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PARKER HANNIFIN CORPORATION
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NIOSH INVESTIGATORS:
DAVID L. ORGEL, M.D., M.P.H.
MARY NEWMAN, Ph.D

I. SUMMARY

On January 5, 1989, the National Institute for Occupational Safety and Health (NIOSH) received a confidential worker request for an investigation of respiratory complaints (including asthma) at the Parflex Division of the Parker Hannifin Corporation in Ravenna, Ohio.

An initial site investigation was conducted February 15-16, 1989. Follow-up visits were conducted on March 8-9, 1989; August 9-10, 1989; January 23-25, 1990; February 6-7, 1990; and May 9-10, 1990.

The initial site visit consisted of a walk-through of the facility and private medical interviews with 28 employees. The medical evaluation determined the primary health concern among employees to be the perception of a high prevalence of asthma among current and past employees. The industrial hygiene evaluation confirmed the potential for exposure to asthma-producing isocyanate compounds.

On the first follow-up visit, a one-page respiratory symptom questionnaire survey was completed by 130 (72%) of 202 hourly employees. The survey confirmed the high prevalence of respiratory symptoms found on the initial site visit, including some consistent with asthma, but no clear high-risk area of the plant was identified.

The second follow-up visit, conducted in August 1990, was performed to assess possible exposures to respiratory irritants or asthma-producing compounds. This industrial hygiene survey found trace amounts of airborne 2,4-toluene diisocyanate (2,4-TDI) during urethane extrusion and 12 inches from a locally ventilated glue pot. In addition, quantifiable amounts of 2,6-diisopropylphenyl isocyanate (PPI) were identified in the same two areas, as well as 12 inches from a glue pot without local ventilation.

Subsequent medical evaluations attempted to determine the prevalence of occupational asthma and to assess the potential relationship between cases of asthma and exposure to either TDI or PPI. During the follow-up visits conducted in January and February, 1990, an in-depth respiratory symptom questionnaire and peak flow meters were distributed to fifty-two employees. The peak flow meters were collected two weeks later. Fourteen employees (27%) had peak flow results indicative of work-related reversible airways obstruction; eight of these (57%) reported a previous diagnosis of asthma. Eleven (21%) had a borderline abnormal peak flow result; six of these (55%) reported a previous diagnosis of asthma. There was no significant association between job and peak flow results. Individuals employed as large and small braiders had an increased prevalence of shortness of breath, wheezing, and chest tightness.

On May 9-10, 1990, the 52 employees who completed the peak flow testing were asked to submit a blood sample for determination of total immunoglobulin G (IgG), immunoglobulin E (IgE), albumin, and globulin, as well as for IgE, IgG4, and IgG specific to PPI and TDI. Thirty-five (67%) submitted an adequate sample. IgE to PPI was elevated in one individual (3%) who had a previous diagnosis of asthma. IgG to PPI was elevated in 16 samples (46%) and borderline elevated in seven (20%). IgG to TDI was elevated in six (17%) and borderline elevated in five (14%); IgE to TDI was elevated in two individuals (6%). No

elevations were found for IgG4 to PPI or to TDI. These results were unrelated to symptoms, a history of asthma, abnormalities on peak flow testing, occupation, or years employed. There was also no significant association between titers of IgG to PPI and IgG to TDI.

This study found a high prevalence of respiratory symptoms and potential exposure to asthma-producing compounds; 2,4-toluene diisocyanate (2,4-TDI) and 2,6-diisopropylphenyl isocyanate (2,6-PPI). Peak flow testing was abnormal in 23% of those tested, and markers of immunologic response to PPI and TDI were positive in 14-45%. Although the immunologic responses do not prove that the symptoms are related to these chemicals, they do indicate that exposure has occurred, and in some individuals may be the cause of the symptoms.

KEYWORDS: SIC 3041 (rubber and plastics hose and belting), asthma, peak flow testing, isocyanates, RAST testing, ELISA testing, 2,4-toluene diisocyanate (2,4-TDI), 2,6-diisopropylphenyl isocyanate (2,6 PPI)

II. INTRODUCTION

On January 5, 1989, the National Institute for Occupational Safety and Health (NIOSH) received a confidential worker request for an investigation of respiratory complaints (including an apparently high prevalence of asthma among current and past employees) at the Parflex Division of the Parker Hannifin Corporation in Ravenna, Ohio.

