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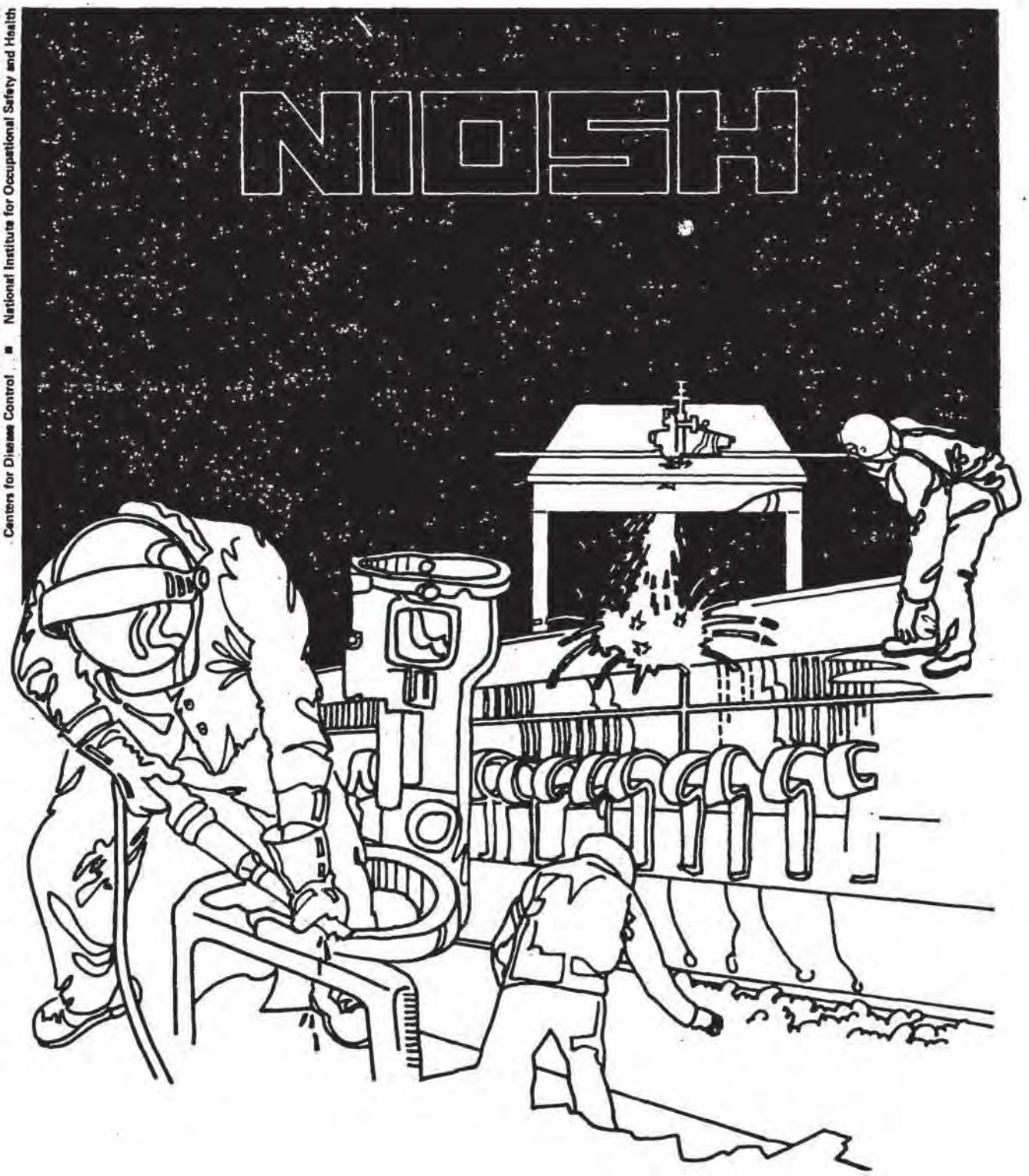

Health Hazard Evaluation Report

HETA 82-315-1320
WILMINGTON CHEMICAL CORP
WILMINGTON, DELAWARE

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, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to Federal, state, and local agencies; labor; industry and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

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I. SUMMARY

In June 1982, the National Institute for Occupational Safety and Health (NIOSH) received a request to evaluate employee exposures to chemicals including glycidyl ethers, solvents and isocyanates at Wilmington Chemical Corporation, Wilmington, Delaware. In September 1982, a NIOSH survey team conducted an initial environmental/medical evaluation; NIOSH conducted a follow-up environmental/medical survey in December 1982.

Samples were collected to evaluate employee exposures to methylene-bis-4-cyclohexyl isocyanate (hydrogenated MDI) in the pilot plant; to toluene, epichlorohydrin and n-butyl glycidyl ether in the epoxy department; and to xylene in the specialty coatings department. NIOSH investigators interviewed 29 of 32 hourly workers and 15 salaried workers, and collected pre- and post-shift urine samples for measurement of hippuric acid (a metabolite of toluene) and serum samples for evaluation of liver function. The chemical operators also participated in pre- and post-shift pulmonary function testing.

Airborne concentrations of epichlorohydrin (eight personal samples) and n-butyl glycidyl ether (seven personal samples) were less than the limit of detection (0.01 mg/sample). Airborne concentration of toluene ranged from 4.4 to 210 mg/m^3 (eight personal samples). NIOSH recommends that time-weighted average (TWA) exposure to toluene not exceed 375 mg/m^3 with a ceiling limit of 750 mg/m^3 for a 10 minute sample. Airborne concentration of xylene was 96 mg/m^3 (one personal sample). NIOSH recommends that TWA exposures to xylene not exceed 434 mg/m^3 with a ceiling limit of 868 mg/m^3 for a 10 minute sample. Airborne concentrations of hydrogenated MDI ranged from less than the limit of detection (0.0003 mg/sample) to 0.05 mg/m^3 (NIOSH recommended TWA exposure to HMDI 0.055 mg/m^3; ceiling 0.21 mg/m^3 for a 10-minute period).

The reported prevalences of one or more gastrointestinal/constitutional symptoms (45% vs 7%), of one or more nervous system symptoms (45% vs 7%), of symptoms of mucous membrance irritation (41% vs 7%), and of skin complaints (48% vs 13%) were significantly greater in the hourly than in the salaried employees. The prevalence of one or more liver function test (LFT) abnormalities (45% vs 13%) and of an abnormal serum glutamic oxaloacetic transaminase (SGOT) (27% vs 0%) was significantly greater in the hourly employees. This difference in LFT abnormalities persisted when non-drinkers, ex-drinkers and those reporting low alcohol consumption were analyzed separately. These differences in prevalence of symptoms and LFT abnormalities appeared mostly in the production workers. Urinary levels of hippuric acid were generally low, although increases in excretion that were not statistically significant appeared in employees in the epoxy department.

