus VA [1981]. Health effects of toluene: a review. *Neurotoxicology* 2:567-568.

81. Anderson I, et al [1983]. Human response to controlled levels of toluene in six-hour exposures. *Scand J Work Environ Health* 9:405-418.

82. EPA [1983]. Health assessment document for toluene. NTIS. Washington, DC: Environmental Protection Agency.

83. Bruckner JV, Peterson RG [1981]. Evaluation of toluene and acetone inhalant abuse I. Pharmacology and pharmacodynamics. *Toxicol Appl Pharmacol* 61:27-38.

84. Bruckner JV, Peterson RG [1981]. Evaluation of toluene and acetone inhalant abuse II. Model development and toxicology. *Toxicol Appl Pharmacol* 61:302-312.

85. ACGIH [1992]. Documentation of threshold limit values and biological exposure indices for chemical substances and physical agents. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

86. NIOSH [1975]. Criteria for a recommended standard: occupational exposure to Xylene. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 75-168.

87. NIOSH [1977]. Occupational diseases: a guide to their recognition. Cincinnati, OH: National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-181.

88. Von Berg R [1982]. Toxicology updates. Xylene. *J Appl Toxicol* 2:269-271.

89. NIOSH [1977]. Criteria for a recommended standard: occupational exposure to formaldehyde. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 77-126.

90. Stayner L, Smith AB, Reeve G, Blade L, Keenlyside R, Halperin W [1985]. Proportionate mortality study of workers exposed to formaldehyde. *Am J Ind Med* 7:229-40.

91. OSHA [1992]. Occupational exposures to formaldehyde: final rule. Occupational Safety and Health Administration, Washington, DC: Federal Register 57(102)22289-22328. U.S. Government Printing Office.

92. Hernberg S, et al. [1988]. Lead and its compounds. In: *Occupational medicine*. 2nd ed. Chicago, IL: Year Book Medical Publishers.

93. Landrigan PJ, et al. [1985]. Body lead burden: summary of epidemiological data on its relation to environmental sources and toxic effects. In: *Dietary and environmental lead: human health effects*. Amsterdam: Elsevier Science Publishers.

94. NIOSH [1978]. Occupational exposure to inorganic lead. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, DHEW (NIOSH) Publication No. 78-158.

95. Code of Federal Regulations [1992]. OSHA lead standard. 29 CFR, Part 1910.1025. Washington, DC: U.S. Government Printing Office, Federal Register.

96. NIOSH [1988]. Occupational health guidelines for chemical hazards - occupational health guideline for ammonia. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 88-118.

97. ILO [1983]. Karpov BD, Acids and anhydrides, inorganic. In: *Encyclopedia of Occupational Health and Safety*. Vol I/a-k. Geneva: International Labour Office. p 43.

98. Doull J, Klaassen C, Amdur MO, eds. [1980]. *Casarett and Doull's toxicology: the basic science of poisons*, 2nd ed. New York, NY: Macmillan Publishing Company, Inc.

99. NIOSH [1981]. NIOSH/OSHA occupational health guidelines for chemical hazards. Cincinnati, OH: U.S. Department of Health, and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 81-123.

100. ACGIH [1992]. Industrial ventilation, a manual of recommended practice, 21<sup>st</sup> edition. Cincinnati, OH: American conference of Governmental Industrial Hygienists.