An initial site investigation was conducted on February 15-16, 1989. Follow-up visits were conducted March 8-9, 1989; August 9-10, 1989; January 23-25, 1990; February 6-7, 1990; and May 9-10, 1990. Interim reports were distributed on July 14, 1989, and February 2, 1990, and participants were notified of their own test results on December 13, 1989; March 13, 1990; and July 14, 1990.

III. BACKGROUND

The population of the plant includes 202 hourly workers. One half of the 275,000 square feet is used for the warehouse, which employs 48; the rest of the plant is involved in the manufacture of fluid connectors. There are three shifts, each with approximately 65 to 70 workers.

The Parflex Division manufactures thermoplastic flexible hose and tubing using an extrusion process. The products may be composed of polyethylene, polyvinylchloride (PVC), polypropylene, nylon, polyester, or polyurethane. Various polyurethane adhesives containing toluene diisocyanates, trichloroethylene, methylene chloride, and 1,1,1-trichloroethane, and resorcinol, as well as an adhesive composed of phenols to which ethanol is added, are used to bond braided yarns to some of the tubing. Within an enclosure, wire sprayed with oil is braided onto some tubing. Inks containing methyl alcohol, ethyl alcohol, butyl alcohol, and methylene chloride, and thinners containing cyclohexanone, are used to print labels on the tubing.

To form a multitube, several tubes are combined, and an outer tube is extruded onto the core. Excess plastic material is removed from tools and machine parts in a heated (850-1000 F) "tool bath" containing aluminum oxide. For equipment too large for the tool bath, a propane blow torch is used to heat the plastic, thus, facilitating its removal. This operation takes approximately five minutes and is performed two to five times per week. A proprietary process, separating the yarn from the plastic tubing, allows waste tubing to be reprocessed. This unit is reported by the employees to create excessive dust.

Material safety data sheets (MSDSs) were reviewed in an effort to understand exposure potentials and identify substances that could cause the adverse health effects of concern to the employees. Thermal decomposition products of the resins that may be released during the extrusion process, tool bath cleaning, and removal of the plastic residue with the blow torch include hydrogen chloride, hydrogen cyanide, oxides of nitrogen and sulfur, tetrahydrofuran, diisopropylphenyl isocyanate, carbon monoxide, acrolein, formaldehyde, amines, and pthalates.

Chemical composition information was obtained from two of the suppliers of adhesives. Both adhesives contained isocyanates in varying amounts, with one adhesive containing greater than 9% of isocyanates, which are known to cause occupational asthma.

The extruders, tool bath, and some of the areas where the adhesives are being applied are equipped with local exhaust ventilation. The effectiveness of these systems were not evaluated during the initial visit. However, it was noted that in one case the ventilation system was hampered by the use of cardboard to prevent dripping of adhesives into the ventilation system. In addition, some adhesives are heated prior to application without local ventilation.

General ventilation in winter is primarily supplied by four wall-mounted air-rotation units, two in the manufacturing area and two in the warehouse area. There are also ten roof intake units and ten exhaust units that are used, depending on ambient conditions. In order to heat the warehouse, air is recirculated from the manufacturing departments into the warehouse. In the summer, additional ventilation is provided by opening the windows.

Respirators are required to be worn for the cleaning operation using the propane blow torch. Respirators are also supplied and used in certain other operations, although their use is not required. There is no written respirator program.

In 1987, a complaint was filed with the Ohio Industrial Commission (OIC) concerning the tool bath. The OIC determined that the exhaust from the tool bath was entering the roof intake unit. In response to this finding, the height of the exhaust stack was increased.

IV. METHODS

A. Environmental

On August 9-10, 1989, the NIOSH industrial hygienist conducted exposure and environmental air monitoring. Air sampling and analysis methodology are presented in Table 1. Two general area air samples ("worst case" locations) and two personal breathing zone (PBZ) air samples were collected to determine the air concentration of acid gases during normal operation of the extruders (PVC extrusion) and during certain maintenance operations on the extruders ("pulling the screw" and torching or "burning off" the screw). Details of the sampling strategy and sampling locations are presented in Table 2.

Three general area air samples ("worst case" locations) were collected to determine the air concentrations of isocyanates during normal operation of the extruders (urethane extrusion) and near the adhesive application operation. Details of the sampling strategy and sampling locations are presented in Table 3.