Although low airborne concentrations of chemicals were determined during sampling periods of this survey, NIOSH has found reported symptoms and abnormal results of liver function tests that may be occupationally-related. Adverse effects attributable to isocyanates have occurred at the plant in the past. Recommendations are contained in Section VIII of this report.

KEYWORDS: SIC 2860 (Industrial organic chemicals), xylene, toluene, epichlorohydrin, glycidyl ethers, hydrogenated Methylene-bis-4-cyclohexyl isocyanate, isocyanates, liver disease.

II. INTRODUCTION

On June 28, 1982, the National Institute for Occupational Safety and Health (NIOSH) received a request from Local 1, United Food and Commercial Workers (Joint Board Fur, Leather and Machine Workers Union), to evaluate employee exposures to hazardous chemicals such as leather finishes, glycidyl ethers, epoxy resins and isocyanates at Wilmington Chemical Corporation, Wilmington, Delaware.

NIOSH conducted an initial environmental/medical survey at Wilmington Chemical in September 1982, and conducted a follow-up environmental/medical survey on December 6-9, 1982. Notification letters informing employees of blood, urine or breathing tests were distributed on March 1, 1983.

III. BACKGROUND

A division of Seton Corporation (New Jersey), the Wilmington Chemical Corporation began production in 1960. The company is engaged in the manufacture of various types of chemical products in batch mixing operations. The three major types of products, glycidyl ethers, specialty coatings, and polyurethanes, are made but not used by Wilmington Chemical. The glycidyl ethers, which are used as diluents in epoxy resin systems, account for 50-60% of the company's production in pounds. They are produced in a reaction vessel from epichlorohydrin and a phenol (base-catalyzed) or an aliphatic (acid-catalyzed) alcohol. Caustic soda is often used as the source of alkali, and solvents such as toluene are involved. After temperature adjustments and agitation, the batch settles. When the product is approved, it is filtered into drums.

The specialty coating products, formed in 250-gallon reactors, are water-based or solvent-based mixtures such as vinyls or acrylics that may contain pigments, polyvinyl chloride, or other vinyl resins, plasticizers, or stabilizers. These finishes are ultimately used to enhance the aesthetic appearance of leather. Organic solvents such as xylene, methyl ethyl ketone, and methyl isobutyl ketone can be involved.

The polyurethane products are used in the treatment of woven and non-woven fabrics, modifying the physical properties to produce an aesthetically pleasing product. At the time of the NIOSH visits, polyurethane dispersions were being produced in a pilot plant, but preparations were underway to manufacture them in large reactors in the main building. Three steps are used to manufacture polyurethane dispersions in water. Initially, a solution is made in a dissolving kettle of dimethyl proprionic acid (DMPA). Then an isocyanate-terminated prepolymer is formed by charging a stirred reaction kettle with diisocyanate and polymeric glycols and triols. The isocyanate being used at the time of the survey was methylene bis 4-cyclohexyl isocyanate (hydrogenated MDI), although toluene diisocyanate (TDI) also has been used in considerable quantities. The mixture is heated to force the reaction of the isocyanate with the hydroxyl materials. A catalyst may be added to further speed the reaction. The extent of reaction is gauged by means of analysis for isocyanate content. When the reaction is complete, the prepolymer is transferred by gravity to a 55-gallon drum positioned beneath the reactor vessel. The prepolymer is then taken to the PUD (polyurethane dispersion unit) where it is further reacted with water to complete the reaction of the isocyanate end groups. Points of potential exposure to isocyanate include the charging the reaction kettle with the unreacted isocyanate, the draining by gravity of the prepolymer into drums, and the pumping of this prepolymer product to the final kettle for dispersion.

At the time of the NIOSH visit, the plant employed about 55 people, of whom about 32 were hourly (production, maintenance, warehouse, and quality control/research and development); the remainder were salaried and clerical. A detailed medical evaluation of these workers had been performed by the Department of Environmental Medicine, Mt. Sinai School of Medicine, earlier in 1982; it included reproductive histories and sperm evaluation. These investigators found evidence of liver function abnormalities. The fertility problems were not addressed by this NIOSH study.

IV. METHODS AND MATERIALS

A. Environmental

On September 20-21, 1982, and December 7-9, 1982, NIOSH conducted an industrial hygiene survey to determine exposures to airborne contaminants. Five personal air samples for methylene-bis-4-cyclohexyl isocyanate (H_{12}-MDI) were obtained in the pilot plant. These samples were collected in impinger samplers at a rate of one liter per minute (lpm) and analyzed according to NIOSH method of high-performance liquid chromatography (HPLC).

Eight personal air samples for epichlorohydrin were collected in the epoxy department. These samples were collected on 150 mg activated charcoal sorbent tubes, using vacuum pumps operating at flow rates ranging from 0.10 to 0.20 lpm and analyzed according to NIOSH method S-118. Seven personal air samples for n-butyl glycidyl ether were collected in the epoxy department. These samples were collected on 150 mg activated charcoal sorbent tubes, using vacuum pumps operating at flow rates ranging from 0.10 to 0.20 and analyzed according to NIOSH method P & CAM 127 modified. Eight personal air samples for toluene were collected in the epoxy department. These samples were collected on 150 mg activated charcoal sorbent tubes, using vacuum pumps operating at flow rates ranging from 0.10 to 1.0 lpm and analyzed according to NIOSH method S-343 modified. One personal air sample for xylene was collected in the specialty coating department. The sample was collected on 150 mg activated charcoal sorbent tube using a vacuum pump operating at 1 lpm and analyzed according to NIOSH method S-318 modified.

The NIOSH industrial hygienist performed smoke tube and velometer assessment of the local exhaust ventilation in the pilot plant, epoxy department and specialty coating department.

B. Medical

During the initial visit, NIOSH investigators interviewed hourly employees, gathered the medical results of the Mt. Sinai evaluation, and reviewed company records of blood tests. During the follow-up study, a NIOSH medical evaluation was made available to all hourly employees. The evaluation included, after signed consent, a questionnaire, a physical examination of exposed skin, a serum specimen for liver function tests (LFTs), and a urine specimen for determination of hippuric acid, a metabolite of toluene. The LFTs performed included the common enzyme tests: gamma-glutamyl transpeptidase (GGT), alkaline phosphatase (AP), serum glutamic oxaloacetic transaminase (SGOT), and serum glutamic pyruvic transaminase (SGPT). To determine if the LFT abnormalities were persistent, the data on those individuals participating in both the Mt. Sinai and NIOSH evaluations were compared. Urine samples for measurement of hippuric acid, a metabolite of toluene, were collected pre-shift, post-shift and where possible, during the final four hours of the shift. (Due to low production volume, biological monitoring of the chemical operators in specialty coatings would not have been informative for exposure to xylene, MEK, etc.)