**Table 1. Noise Dosimeter Data. Woodward Governor Co. March 11-12, 1997. HETA 97-0084**

Sample Location	Time hh:mm	L <sub>avg</sub> [dB(A)]	8-hr. Dose	9-hr. Dose	10-hr. Dose	L <sub>eq</sub> [dB(A)]	8-hr. Dose	9-hr. Dose	10-hr. Dose
Dept. 595 Tumbler Area	06:22	78.1	19.2	21.6	24.0	85.2	104.7	117.8	130.9
Lathe Dept. Mach. #1091	08:08	71.9	8.1	9.1	10.1	81.0	39.8	44.8	49.8
Heat Treat Dept.	06:13	79.1	22.1	24.9	27.7	84.5	89.1	100.3	111.4
Lathe Dept. Mach. #1046	06:46	69.0	5.4	6.1	6.8	79.6	28.8	32.4	36.0
Dept. 516 Deburring Area	07:06	71.0	7.2	8.0	8.9	79.2	26.3	29.6	32.9
Dept. 521 Mach. #5832	07:36	73.0	9.5	10.7	11.9	80.2	33.1	37.2	41.4
Sheet Metal Area Emp. #1	05:51	75.4	13.2	14.9	16.5	81.8	47.9	53.8	59.8
Sheet Metal Area Emp. #2	05:46	73.6	10.3	11.6	12.9	80.9	38.9	43.8	48.6
Electrical Plating Dept.	05:40	78.4	20.1	22.6	25.2	82.6	57.5	64.7	71.9
Powder Paint Dept.	07:03	83.1	38.4	43.2	48.0	87.1	162.2	182.4	202.7
Sheet Metal Area Emp. #2	07:01	78.2	19.4	21.9	24.3	82.7	58.9	66.2	73.6
Drill & Router Dept. Emp. #1	07:55	71.0	7.1	8.0	8.9	79.2	26.3	29.6	32.9
Drill & Router Dept. Emp. #2	06:54	75.5	13.4	15.1	16.7	83.2	66.1	74.3	82.6

Noise dosimeter data for the surveyed locations in the facility. The L<sub>avg</sub> noise levels are based on a 5-dB exchange rate and an 80 dB(A) threshold as regulated by OSHA. The L<sub>eq</sub> levels are based on a 3-dB exchange rate and no threshold according to the NIOSH criterion. The various dose percentages are the amounts of noise accumulated during different shifts with 100% representing the maximum allowable daily dose.

**Table 2. Total Particulate Personal Breathing Zone (PBZ) Air-Sampling Results. Woodward Governor Machining Department. March 11, 1997. HETA 97-0084.**

Machine No.	Machine/Operation	Flowrate (liters per minute)	Sample Volume (liters)	Total Particulate (milligrams per cubic meter, mg/m <sup>3</sup> )
578	Machine Center	2	792	0.32
158	Lathe	2	902	0.14
440	Process Drawing	2	804	<b>1.4</b>
579	#4 Makino Machine Center	2	808	0.17
425	Angular Grinding	2	828	<b>3.2</b>
541	Vertical Machine Center	2	850	0.18
204*	Gang Drill*	2	840	0.15
540**	Gear Shaper	2	844	0.15
NIOSH REL				0.5

\*Only on this machine for first 4 hours; spent last 3 hours at the Horizontal Mill where no MWFs are used.

\*\*This sample collected on 3/12/97 because not operating on 3/11/97.

**Table 3. Real-time Total Particulate General Area Air Sampling Results. Woodward Governor Machining Department. March 11, 1997. HETA 97-0084. (See Figure 1.)**

Machine No.	Time of Sampling	Total Particulate Mass (micrograms per cubic meter) by Size of Particulate (micrometers (µm) diameter)								
		0.35-0.5 µm	0.5-0.75 µm	0.75-1.0 µm	1.0-2.0 µm	2.0-3.5 µm	3.5-5.0 µm	5.0-6.5 µm	>6.5 µm	Total >3.5µm
158	1:00-1:10 pm	8.2	5.2	7.8	19.4	58.8	54.8	37.5	43.9	235.6
541	1:12-1:22 pm	8.5	5.2	6.8	15.4	38.5	27.8	20.2	16.3	138.9
579	1:24-1:34 pm	8.0	4.9	8.1	21.0	59.2	59.8	45.6	58.7	265.3
425	1:46-1:56 pm	15.1	7.3	77.6	198.0	851.1	815.7	659.2	729.1	3353.1
440	2:03-2:13 pm	13.0	8.9	22.2	58.3	168.0	133.9	120.3	149.9	674.5
578	2:18-2:28 pm	7.8	5.0	10.8	30.8	101.4	95.9	62.7	53.1	367.5



**Table 4. Airborne Toluene and Xylene Personal Breathing Zone (PBZ) Air-Sampling Results. Woodward Governor Co. March 11-12, 1997. HETA 97-0084.**