Two long-term (approximately five-hour) general area air samples were collected to determine the air concentration of tetrahydrofuran during normal operation of the extruders in department 4902. One sample was collected on line 12 while Hytrel was being extruded (sampling probe placed 14" from nose and die), and the other sample on line 9 while urethane was being extruded (sampling probe placed 5" from nose and die).

Two long-term (approximately six-hour) general area air samples were collected to determine the air concentration of acrolein and formaldehyde during normal operation of the extruders in department 4902. One sample was collected on line 12 while Hytrel was being extruded (sampling probe placed 14" from nose and die), and the other sample on line one while polyethylene was being extruded (sampling probe placed 12"

from nose and die).

One long-term (approximately 5-hour) general area air sample was collected to determine the air concentration of cyclohexanone. The sampling probe was placed at a "worst case" location, 12" from the inkjet printer.

Two general area air samples and one personal breathing zone air sample (for the operator of the separator) were collected to determine the air concentration of respirable particulates during normal operation of the separator. One sample was collected at a "worse case" location, with the sampling probe placed at the face of the separator. The other area sample was collected 40' from the separator at the nearest work station.

Using colorimetric indicator tubes (Draeger tubes) the instantaneous concentration of oxides of sulfur and nitrogen, carbon monoxide, and hydrogen cyanide, were determined at "worst case" locations during normal operation of the extruders (PVC, Hytrel, polyethylene, and urethane extrusion), and while "pulling the screw."

Eight short-term area and one short-term PBZ air samples for volatile organics were collected at "worst case" locations for the following operations: normal operation of the extruder (PVC extrusion), removal of nylon from tools with a torch, and on the roof within 20' of the local exhaust vent for the tool bath. The air samples were collected using calibrated battery-powered sampling pumps operating at a flow rate of 0.1 liters per minute. The pumps were attached via Tygon® tubing to a charcoal tube collection media. One tube from each location was qualitatively analyzed for volatile organic compounds by gas chromatography. A quantitative analysis for the substances identified on the qualitative analysis was subsequently performed on the remainder of the tubes.

A bulk sample of a "tar-like" substance that had condensed on the electrical conduits near the ceiling was collected and qualitatively analyzed for volatile organic compounds by gas chromatography.

Smoke tubes were used to qualitatively evaluate the capture effectiveness of the local exhaust ventilation systems for each of the extruders and the application of urethane adhesive.

B. Medical

Review of the OSHA 200 logs and private interviews with 28 employees were conducted during the initial survey on February 15-16, 1989, the results of which were summarized in an interim report dated July 14, 1989.

1. First follow-up medical evaluation

   A follow-up medical evaluation was conducted on March 8-9, 1989. This consisted of a questionnaire survey to estimate the prevalence of symptoms and identify high-risk areas of the plant. Parflex employed 202 hourly workers as of February 28, 1989; of these, the 14 new employees and 7 on sick leave were excluded. Employees were asked their birth date and if they had a personal or family history of allergies or smoked cigarettes. They were also asked if they experienced within the last month shortness of breath, chest pain or tightness, wheezing, stuffy nose or watery eyes, and/or cough. Those who answered affirmatively to any of these questions were asked if they felt any of these symptoms were work related, the activity that caused the symptom(s), if there was any improvement away from work, and if they had a history of asthma.

2. Second follow-up medical evaluation

   From the 130 employees who had completed the symptom questionnaire distributed March 8-9, 1989, 60 were selected for peak flow monitoring from January 23 through February 7, 1990. Forty (67%) were considered potential asthma cases, because in the March survey they reported work-related respiratory symptoms. The remaining 20 participants had no respiratory complaints of any kind and were considered "controls."

   Participating employees were instructed in the appropriate use of the peak flow meters. They were asked to use the meter as many times throughout the day as possible, up to every two hours, at work and away from work. The best three efforts within 20 cc were used; employees marked on the record sheet whether they noted any symptoms, whether they were at work or not at work, and any event that might have effected the result (e.g., use of asthma medications, exposure to a process that bothered them, etc.).

   Participants were asked to complete a three-page questionnaire at the same time peak flow meters were distributed. This questionnaire obtained demographic information (age, race, sex); year first employed at Parflex; current job; symptoms of wheezing, shortness of breath, and chest tightness; and whether these symptoms first began before or after initial employment at Parflex; their duration; information on other illnesses; and smoking history.