In addition, the chemical operators underwent pre- and post-shift spirometry; forced vital capacity (FVC), and one-second forced expiratory volume (FEV_1) were measured, and FEV_1/FVC ratio was calculated. We used an Ohio Medical Products Model 822 dry-rolling seal spirometer connected to a Spirotech dedicated model computer which records the flow curves as well as calculates expected values based on age, height, sex and race. A test was considered adequate for interpretation only if there were three acceptable trials and the best two curves differed by no more than 5% with respect to FVC and FEV_1. Predicted normal values were calculated according to the method of Knudson.[26]

Fifteen salaried employees, representing over 80% of the male salaried workforce, volunteered as a comparison group; they were evaluated by questionnaire and LFTS. Because high prevalence of tremors had been previously noted in the chemical workers, we examined participants for evidence of tremor.

V. EVALUATION CRITERIA

A. Environmental Criteria

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for 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 if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy).

In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the evaluation 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 Criteria Documents and recommendations, 2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLV's), and 3) the U.S. Department of Labor (OSHA) occupational health standards. Often, the NIOSH recommendations and ACGIH TLV's are lower than the corresponding OSHA standards. Both NIOSH recommendations and ACGIH TLV's usually are based on more recent information than are the OSHA standards. The OSHA standards also may be required to take into account the feasibility of controlling exposures in various industries where the agents are used; the NIOSH-recommended standards, by contrast, are based solely on concerns relating to the prevention of occupational disease. In evaluating the exposure levels and the recommendations for reducing these levels found in this report, it should be noted that industry is legally required to meet only those levels specified by an OSHA standard.

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 or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from high short-term exposures.

The criteria used for this evaluation are listed in Appendix A.

B. Physiologic Effects

1. Solvents

Solvents have been noted to be associated with liver damage in the past. A number of solvents are used at various times in the chemical processes, including (in major quantities) cyclohexane, methyl ethyl ketone (MEK), methanol, cellosolve acetate, methyl isobutyl ketone (MIBK), n-butanol, toluene, xylol. Exposure to organic solvents can cause varying degrees of anaesthesia, headaches, lightheadedness, "drunkenness", and even unconsciousness. They may have a disagreeable odor and can be irritating to the eyes and upper respiratory tract (nose and throat). Skin contact with solvents can, if prolonged, remove the natural oil from the skin causing dryness and cracking.

One of the major solvents used, by frequency and volume, toluene, has adverse effects like other solvents but is not generally reported to be toxic to the liver, except in the case of intentional gross overexposure ("glue-sniffing").[9] Hippuric acid has been used as an index of toluene exposure. Urinary hippuric acid in nonexposed persons has been reported to average 0.8 mg/ml (range 0.4-1.4 mg/ml).[3] Workers exposed to concentrations of 50 parts per million developed concentrations of 1.26-2.93 mg/ml (average 1.92) by late afternoon, while exposure to 100 ppm would produce a urinary hippuric acid concentration of about 4 g/L at the end of shift.[3] The principal limitation of the test is that hippuric acid is a normal urinary consitituent originating in foods containing benzoic acid or precursors of benzoic acid. Thus diets high in fruit and vegetables which contain benzoic acid or precursors such as quinic acid (prunes, cranberries, plums) and soft drinks increase the hippuric acid output.[19]

Xylene [3-7] (also called xylol or dimethylbenzene) is a colorless liquid that exists in three isomeric forms differing in the distribution of methyl groups. These isomers are often found as components of solvents used in paints, lacquers, cleaning agents, and gasoline. Baselt[3] claims that chronic organ toxicity has not been noted in man. Reports of hematopoietic (bone marrow) suppression associated with xylene exposure in the past may have been due to the presence of benzene in the xylene.[5] Because organic solvents (particularly chlorinated hydrocarbons) as a broad class are associated with hepatotoxicity, it has also been considered a potential adverse effect of xylene. Indeed, in Section 2 (medical) of NIOSH's Recommendations for a Xylene Standard (Reference 5, page 2), laboratory tests recommended at the time of biennial examination include "appropriate liver function tests". In fact, there is little documentation to support this recommendation. An often-quoted reference[7] describes three painters in a confined space where exposure to xylene estimated to have been 10,000 ppm occurred. Discovered after up to 18.5 hours, one of the men died while the other two were unconscious, but eventually recovered. Both had "what was interpreted as evidence of hepatic impairment (elevation of serum transaminase levels)".[5] However, there is little evidence that chronic low-level exposure to xylene at concentrations not causing irritation or neurological effects (i.e. in the range of the evaluation criteria) is associated with hepatotoxicity.

Cellosolve acetate and other glycol ethers have recently been shown to be potential reproductive toxins in animals and hazardous by both inhalation and cutaneous routes. In male animals, testicular atrophy, and abnormal sperm head morphology have been observed.[10]

Ethylene dichloride, a chlorinated hydrocarbon which has been used in smaller quantities at the plant, has been associated with liver toxicity in animals[1] and in humans.[2] It has been used for approximately four batches per year, with each batch requiring about two days.

2. Epichlorohydrin[11,12] and glycidyl ethers[13,14]

NIOSH recommends that epichlorohydrin be handled as if it were a human carcinogen. Both human and animal studies have suggested increase in deaths due to cancer. Evidence of mutagenicity (increased chromosomal aberrations) has been found in exposed humans. In addition, epichlorohydrin is an irritant to the skin and upper respiratory tract. A 1964 case report of a worker exposed to a "gust of epichlorohydrin" described liver function abnormalities.[11] Glycidyl ethers are often used as diluents in epoxy resin systems and are formed by the reaction of various alcohols with epichlorohydrin. As with epoxy resins in general, they can be both irritant to and sensitizers of the skin. Some of these compounds have been associated in laboratory animals with adverse effects on the hematopoietic system and on the testes, including testicular atrophy, with decreased spermatogenic activity. Positive tests for mutagenicity for some glycidyl ethers have been reported but only one, butyl glycidyl ether (BGE), was mutagenic in mammals in the dominant lethal test.[13] Tumorigenic activity in laboratory animals has also been reported.