Sample No.	Job Description/Area	Flowrate (liters per minute)	Sample Volume (liters)	Toluene Conc. (ppm)	Xylene Conc. (ppm)
WCT-01	Silk screening	0.2	78	0.01	0.2
WCT-02	Conformal Coating	0.2	76	1.3	0.8
WCT-03	Mechanical Assembly, using adhesives	0.5	74	0.04*	0.02*
WCT-04	Mechanical Assembly, adhesives	0.1	47	0.15#	0.04#
WCT-06	Conformal Coating	0.2	97	1.5	0.7
OSHA PEL				200	100
NIOSH REL				100	100
ACGIH TLV				50	100

\*A large unidentified peak was noticed on analysis

# Significant amounts of solvents were found on the back-up section of the sampling tube

**Table 5. Airborne Lead Personal Breathing Zone (PBZ) and Area Air-Sampling Results. Woodward Governor Co. March 11-12, 1997. HETA 97-0084.**

Sample No.	Job Description/Area	Flowrate (liters per minute)	Sample Volume (liters)	Lead Conc.(micrograms per cubic meter, $\mu\text{g}/\text{m}^3$ )
WG-100	Area, above lead solder pot in Electrical Assembly	3	1,070	0.06
WG-101	Area, above wave solder	2	724	0.07
WG-102	Personal, cleaning dross from wave solder	2	30	28.3
WG-103	Personal, assisting with dross cleaning ,wave solder	3	33	15.1
OSHA PEL				50
NIOSH REL				100
ACGIH TLV				50

**Table 6. Airborne Ammonia Personal Breathing Zone (PBZ) and Area Air-Sampling Results. Woodward Governor Co. March 11-12, 1997. HETA 97-0084.**

Sample No.	Job Description/Area	Flowrate (liters per minute)	Sample Volume (liters)	Ammonia Conc. (ppm)
WAM-20	Area, next to ammonia tank on Plating Line	0.2	86	1.0
WAM-21	Personal, Plating Operator	0.2	87	0.16
WAM-22	Area, on wall behind Chem Cat machine, Plating	0.2	44	0.09
WAM-23	Personal, cleaning the Chem Cat	0.2	4.2	1.5
WAM-24	Area, Waste Water area with ventilation shut off	0.2	43	0.5
WAM-25	Area, on wall behind Chem Cat machine	0.2	54	0.5
WAM-26	Personal, working line, starting to clean Chem Cat	0.2	48	0.55
OSHA PEL	TWA			25
NIOSH REL	TWA			25
	STEL			35
ACGIH TLV	TWA			25
	STEL			35

**Table 7. Airborne Nitric and Sulfuric Acid Personal Breathing Zone (PBZ) and Area Air Sampling Results. Woodward Governor Co. March 11-12, 1997. HETA 97-0084.**

Sample No.	Job Description/Area	Flowrate (liters per minute)	Sample Volume (liters)	Nitric Acid Conc. (mg/m <sup>3</sup> )	Sulfuric Acid Conc. (mg/m <sup>3</sup> )
WAC-40	Personal, Carey	0.5	193	<0.01	<0.01
WAC-41	Personal, Jon	0.5	191	<0.01	<0.01
WAC-44	Area, next to Sulfuric Acid Still	0.5	150	<0.01	<0.01
WAC-45	Area, Water Treatment, East side	0.5	93	0.12	<0.02
WAC-46	Area, North stagnant corner of Water Treatment	0.5	144	<0.01	<0.01
WAC-47	Area, Water Treatment, Ventilation OFF	0.5	150	<0.01	<0.01
WAC-48	Area, Water Treatment, Ventilation ON	0.5	150	<0.01	<0.01
OSHA PEL				5	1
NIOSH REL				5	1
ACGIH TLV				5.2	1

**Table 8 Area Air Sampling Data for 2,4- and 2,6-Toluene Diisocyanate (TDI) Monomer and Oligomers During the Spray Painting Operation. Woodward Governor Co. - Fort Collins, CO. March 12-13, 1997**