   All participants' peak flow results were checked the day after distribution of the meters to insure the meters' appropriate use. The meters and test results were collected two weeks later, on February 7-8, 1990.

   A peak flow result was considered suggestive of work-related asthma if there was a greater than 20% change in peak flow from best to worst result, on more than one occasion, in a pattern that could be work related (i.e., a decline at work, either throughout the day or throughout the week, with improvement away from work, either overnight or through the weekend or holiday). The highest of the best and worst three values were used for the calculation. Borderline abnormal was defined as only one 20% decline, or a pattern of decline that did not seem to be work related.

3. Final follow-up medical evaluation

On May 9-10, 1990, the employees who completed the peak flow part of the study were asked to provide a blood sample for immunologic testing. The blood was tested for total protein, albumin, globulin, IgG, IgE, and IgG, IgG4, and IgE specific to TDI and PPI.

V. EVALUATION CRITERIA

A. Environmental Evaluation Criteria

As a guide to the evaluation of the hazards posed by the 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 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), 2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs), and 3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs). 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 those levels specified by an OSHA standard. Except for isocyanates, which are discussed below, the evaluation criteria and brief comments on health effects for chemical compounds sampled during this survey are presented in Table 4.

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

B. Isocyanates

Isocyanates are reactive chemicals used in foams, coatings, adhesives, rubbers, and fibers.[1] Toluene diisocyanate (TDI) is the most commonly used isocyanate, primarily as a precursor in the production of polyurethanes, polyureas, polyamides, etc.

Acute effects of TDI exposure include eye, upper respiratory tract, and skin irritation at high concentrations, an asthma-like response in nonsensitized individuals, and asthma in sensitized individuals, including decrements in pulmonary function during a workshift. Symptoms in nonsensitized individuals may include chest tightness, chills, cough, fever, headache, wheezing, and shortness of breath, which can be delayed up to eight hours. In sensitized individuals, symptoms may occur at much lower concentrations, and are similar to classic asthma. In general, between 4 and 15% of workers exposed to isocyanates become sensitized. Sensitized individuals usually may not safely return to work where a continuing exposure occurs, as chronic exposure to TDI in employees sensitized to this agent may lead to long-term impairment in lung function.

In December 1989, NIOSH recommended that TDI be regarded as a carcinogen based on its ability to produce benign and malignant tumors in rats and mice.[3] In this document, NIOSH stated that "the excess cancer risk for workers exposed to TDI...has not yet been quantified, but the probability of developing cancer should be decreased by minimizing exposure. Employers should therefore assess the conditions under which workers may be exposed to TDI...and reduce exposures to the lowest feasible concentration."[4]

The OSHA PEL and ACGIH TLV for TDI are 5 parts per billion (ppb) for a full shift time-weighted average, and a ceiling limit of 20 ppb for any 10-minute period.[2,3] Its odor threshold is well above the OSHA limit of 0.02 parts per million (ppm). Presently, the OSHA PEL for MDI is a ceiling limit of 200 micrograms per cubic meter (ug/m^3).[2] The ACGIH TLV is 51 ug/m^3, which is an 8-hour TWA.[2] The NIOSH REL is a TWA of 50 ug/m^3 for up to 10 hours, and a ceiling limit of 200 ug/m^3.[3,5] Currently, evaluation criteria do not exist for occupational exposure to PPI.

C. Peak Flow Metering and the Evaluation of Occupational Asthma

Peak flow metering is an accepted form of surveillance for occupational respiratory diseases.[6] Peak flow meters measure variability in peak flow over the day, both at work and during nonwork activities. A pattern of decline in peak flow during work that is reversed during nonwork hours is evidence of occupational asthma. In one selected population, the sensitivity of peak flow metering is reported to be 77% and specificity 100%.[7] Peak flow meters have been used in the diagnosis of occupational asthma due to isocyanates.[8] However, potential confounding may occur due to the variability in subject effort and cooperation, and this may be of greater concern with peak flow meter testing than with other types of pulmonary function testing due to its performance in an unobserved environment.