3. Diisocyanates[15,16]

Occupational exposure to diisocyanates has well-recognized adverse health effects; the most common compound is toluene diisocyanate (TDI). The isocyanates have been described as irritants of the skin and conjunctiva (surface of the white part of the eye). The main effects are on the respiratory system. Acutely, in high concentrations, these materials are severe irritants of the upper and lower respiratory tract. Second, and of additional concern, is the potential development of sensitization to diisocyanates in which some individuals may have asthma-like reactions (immediate, delayed or both) at concentrations much lower than those producing irritation. Chronic effects that have been reported include excess declines in the forced expiratory volume in 1 second (FEV_1) and the forced vital capacity (FVC), increased prevalence of bronchitis and dyspnea and possibly, hypersensitivity pneumonitis.[17,18]

VI. RESULTS

A. Environmental

Results of the environmental samples collected on September 20-21, 1982 are presented in Table I. Airborne epichlorohydrin and n-butyl glycidyl ether were not present at a detection limit of 0.01 mg/sample. Toluene concentrations ranged from 61 to 210 mg/M^3. Both are below the NIOSH recommended time-weighted average (TWA) and 10-minute ceiling.

Results of the environmental samples collected on December 7-9, 1982 are presented in Table II. Epichlorohydrin and n-butyl glycidyl ether concentrations were less than the limit of detection (0.01 mg/sample). Hydrogenated methylene bis-4-cyclohexyl isocyanate (HMDI) concentrations ranged from less than the limit of detection (0.0003 mg/sample) to 0.05 mg/M^3. Toluene concentrations ranged from 4.4 to 5.6 mg/M^3.

B. Medical

1. Demographic Data

In all, 44 employees were evaluated; 15 of about 18 salaried and 29 of 32 hourly. The salaried group was comparable to the hourly group with respect to age, race and seniority, but not education (Table III). A significantly greater proportion of the salaried group had training beyond high school. The hourly group included 4 maintenance workers, 6 warehousemen (shipping and receiving), 6 from Quality Control and Research and Development (QC/R&D) and 13 production workers or chemical operators (composed in turn, of 5 working primarily in specialty coatings at the time of our visit, 3 in the isocyanate/pilot plant, and 5 in the epoxy plant but these locations switched somewhat from week to week).

2. Questionnaire Data

Very little chemical exposure was reported by the salaried employees. Of the 29 hourly workers, daily exposure was reported to epichlorohydrin by 9, toluene by 17, MEK by 7, glycidyl ethers by 8, caustic soda by 5, MIBK by 3, xylene by 2, ethyl acetate by 2.

Before examining symptoms and liver function test results, the two groups were compared for possible confounding factors related to the liver (Table IV). Although none of the differences between the groups was statistically significant, the hourly workers reported a higher prevalence of tattoos (32% vs 7%), a higher mean daily alcohol consumption among drinkers (12.1 units vs 9.2 units, (one "unit" of alcohol is 1 bottle or can of beer, 1 glass of wine, or 1 oz of whiskey or other hard liquor) and a lower percentage of "low" drinkers (arbitrarily defined as less than 7 units of alcohol reported per week) (43% vs 69%) than the salaried workers.

The prevalence of reported symptoms is shown in Table V. The reporting of all gastrointestinal tract or constitutional symptoms (poor appetite, nausea, persistent abdominal pain, feeling easily tired, "feeling down") "in the past month" was greater by the hourly than the salaried employees. The hourly employees reported a significantly higher prevalence of one or more such symptoms [13(45%) of 29 vs 1(7%) of 15; p=0.0095] and two or more such symptoms (31% vs 0%; p=0.0135). Similarly, the hourly group reported more frequently positive responses to symptoms related to the neurological system (NS), including headaches, dizziness, numbness or tingling, incoordination, and trouble concentrating in the past month. The prevalence of reporting one or more NS symptom was significantly greater in the hourly workers (45% vs 7%; p=0.0095). Symptoms of mucous membrane irritation in the past month (41% vs 7%; p=0.016) and skin complaints during the past three months (48% vs 13%; p=0.024) were also reported signficantly more frequently by the hourly employees.

Respiratory symptoms (chest tightness, wheeze or difficulty breathing, with no time limit on time of occurrence), that appeared to be work-related were reported by 7 (54%) of the 13 chemical operators questioned. Another employee who worked with isocyanates in the past described a severe episode of chest tightness following exposure to a TDI spill at Wilmington Chemical over 5 years previously. Re-entry into the pilot plant earlier this year for one week caused recurrence of chest tightness.

Physical examination revealed various skin lesions in 10 hourly workers: 5 (minor peeling, redness or dryness confined to the hands) were consistent with work-related skin contact with organic chemicals. Skin lesions were observed in four salaried workers but only one (red indurated patches on both lower eyelids) was suggestive of exposure to workplace chemicals. Tremor of the outstretched arms was observed in two hourly employees (both epoxy chemical operators with 7 and 1.5 years total duration of employment at the plant); very slight tremor was observed in two other hourly employees (a specialty coatings chemical operator and a maintenance employee with 9 and 3 years employment, respectively).

3. Liver Function Tests

LFT results are shown in Table VI. The mean log-transformed values for all four enzymes were greater in the hourly than in the salaried workers. This difference was statistically significant for SGOT ($t=3.15$; $p=0.0031$). No abnormal results for AP were observed. For the other three enzymes, the prevalence of abnormal tests was greater in the hourly than in the salaried workers; for SGPT, where 7 (27%) of the former vs none of the latter had abnormal results, the association of hourly job and abnormal test was statistically signficant ($p=0.040$). Moreover, 13 (45%) of 29 chemical workers compared to 2 (13%) of the comparison group had one or more abnormal tests [odds ratio = 5.3; 95 percent confidence interval (1.1, 25.6)] (Table VII). In addition, 5 (17%) of the hourly but none of the salaried employees had elevation of more than one test.

This association could not be explained by reported alcohol use. Reported alcohol consumption was stratified into "low" (<7 units reported/week plus ex-drinkers plus never-drinkers) and "high" (>7 units/week) levels (Table VII). The greater prevalence of abnormal liver function tests persisted in both strata. Combining across the two strata, the summary odds ratio[25] was 4.9 (95 percent confidence interval 0.93, 25.7). The increased risk of almost the same magnitude persists, suggesting an association (i.e. hourly status) is associated with abnormal LFTs after adjusting for alcohol.

Within the hourly group, however, there was not a marked effect of duration of employment. Among those employed 0-4 years, 5 (38%) of 13 had abnormal LFTs; among those employed 5-9 years, 4 (57%) of 7 had abnormal tests; and among those with 10 or more years, 4 (44%) of 9, had abnormal tests.