LOCATION	SAMPLE TIME <sup>1</sup>	SAMPLE VOLUME <sup>2</sup>	[2,4-TDI] <sup>3</sup>	[2,6-TDI] <sup>3</sup>	[TDI OLIGOMERS] <sup>3</sup>	[TOTAL NCO GROUPS] <sup>4</sup>
On floor near east wall, in paint booth	0800-1530	450	(5.1)	ND	10.4	7.4
On drum at south wall, in paint booth	0800-1530	450	9.6	ND	22.0	15.2
On south wall ledge, 5' from ground, in paint booth	0800-1530	450	8.9	ND	22.2	14.9
On mixing table in paint booth	0800-1530	450	8.4	ND	28.9	17.9
On floor near west wall, in paint booth	0800-1530	450	8.7	ND	15.1	11.4
On table near paint booth door, outside paint booth	0805-1530	445	ND	ND	ND	-
Minimum Detectable Concentration		450	2.2	4.4	None	Not Applicable
Minimum Quantifiable Concentration		450	7.8	11.3	None	Not Applicable

<sup>1</sup> This is the start and stop time (in military time) for the sampling device.

<sup>2</sup> Sample volumes are expressed in units of liters of air.

<sup>3</sup> Concentrations are expressed in micrograms of analyte per cubic meter of air ( $\mu\text{g}/\text{m}^3$ ). An "ND" (none detected) in this column indicates that none of the analyte was detected in the sample, and the airborne concentration was below the minimum detectable concentration (MDC) for the sampling and analytical method. Concentrations in parentheses are between the minimum quantifiable concentration (MQC) and the MDC and are considered to be semi-quantitative.

<sup>4</sup> Concentrations are expressed in micrograms of NCO group per cubic meter of air ( $\mu\text{g}/\text{m}^3$ )

**Table 9 Area Air Sampling Data for 4,4'-Diphenylmethane Diisocyanate (MDI) Monomer and Oligomers During the Polyurethane Foam Packaging Operation. Woodward Governor Co. Fort Collins, CO. March 12-13, 1997**

LOCATION	SAMPLE TIME <sup>1</sup>	SAMPLE VOLUME <sup>2</sup>	[MDI] <sup>3</sup>	[MDI OLIGOMERS] <sup>3</sup>	[TOTAL NCO GROUPS] <sup>4</sup>
On top of plenum for foaming station	0808-0846	38	ND	15.5	<9.8
On top of left side shield for foaming station	0808-0846	38	ND	14.7	<9.5
On right side of work surface for foaming station	0808-0846	38	ND	ND	-
On Richpak pallet adjacent to the foaming station	0808-0846	38	ND	13.4	<9.0
On parts table adjacent to foaming station	0808-0846	38	ND	13.4	<9.0
On table located 10 feet from foaming station	0808-0846	38	ND	14.7	<9.5
Minimum Detectable Concentration		38	13.2	None	Not Applicable
Minimum Quantifiable Concentration		38	44.7	None	Not Applicable