D. Immunologic Testing (IgG and IgE titer) and the Evaluation of Occupational Asthma

Measurement of titers of antibodies to specific agents holds intuitive appeal in the evaluation of occupational asthma. Logically, the presence of specific antibody would be

additional evidence of an immunologic mechanism for the observed signs and symptoms. The research in this area presents a mixed picture. IgE antibodies are classically associated with immediate hypersensitivity reactions and are associated with acute exposures to isocyanates and changes in pulmonary function.[9,10] IgE and IgG titers to isocyanates have been associated with severe disease.[11] In subjects with positive inhalation challenges to hexamethylene diisocyanate (HDI) and diphenylmethane diisocyanate (MDI), IgG titers were more closely associated with disease than IgE titers.[12] However, in another study looking at all exposed workers, these titers were not associated with disease.[13] In a study comparing exposed and non-exposed subjects, IgG titers were more predictive of exposure than disease.[14]

In summary, IgE titers appear to correlate with isocyanate-induced asthma, but IgG titers are most strongly associated with exposure. Non-immunologic mechanisms may contribute to isocyanate asthma, perhaps through irritative phenomenon superimposed an bronchial hyperreactivity (reactive airways disease syndrome or RADS).[15]

VI. RESULTS

A. Environmental Survey

The results of the general area air samples for isocyanates are presented in Table 3. Of the four isocyanates evaluated, only 2,6-diisopropylphenol isocyanate (PPI) was found in levels above the limit of quantification (LOQ) (4 ug/sample). 2,4-toluene diisocyanate (2,4-TDI) was found in trace concentrations (e.g., concentrations between the limit of detection (LOD) and LOQ). The area air samples collected were at "worst case" locations and not indicative of personal exposures. The concentration of PPI and 2,4-TDI were less near the glue pot that had local exhaust ventilation.

No airborne tetrahydrofuran, acrolein, formaldehyde, cyclohexanone, respirable dust, sulfur dioxide, nitrogen dioxide, or hydrogen cyanide was detected. The highest concentration of carbon monoxide was 10 ppm at a location 6" from the torch during the "burn off" procedure. This is a "worst case" location and not indicative of personal exposure, and significantly lower than the NIOSH REL of 35 ppm.

The air samples collected for qualitative analysis for volatile organic compounds during "burning off" the nylon coated tools, and on the roof near the tool bath exhaust did not detect any volatile organic compounds. This could have been due partly to the short sampling duration. The entire "burning off" process took less than seven minutes; sampling was conducted for this time period. The air samples collected on the roof were over a two-hour time period. The qualitative analysis for volatile organic compounds for the short-term (2-hour) sample collected at a location 16" from the nose and die while PVC extrusion was operating normally indicated 1,1,1-trichloroethane and trichloroethylene as the largest components. The subsequent analysis of all remaining charcoal tubes (including the roof samples and "burn off" samples) for these two compounds indicated concentrations of either no detectable amounts or trace quantities. The limit of detection (LOD) was 0.01 ug/sample, and the LOQ was 0.03 ug/sample. The two samples with trace quantities of these substances were the one collected by the PVC extruder (approximately 0.14 ppm 1,1,1-trichloroethane and 0.14 ppm trichloroethylene), and the one near the roof intake for the general ventilation system that was closest to the roof exhaust for the tool bath (approximately 0.14 ppm 1,1,1-trichloroethane and 0.14 ppm trichloroethylene). All values are far below the

OSHA PEL of 350 ppm for 1,1,1-trichloroethane and 50 ppm for trichloroethylene. NIOSH considers trichloroethylene a potential human carcinogen and recommends exposures be reduced to the lowest feasible levels.

The only compound detected in the bulk sample of the condensate on the electrical conduits was caprolactam. This compound is listed on the material safety data sheet (MSDS) for the nylon copolymer material. Caprolactam has low volatility at ambient temperatures. Exposures to caprolactam as a dust or mist can cause skin irritation. Caprolactam vapor is less irritating than the dust, with the response ceasing promptly after exposure.

B. Medical

1. First Follow-up Evaluation, March 8-9, 1989

A self-administered questionnaire was completed by 130 (72%) of 181 current hourly employees. Their average age was 39 years; 47 (36%) of these employees smoked; and 22 employees (17%) had a personal or family history of allergies. Of the 130 respondents, 25 individuals (19%) had no shortness of breath, chest pain or tightness, or wheezing in the preceding month. Of the 105 symptomatic employees, 65 (62%) felt that at least some of their symptoms were work-related. Of the 65 employees with work-related complaints, 71% reported shortness of breath, 49% noted chest pain or tightness, and 46% complained of wheezing. Table 5 indicates the distribution of symptomatic employees by department. (No employee working in bobbin winding and material handling had any work-related respiratory complaints.)