A comparison was made of those individuals assessed by Mt. Sinai and by NIOSH. Of the workers seen by Mt. Sinai who had abnormal results (in one or more LFT), and who also participated in the NIOSH study, eight (80%) were also abnormal by the NIOSH blood tests. Of eleven workers participating in both studies who were normal in Mt. Sinai's study, nine (82%) were normal in the NIOSH study. There appeared to be a high degree of concordance in the two sets of results. Abnormalities in LFTs appeared to be persistent.

4. Symptoms and Liver Function Tests by Job Classification

Within the hourly workers, an attempt was made to see if the excess prevalence of reported symptoms and liver function tests could be attributed to a department. The 13 production workers (who appeared more likely to be intimately and repeatedly exposed to chemicals) were compared to the 16 others (maintenance, warehouse, quality control) to avoid very small numbers (Table VIII).

The prevalence of reported symptoms related to the neurological system (as described above) (62% vs 44%), to mucous membrane irritation (69% vs 38%), or to the gastrointestinal system (69% vs 19%), was greater in the production workers than the other hourly workers. The last difference was statistically significant. The prevalence of one or more abnormal LFTs was also greater (69% vs 25%; Chi-square = 5.48; p=0.019). The proportion of current alcohol drinkers was similar, although the mean reported alcohol units/week was greater and the proportion of low consumers among drinkers was lower in the production workers (Table VIII).

5. Hippuric acid excretion

An attempt was made to assess, by questionnaire, the potential dietary effect but too few participants reported eating the pertinent foods. The hippuric acid excretion is determined in both mg/ml and g/g creatinine. No normal range has been established for the latter. The results were analyzed in two ways: (1) prevalence of an elevated sample (pre-shift sample, last 4 hours of shift sample, or post-shift sample), using 1.4 mg/ml as the upper limit of normal; and (2) the pre- to post-shift change. It was expected, a priori, that levels would be greater in the epoxy plant where toluene is a major solvent but the environmental concentrations proved to be quite low.

(1) The proportion of elevated results in: production (specialty coatings) was 40%; in production (pilot plant/polyurethane) 0%; in production (epoxy) 25%; in maintenance 0%; warehouse 0%; in QC/R&D 20%.

(2) Pre- to post-shift differences are shown in Table IX. These differences may be somewhat unstable, of course, due to the small numbers. However, it is clear that only in the production (epoxy) and QC/R&D departments had increases in hippuric acid excretion over the shift occur that were consistent by both the mg/ml and g/g creatinine analyses. Toluene is used in the epoxy production area and environmental sampling indicated detectable levels. Daily use of toluene was reported by six (100%) of the six employees in QC/R&D. However, environmental sampling was not performed in these areas. None of these increases was statistically significant.

6. Pulmonary Function Tests (PFTs)

Pre- and post-shift PFTs were performed only in production workers and were available for 5 in Specialty Coatings; 3 in isocyanate/pilot plant (all of whom had 2 sets because the polyurethane process went on over two days); and 4 in the epoxy plant. The number and proportion of current smokers in these 3 groups was 2 (50%), 2 (67%) and 4 (100%), respectively. Very few abnormal results (FEV_1 or FVC < 80% predicted or FEV_1/FVC ratio < 70%) were observed: 1) pre- and post-shift FEV_1 and FEV_1/FVC ratio in a pilot plant employee; and 2) a post-shift FEV_1 and FVC in an epoxy plant worker. The range of changes over the shift was similar in the three groups; small changes were noted (Table X). Pre- to post-shift decreases of 10% and 10.5% in FEV_1 on successive days, (a 10% decrement is generally considered as a "significant" change) was seen in only one employee, a worker in the polyurethane/pilot plant. At the end of the first shift, this employee reported burning eyes, cough and chest tightness that were worse than at the beginning of the shift, and on examination, had diffuse wheezes. However, the employee also had an upper respiratory infection at the time (his chest was not examined at the beginning of the shift). The symptoms and wheezes were not present during the second day. The second day pre-shift spirometry values were slightly lower than the first day post-shift values. This resulted in pre- to post-shift two-day decrement in FEV_1 of about 20%. He described

problems on exposure to isocyanates with wheezing several years prior to this NIOSH study. He had had to be moved out of the area at that time and had only been back working in the isocyanate area for 5 weeks at the time of our survey. In the two individuals in the polyurethane department with consecutive daily spirometry, the second day pre-shift values exceeded the first day pre-shift ones. Thus the two day change (1st day pre- to 2nd day post-shift) were smaller than those reflected in Table X.

VII. DISCUSSION

It should be noted that the glycidyl ether being manufactured at the time of the NIOSH surveys (butyl glycidyl ether) is acid-catalyzed. It was evident from the process description, from discussions with both union and management representatives and from the company's own environmental sampling, that potential exposure is greater during base-catalyzed operations. Airborne sampling conducted by Wilmington Chemical Corporation showed epichlorohydrin concentrations up to 0.71 ppm during base-catalyzed operations and none detectable concentrations during acid-catalyzed operations. These data show that during the manufacturing of base-catalyzed glycidyl ethers, epichlorohydrin concentrations can exceed the NIOSH recommended standard of 0.5 ppm.

Despite the low airborne concentrations of various chemicals at the time of NIOSH environmental sampling, the prevalence of reported symptoms was significantly greater among hourly than among those in salaried/administration positions. Exposure to solvents and other chemicals, both in frequency and in severity, is presumably greater in the former group. The symptoms reported by the hourly employees are compatible with exposure to mixed solvents. Abnormalities of liver function tests were significantly more frequent in the hourly workers; three of the four enzyme tests were more frequently abnormal. The difference was most marked for SGPT. The differences persisted after stratification by alcohol consumption.

These symptoms and abnormal tests appeared, in turn, to be more frequent among the chemical operators rather than the maintenance or warehouse employees. However, this subgroup of hourly workers reported greater alcohol consumption. Additional evidence of solvent absorption was a small but not statistically significant increase in hippuric acid excretion observed in the epoxy workers. The cause of the tremors noted in the hourly workers is not clear. Permanent neurological findings have not been associated with the solvents used at the plant.