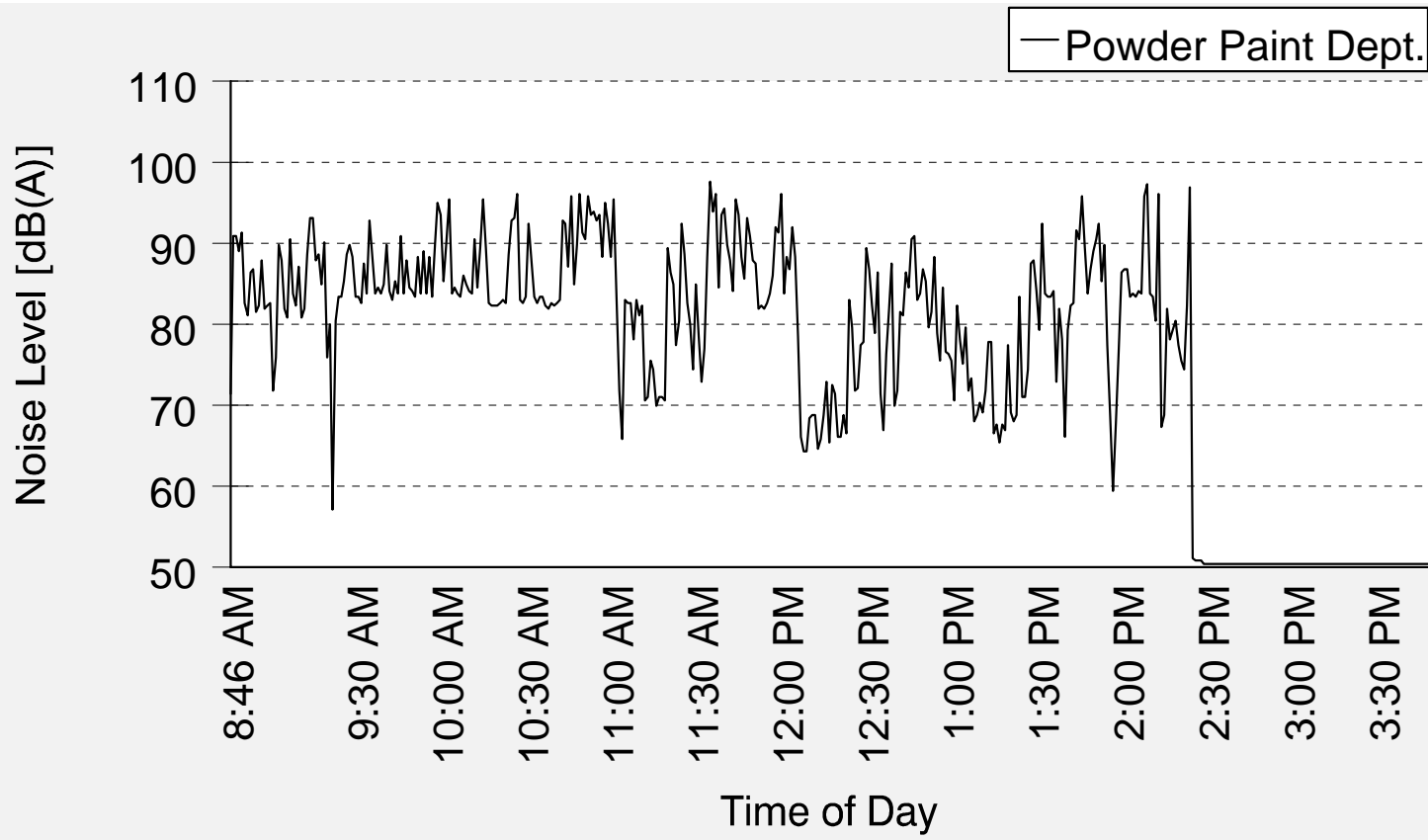
<sup>1</sup> This is the start and stop time (in military time) for the sampling device.

<sup>2</sup> Sample volumes are expressed in units of liters of air.