Among the 65 employees with work-related respiratory symptoms, 58 (89%) felt that their symptoms improved away from work, six (9%) noted no change, and one did not complete this part of the question. Of note was that 18 (28%) of the employees with work-related respiratory complaints had a history of asthma. There was no significant relationship between any of the symptoms and age, smoking history, or history of allergies.

2. Second Follow-up Evaluation (January 23 - February 7, 1990)

Fifty-two employees participated in the follow-up medical evaluation (33 with respiratory symptoms, 19 without). This group of participants represented 30 of 40 (75%) symptomatic employees and 19 of 20 (95%) asymptomatic employees from the first questionnaire; three employees not included in the original list of participants wished to participate and are included in further analysis with the symptomatic group. Their average age was 42 years, and their average duration of employment was 10 years (range was one to 21 years) (Table 6). Twenty employees (38%) worked in the warehouse, 11 (21%) in extrusion, 6 (12%) in braiding, and 15 (29%) in other jobs throughout the plant.

a. Symptoms

Of the 52 participants, 28 (54%) complained of wheezing at work (Table 7), of which 27 individuals noted onset of wheezing after employment at Parker. Nineteen (68%) examinees noted wheezing lasting more than one hour.

Twenty-eight (54%) participants complained of shortness of breath at work. In all of these, the shortness of breath began after employment at Parker; seventeen (61%) noted a duration of greater than one hour.

Thirty-two (62%) participants complained of chest tightness at work. Thirty-one of these (97%) first noted it after their employment with Parker. In 19 (59%), the duration was greater than one hour.

Symptomatic employees did not differ significantly from asymptomatic employees in terms of age, sex, race, years employed, or job location.

b. Medical conditions

Fourteen employees (27%) reported a previous diagnosis of asthma, 24 (46%) had a sinus problem, two (4%) had eczema, six (12%) had hay fever, and nine (17%) had allergies (Table 8). Individuals with work-related symptoms were significantly more likely than asymptomatic employees to have allergies (RR=1.8, p=.03, but with an expected cell less than 5) and sinus complaints (RR 1.8, p=.01), but were no more likely to have a diagnosis of asthma, hay fever, or eczema. In addition, individuals with work-related symptoms were no more likely than participants without symptoms to be smokers, be under the care of a physician, or take medications.

c. Peak flow

Twenty-seven (52%) employees had normal peak flow results, fourteen (27%) had an abnormal peak flow (suggestive of work-related asthma), and eleven (21%) had a borderline abnormal result. Symptomatic employees were no more likely than asymptomatics to have an abnormal peak flow result. There was no association between smoking status and peak flow result with six (32%) of the 19 nonsmokers having abnormal or borderline peak flow results compared to 19 (58%) of the 33 employees who currently smoke or had ever smoked.

d. Job

There was no association between job and peak flow result (Chi-square 3.28, 3 df, p=.35) (Table 9). There was a borderline significant association between job and symptoms of wheezing (Chi-square 7.29, 3 df, p=.06) and chest tightness (Chi-square 7.17, 3 df, p=.07), and a significant association between job and shortness of breath (Chi-square 8.28. 3 df, p=.04). For these three symptoms, large and small braiders was the occupational group with the highest prevalence of respiratory symptoms.

e. Potential cases of occupational asthma

Peak flow metering documented eight employees (15%) with a pattern of decreased peak flow at work, respiratory symptoms at work, and a history of asthma. An additional five (10%) had borderline peak flow results, respiratory symptoms at work, and a history of asthma (one employee who gave a history of asthma on interview but not on questionnaire is included in this group).

3. Final Follow-up Evaluation

Thirty-five of the 52 (67%) employees provided an adequate specimen. This include 12 of the 14 (86%) employees with an abnormal peak flow, 9 of the 11 (82%) with a borderline peak flow, 11 of 19 with wheezing or chest tightness related to work but without peak flow changes, and 3 of 8 (38%) without symptoms and without peak flow changes. A priori case/control status was not associated with completion of this portion of the study; however, employees with an abnormal peak flow result were more likely to participate that individuals with normal peak flows (p=.01).