These findings are consistent with the biochemical changes of subclinical liver injury, but it is not possible to be more specific without histologic diagnoses. It is difficult to attribute these liver findings to exposure to a specific chemical because of the multiple exposures and because, with the exception of the infrequently used ethylene dichloride, most are not particularly hepatotoxic. However, there is the possibility of hepatotoxicity resulting from chronic, low-level mixed exposure to organic solvents.[20] A recent Scandinavian study[21] of 23 young males (painters, chemical industry workers) exposed to low doses of organic solvents, lacquers, paints and plastics such as ethylene glycol, xylene, toluene, butyl acetate, acetone, butyl alcohol, benzene and turpentine. They were investigated because abnormal LFTs (2-4 fold increase in SGPT and SGOT) were found on routine occupational medical examinations. Liver biopsy was normal in four; the rest showed a non-specific reactive hepatitis with varying amounts of fatty infiltration on light microscopy. Electron microscopy showed marked changes including hypertrophy of smooth endoplasmic reticulum. The biochemical abnormalities resolved completely within 3-6 weeks after cessation of exposure; liver biopsies were not repeated. While this study has been criticized because of the lack of known levels of exposure or of adequate epidemiologic controls[23] and because an association between chemical exposure and liver abnormalities was predetermined.[24] One critic[23] supplied data showing no LFT abnormalities in a similarly exposed group. Thus, controversy regarding this issue persists. The fact that there was not a strong relationship between duration of employment and abnormal LFTs in the present study may reflect the acute nature of the injury, as suggested by the rapid resolution of the abnormalities with cessation of exposure in the Scandinavian study.

The decrements in FEV_1 described above in the Results section in a pilot plant worker, may represent an adverse response to the levels of HMDI present. However, the symptoms and wheezing, which stopped abruptly, can not necessarily be associated with the exposure, particularly in view of the respiratory infection present. Despite the generally low HMDI environmental levels, the 50 ug/M^3 short-term exposure (approximately one-fourth of the NIOSH recommended ceiling), is high enough to produce adverse effects in those workers already sensitized to isocyanates. From our results and interviews with previously exposed workers at Wilmington Chemical, it appears that isocyanate-associated respiratory problems have occurred at the plant.

VIII. RECOMMENDATIONS

Recommendations 1 to 5 were communicated in a letter to Wilmington Chemical Corporation on December 16, 1982.

1. The existing ventilation (consisting of a 6-inch diameter flexible duct having a centerline velocity of 1500 fpm) for the 20 gallon reactor vessel should be modified to include a local exhaust hood to improve the contaminant capture efficiency. Preferably, the hood should have a crescent geometry adaptable to the charging of the reactor vessel.

2. A standard operating procedure should be written to specify that a funnel should be used when charging the 20-gallon reactor vessel. The procedure will minimize spillage of the ingredients and subsequent exposure resulting from rapid vaporization upon contact with the reactor vessel.

3. Exposure to unreacted isocyanate during the urethane prepolymer drumming procedure could be further reduced or prevented by one of the following modifications:

   (a) The existing ventilation (consisting of a 6-inch diameter flexible duct having a centerline velocity of 750 fpm) could be modified to include a standard barrel filling local exhaust hood.

   (b) Although a little more difficult to institute, the most effective exposure control would be to directly pump the prepolymer from the reactor vessel to a drum at the urethane dispersion unit. Selecting the proper diameter of pipe to transfer the liquid is important.

4. Although the basic prepolymer ingredients are pumped into the 250 gallon reactor vessel via a positive displacement self-priming pump, occasional malfunction of the pump (as we observed) requires priming by the chemical operator. This is extremely important when the pump malfunctions during transfer of the free isocyanate. It is recommended that the preventative maintenance of the pump be improved to minimize the frequency of malfunction.

5. General housekeeping in the pilot plant needs to be improved to limit the storage of chemicals. Specific attention needs to be given to the more highly reactive and explosive compounds such as the one gallon glass container of boron trifluoride etherate. (The boron trifluoride compound has since been removed.)

6. A program for medical surveillance of workers potentially exposed to isocyanates should be instituted. This has a number of components, most features of which have been summarized in a NIOSH publication.[15] New employees should have medical histories to seek pre-existing respiratory symptoms and disease, especially asthma, and occupational histories to seek evidence of previous exposure to isocyanates. They should have baseline PFTs including, at least, FEV_1, and FVC (and calculation of the FEV_1/FVC ratio). Worker education concerning possible effects of isocyanates and work practices to minimize exposure should be instituted. Any worker reporting symptoms such as persistent cough, cough at night, wheezing, shortness of breath or difficulty breathing should be further evaluated, including pre- and post-shift PFTs. Those with greater than 10% decrease in FEV_1 over the shift should be referred to a pulmonary physician for determination of sensitization. Current employees should also have pre- and post-shift PFTs performed (after two consecutive work days if possible) at the beginning of the program and should be questioned about symptoms of isocyanate sensitization. Referral should be as for new employees. Workers determined to be sensitized should be removed from further exposure. All workers potentially exposed should be interviewed and undergo PFTs at least annually. Again, symptoms compatible with isocyanate sensitization should be investigated and significant pre- to post-shift decrements in FEV_1 or loss of FEV_1 greater than about 10% from one year to the next, should be further evaluated. Anyone with documented hypersensitivity to isocyanate should not have a work assignment involving exposure to isocyanates and may even be unable to tolerate working in the general area of isocyanate use or production.

   For proper performance of spirometry, a number of technical considerations should be addressed, including the use of a spirometer meeting ATS specifications,[27] employing a trained and enthusiastic technician, and, to the extent feasible, doing the tests with same machine, technician and time of day from year to year. Other features of an occupational pulmonary disease surveillance program include education of workers, maintenance of medical records and records of environmental exposure, and epidemiologic evaluation of data.

7. Although one cannot conclude that the abnormalities of liver function are definitely due to the chemical exposures, similar results have now been found in two studies of this group of workers in 1982 (Mt. Sinai and NIOSH). These abnormalities should be followed-up by liver specialists who can be informed by NIOSH or by the union of the previous results and potential exposures with a view to possible liver biopsies or other clinical tests of liver function for those with persistent abnormalities.

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XI. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report are currently available upon request from NIOSH, Division of Standards Development and Technology Transfer, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After 90 days, the report will be available through the National Technical Information Service (NTIS), 5285 Port Royal, Springfield, Virginia 22161. Information regarding its availability through NTIS can be obtained from NIOSH Publications Office at the Cincinnati address. Copies of this report have been sent to:

1. Wilmington Chemical Corporation, Wilmington, Delaware.
2. Authorized representatives of Employees, Joint Board Fur, Leather and Machine Workers Union, Local 1, United Food and Commercial Workers.
3. NIOSH, Region III
4. OSHA, Region III

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

APPENDIX A

Evaluation Criteria

Wilmington Chemical Company
Wilmington, Delaware
HETA 82-315

	NIOSH Recommended Criteria TWA (mg/m^3)	OSHA Standards TWA (mg/m^3)
Epichlorohydrin	LFL*	19
n-Butyl Glycidyl Ether	30 Ceiling	270
Toluene	375 750 Ceiling	750
Xylene	434 868 Ceiling	434
Methylene Bis-4-Isocyanate	.05 0.2 Ceiling	0.2