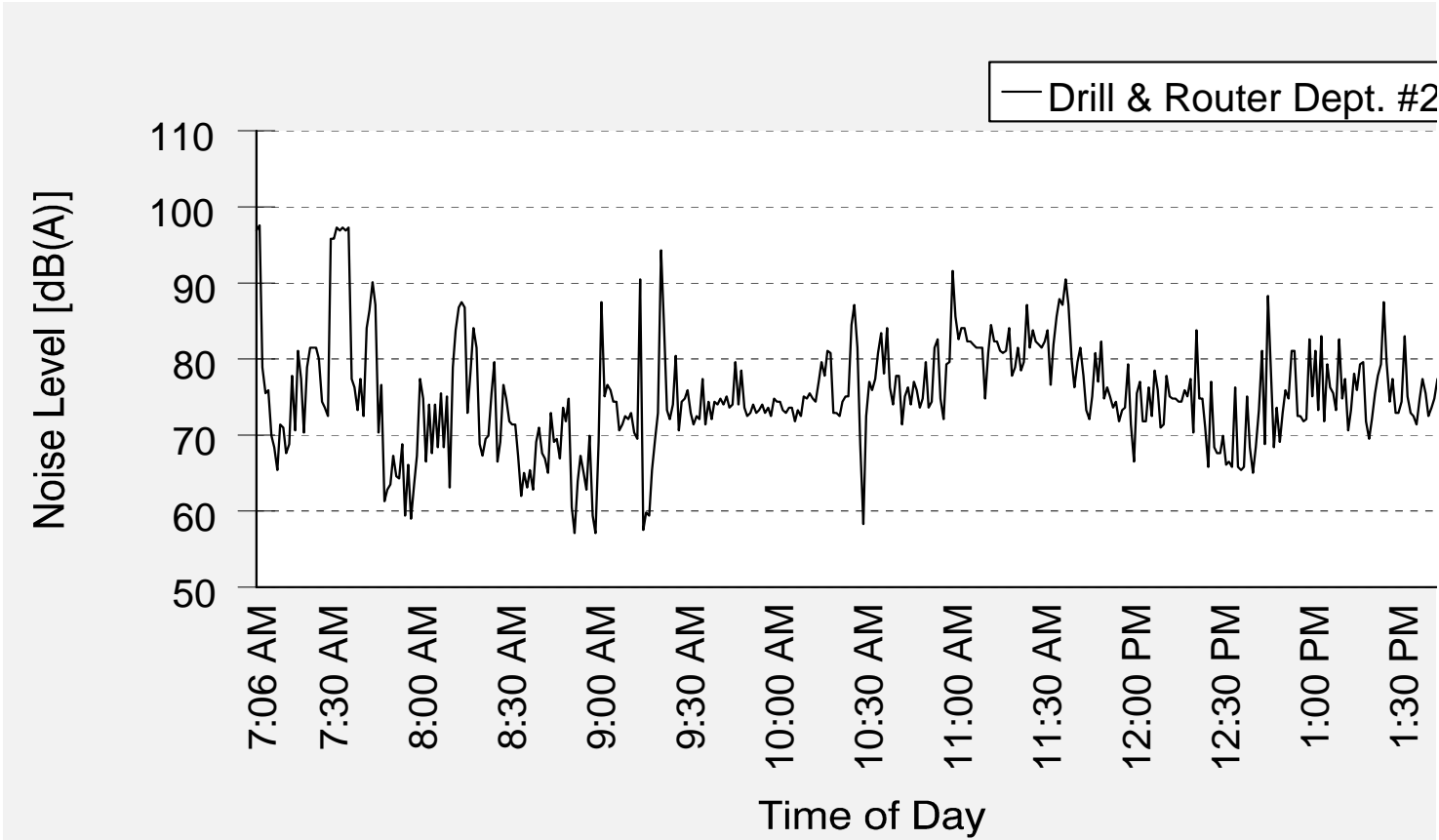
<sup>3</sup> Concentrations are expressed in micrograms of analyte per cubic meter of air ( $\mu\text{g}/\text{m}^3$ ). A "ND" (none detected) in this column indicates that none of the analyte was detected in the sample, and the airborne concentration was below the minimum detectable concentration (MDC) for the sampling and analytical method. Concentrations in parentheses are between the minimum quantifiable concentration (MQC) and the MDC and are considered to be semi-quantitative

<sup>4</sup> Concentrations are expressed in micrograms of NCO group per cubic meter of air ( $\mu\text{g}/\text{m}^3$ )