* Suspect Carcinogen - Lowest Feasible Limit

TABLE I

Results of Personal Breathing Zone Area Concentrations of
Epichlorohydrin, n-Butyl Glycidyl Ether, Toluene, and Xylene

Wilmington Chemical Company
Wilmington, Delaware
HETA 82-315

Date	Job And/Or Location	Sampling Period	Sample Volume (Liters)	Epichlorohydrin mg/m^3*	n-Butyl Glycidyl Ether mg/m^3	Toluene mg/m^3	Xylene mg/m^3
9-20-82	Epoxy Area-Chemical Operator	1036-1051	3	LD**	LD	-	-
9-20-82	Epoxy Area-Chemical Operator	1036-1102	2.7	LD	-	-	-
9-20-82	Epoxy Area-Chemical Operator	1051-1102	2.2	LD	LD	-	-
9-21-82	Epoxy Area-Chemical Operator	1046-1117	6.2	LD	LD	-	-
9-21-82	Epoxy Area-Production Manager	1339-1343	0.8	LD	LD	-	-
9-21-82	Epoxy Area-Senior Operator	1538-1548	10	-	-	120	-
9-21-82	Epoxy Area-Senior Operator	1539-1549	10	-	-	150	-
9-21-82	Epoxy Area-Senior Operator	1548-1558	10	-	-	210	-
9-21-82	Epoxy Area-Senior Operator	1549-1559	10	-	-	170	-
9-21-82	Epoxy Area-Senior Operator	1601-1613	12	-	-	61	-
9-21-82	Specialty Coating Senior Operator	1451-1501	10	-	-	-	96
Environmental Criteria (mg/m^3)				2	30	375	434
NIOSH Ceiling Limit for Toluene and Xylene (10-minute)				-	-	750	868
Limit of Detection (mg/sample)				0.01	0.01	0.01	0.01

* mg/m^3 = milligrams of substance per cubic meter of air sampled
** LD = less than limit of detection. The volume of adjusted lower limit of detection equals the analyte's lower limit of detection (mass per sample) divided by the air volume (cubic meter) sampled.

TABLE II

Results of Personal Breathing Zone Area Concentrations of Methylene Bis-4-Cyclohexyl Isocyanate, Epichlorohydrin, Glycidyl Ether, and Toluene

Wilmington Chemical Company
Wilmington, Delaware
HETA 82-315

Date	Job and/or Location	Sampling Period	Sample Volume (Liters)	Methylene Bis-4-isocyanate (MDI) mg/m³*	Epichlorohydrin mg/m³	n-Butyl Glycidyl Ether mg/m³	Toluene mg/m³
12-7-82	Pilot Plant - Chemical Operator	0832-1145	313	LD**	-	-	-
12-7-82	Pilot Plant - Chemical Operator	1555-1852	177	LD	-	-	-
12-7-82	Pilot Plant - Chemical Operator	1853-1930	37	LD	-	-	-
12-8-82	Pilot Plant - Chemical Operator	1637-1720	43	0.05	-	-	-
12-9-82	Pilot Plant - Chemical Operator	0420-0438	18	LD	-	-	-
12-7-82	Epoxy Area - Chemical Operator	0640-1450	49	-	LD	-	-
12-7-82	Epoxy Area - Chemical Operator	1510-1935	27	-	LD	-	-
12-8-82	Epoxy Area - Chemical Operator	0732-1500	44	-	LD	-	-
12-7-82	Epoxy Area - Chemical Operator	0640-1450	48	-	-	LD	-
12-7-82	Epoxy Area - Chemical Operator	1510-1935	27	-	-	LD	-
12-8-82	Epoxy Area - Chemical Operator	0732-1500	36	-	-	LD	-
12-7-82	Epoxy Area - Chemical Operator	0640-1450	49	-	-	-	4.5
12-7-82	Epoxy Area - Chemical Operator	1510-1935	27	-	-	-	4.4
12-8-82	Epoxy Area - Chemical Operator	0732-1500	44	-	-	-	5.6
Environmental Criteria (mg/m³)				0.2	2	30	375
NIOSH Ceiling Limit for Toluene and MDI (10-minute) Epichlorohydrin (15 minute)				0.06	-	-	750
Limit of Detection mg/sample				0.0003	0.01	0.01	0.01

* mg/m³ = milligrams of substance per cubic meter of air sampled.
** LD = less than limit of detection. The volume adjusted lower limit of detection equals the analyte's lower limit of detection (mass per sample) divided by the air volume (cubic meter) sampled.

TABLE III

Wilmington Chemical Corporation
Wilmington, Delaware
HETA 82-315

December 6-9, 1982

	Hourly (n=29)	Salaried (n=15)	P Value
Age(yr): Mean+S.D.	37.1+11.6	41.4+10.9	N.S*
Range	26-69	25-62	
#(%)greater than 40	8 (27)	7 (47)	N.S.**
Race (White/Nonwhite)	26/3	13/2	N.S.***
School			
#(%) with any Post-Grade 12	6 (21)	11 (73)	P=0.001**
Years, current job			
Mean+ S.D.	2.5+1.5	3.6+3.9	
Range	0.1-6	1-15	
Years, total at company			
Mean+S.D.	7.6+8.1	6.9+5.4	
Range	1-40	1.25-15	

*N.S.= Not significant (P>0.05)
* T-test, 2-tailed
** Chi-Square
*** Fisher's Exact Test, 1-tailed

TABLE IV

Background Data from Questionnaire
(Hourly vs Salaried)

Wilmington Chemical Corporation
Wilmington, Delaware
HETA 82-315

December 6-9, 1982

	Hourly (n=29)		Salaried (n=15)		P value[a]
	#	(%)	#	(%)	
Travel out of country	6	(21)	6	(40)	N.S.[b]
Hobbies with chemicals	6	(21)	2	(13)	N.S.
Previous liver disease	4	(14)[c]	0	(0)	N.S.
General anesthesia	22	(76)	10	(67)	N.S.
Potentially hepatotoxic medications	13	(45)	5	(33)	N.S. (Chi-square)
Ever used needles or syringes for nonmedical purposes	5	(17)	0	(0)	N.S.
Tattoos	7	(32)	1	(7)	N.S.
Alcohol consumption: present drinker/ ex/never drinker	21/7/1		13/1/1		
Units/week among present drinkers,					
Mean+S.D.	12.1+11.6		9.2+12.7		N.S[d]
Range	1-41		0.25-40		
# (%) of drinkers with <7 units/week	9	(43)	9	(69)	N.S.(Chi Square)

a Fisher's Exact Test, 1-tailed
b N.S.=Not Significant
c Two of the four initially learned of this during Mt. Sinai evaluation
d T-test, 2-tailed, t=.658, df=32

TABLE V

Prevalence of Reported Symptoms [a]
(Hourly vs Salaried)

Wilmington Chemical Corporation
Wilmington, Delaware
HETA 82-315

December 6-9, 1982

	Hourly (n=29)		Salaried (n=75)		p value[b]
Gastrointestinal(GI)	#	(%)	#	(%)	
Poor appetite	5	(21)	0	(0)	N.S.[d]
Persistent nausea	5	(21)	0	(0)	N.S.
Persistent abdominal pain	3	(10)	0	(0)	N.S.
Easily tired	7	(32)	1	(7)	N.S.
Feeling down	7	(32)	0	(0)	0.04
One or more GI symptoms	13	(45)	1	(7)	0.0095
Two or more GI symptoms	9	(31)	0	(0)	0.0135
Nervous System (NS) symptoms					
Headaches	7	(32)	1	(7)	N.S.
Dizziness	8	(28)	0	(0)	0.024
One or more NS symptoms	13	(45)	1	(7)	0.0095
Two or more NS symptoms	4	(14)	1	(7)	N.S.
Mucous membrane irritation (eyes, nose or throat	12	(41)	1	(7)	0.016
Skin rash(itch/ burning/redness)	14	(48)	2	(13)	0.024[c]

a All questions refer to period "in the past month" except skin which was "during past three months"
b All are Fisher's Exact Test, 1 tailed, except those marked c
c Chi-square
d N.S.=Not significant ($p>0.05$)

TABLE VI

Liver Function Test Results

Wilmington Chemical Corporation
Wilmington, Delaware
HETA 82-315

December 6-9, 1982

Test (Normal Range)	Hourly (N=29) Mean[a] ±S.D.	Abnormal Results* #	(%)	Salaried (N=15) Mean[a] ±S.D.	Abnormal Results* #	(%)
GGT (5-37IU)	3.5±0.8[b]	10	(34)**	3.0±0.7[b]	2	2 (13)**
AP (15-65IU)	3.7±0.2[c]	0	(0)	3.6±0.2[c]	0	0 (0)
SGOT (12-37IU)	3.2±0.3[d]	3 (done on 28-one lipemic)	(11)**	2.9±0.2[d]		0 (0)**
SGPT (6-39IU)	3.3±0.5[e]	7 (done on 26-3 lipemic)	(27)***	3.1±0.3[e]		0 (0)***
1 or more tests abnormal		13	(45)****			2 (13)****
More than one test abnormal		5	(17)**			0 (0)**

* Fisher's Exact Test, 1-tailed
** Not significant
*** p=0.040
**** p=0.039; chi-square

a Log-transformed values
b t=1.96; p=0.056
c t=1.91; p=0.064
d t=3.15; p=0.003
e t=1.71; p=0.095

TABLE VII

Liver Function Test and Exposure Status.

Wilmington Chemical Corporation
Wilmington, Delaware
HETA 82-315

December 6-9, 1982

Case: one or more liver function tests abnormal

Overall	Case	Non-Case		
Hourly	13	16	29	Odds ratio=5.3 95 percent confidence limits (1.1, 25.6)
Salaried	2	13	15	p<0.05
	15	29	44	

Stratified:	Low Alcohol			High Alcohol		
	Case	Non-Case		Case	Non-Case	
Hourly	5	12	17	8	4	12
Salaried	1	10	11	1	3	4
	6	22	28	9	7	16

Odds Ratio: 4.17
95 Percent Confidence
Interval (0.45, 38.6)

Odds Ratio: 6.00
95 Percent Confidence
Interval (0.50, 72.6)

Summary odds Ratio (Ref 25): 4.9
95 Percent Confidence
Interval (0.9, 25.7)

TABLE VIII

Comparison of Results, Production
vs other Hourly Workers

Wilmington Chemical Corporation
Wilmington, Delaware
HETA 82-315

December 6-9, 1982

	Production (n=13) #	(%)	Other (n=16) #	(%)	P value*
One or more GI symptoms	9	(69)	3	(19)	0.0069 (Chi sq.)
Two or more GI symptoms	6	(46)	3	(19)	N.S.
One or more NS symptoms	8	(62)	7	(44)	N.S.
Mucous membrane irritation	9	(69)	6	(38)	N.S.
ALCOHOL					
Present drinkers	9	(69)	12	(75)	N.S.
Proportion of drinkers with <7 units/week	3	(23)	6	(38)	N.S.
Units/week in drinkers, Mean ± S.D.	16.4±14.4		8.8±8.2		
LIVER FUNCTION TESTS					
1 or more abnormal	9	(69)	4	(25)	P=0.019 (Chi sq.)
2 or more abnormal	3	(23)	2	(13)	N.S.
GGT abnormal	6	(46)	4	(25)	N.S.
SGOT abnormal	2	(15)	1	(7)	N.S.
SGPT abnormal	5	(42)**	2	(14)***	N.S.

* Fisher's Exact Test, 1-tailed
** of 12-1 1; pemic
*** of 14-2 1; pemic

TABLE IX

Pre- to Post- Shift Change in Hippuric
And Excretion, By Department

Wilmington Chemical Corporation
Wilmington, Delaware
HETA 82-315

December 6-9, 1982

Department/Job (N)	Mean Change ±S.E. (mg/ml)	P*	Mean Change ± S.E. (g/g creatinine)	P*
Production: Specialty coatings (5)	-0.31±2.12	NS	+0.9±0.32	NS
Production: Polyurethane (3)	-0.7±0.41	NS	+0.12±0.20	NS
Production: Epoxy (4)	+0.54±1.07	NS	+0.79±1.69	NS
Maintenance (4)	-0.01±0.47	NS	-0.07±0.27	NS
Warehouse (4)	+0.18±0.41	NS	+0.04±0.31	NS
QC/R+D (6)	+1.09±2.10	NS	+0.39±0.68	NS

* Paired t-test, 2-tailed

TABLE X

Spirometry - Production Employees
(Percent change, pre- to post shift)

Wilmington Chemical Corporation
Wilmington, Delaware
HETA 82-315

December 6-9, 1982

Production Subgroup (number)		FVC	FEV_1
Specialty coatings (5)	Range	-5.8% to +2.0%	-6.5% to +7.2%
	Median	-0.5%	-1.3%
Polyurethane (Pilot plant) (5)*	Range	-8.2% to +7.8%	-10.5% to + 3.7%
	Median	-3.1%	-2.7%
Epoxy (4)	Range	-5.3% to + 6.4%	-9.7% to + 11.7%
	Median	+2.6%	+0.8%

* This represents measurements over two days in these individuals