**Figure 1**  
**Woodward Governor Co.**  
**Fort Collins, Colorado**  
**March 11, 1997**



**Figure 2**  
**Woodward Governor Co.**  
**Fort Collins, Colorado**  
**HETA 97-0084**  
**March 12, 1997**



**Figure 3. Particle Size Distribution at Six Machines  
Woodward Governor Co., March 11, 1997  
HETA 97-0084**

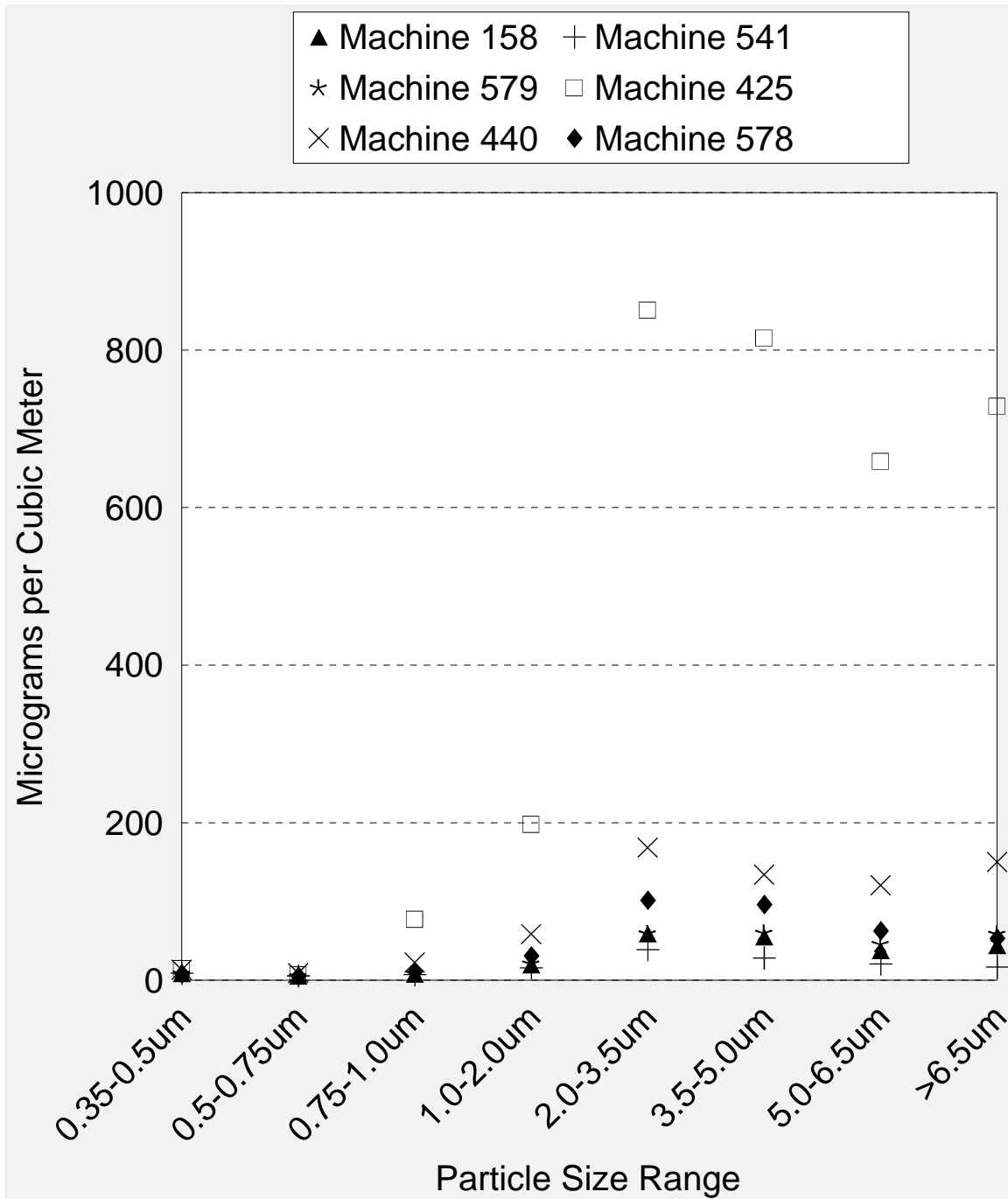




Figure 4

*Ventilation Measurements for the Local Exhaust Ventilation System at the  
Polyurethane Foaming Station*

Woodward Governor Co. - Fort Collins, CO  
March 12-13, 1997

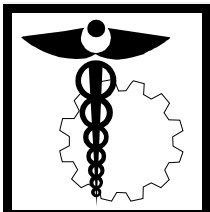
1290	1640	625
900	910	785
640	720	590

All the above measurements are in feet per minute (fpm)

Average Linear Velocity = 900 fpm

Dimensions for Plenum: 38" long, 24.5" wide

Volumetric Flowrate: 5820 cubic feet per minute



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