Results of the blood testing are summarized on Table 10. Fifteen employees (43%) had a clearly positive IgG titer to PPI, and an additional seven (20%) had a borderline titer. No employee had a positive or borderline IgG4 titer to PPI, and only one had a positive IgE titer. In addition, six employees (17%) had a positive IgG titer to TDI, and five (14%) had a borderline titer. There were two (6%) positive IgG4 titers to TDI and no borderline titers, and no borderline or positive IgE titers to TDI. There was no significant correlation between the IgG titers to PPI and TDI.

There was no relationship between a positive or borderline IgG titer to PPI or TDI and an abnormal or borderline peak flow test (Table 11). There was also no association between job and an abnormal or borderline IgG to PPI or TDI (Table 12), or between a history of asthma and an abnormal or borderline IgG to PPI or TDI (Table 13). The one employee with a positive IgE titer (to PPI) reported a diagnosis of asthma and had an abnormal peak flow test.

Finally, there was no relationship between IgG titers to PPI or TDI and symptoms (history of wheezing, shortness of breath, or chest tightness at work), years employed at Parker, age or sex.

VII. CONCLUSION AND DISCUSSION

This investigation documented a high prevalence of respiratory complaints among the employees of the Parker Hannifin Ravenna plant. These complaints were not isolated to a particular area of the plant or occupation, but were instead generalized throughout the plant.

There was potential exposure to isocyanates during both extrusion and cabling, the latter through the use of isocyanate containing adhesives. This exposure was not controlled with local ventilation in every case, but instead relied on general ventilation, which may have disseminated the isocyanates throughout the plant. Exposures were potentially worse in the winter, when dampers were placed on wall units to maintain a constant internal temperature, thus reducing the inflow of fresh air.

Peak flow monitoring documented eight (15%) of 52 employees tested with results indicative of work-related reversible airway obstruction who also had respiratory symptoms at work and a history of asthma. These eight would fit the current NIOSH surveillance criteria for occupational asthma.[16] An additional five individuals (10%) had borderline peak flow results, respiratory symptoms at work, and a history of asthma, and could potentially also have occupational asthma.

Immunologic testing revealed only one employee with a isocyanate-specific IgE; of interest, this was to PPI, and was in an employee with an abnormal peak flow result, history of asthma, and work-related respiratory symptoms. However, a large number of employees had PPI- and/or TDI-specific IgG, which, at a minimum, indicates exposure to these chemicals.

This study indicates a potential association between exposure to PPI and symptoms and findings consistent with asthma. This association has not been previously described. While this association is confounded by the additional finding of exposure to TDI, a known cause of occupational asthma, it does indicate the need for additional research into the potential role of PPI in the genesis of occupational asthma.

VIII. RECOMMENDATIONS

1. Local exhaust ventilation should be provided to all processes using isocyanate-containing adhesives.

2. Local exhaust ventilation should be provided to the extrusion process, with exhaust air not recirculated in the plant.

3. Only supplied air respirators should be used whenever there is potential for exposure to isocyanates, such as in the mixing and use of isocyanate-containing adhesive. Whenever respirators are used, a complete respiratory protection program must be provided with minimum standards for such a program as set forth in the OSHA General Industry Standards 29 CRF 1910.134.

4. The area where mixing and storing of adhesives is done should be separated from the general area of the plant and provided with its own ventilation system. Exhaust air should not be recirculated.

5. A medical surveillance system should be provided to workers exposed to isocyanates.[4]

6. Given the high prevalence of respiratory symptoms in the plant and the known effect of cigarette smoke on pulmonary function, a no-smoking policy should be implemented. Employees who continue to smoke should be counseled on how smoking may exacerbate the adverse health effects of occupational respiratory hazards.

7. The possibility of skin and eye contact with isocyanate-containing liquids should be minimized using proper personal protective equipment.

8. An exposure monitoring program should be implemented for all workers potentially exposed to hazardous chemicals. This program should consist of air sampling in the breathing zone to determine the workers' exposures. The purpose of this exposure monitoring is to determine whether exposures to any chemical agent exceeds the applicable limits, and to develop control procedures for protecting workers from hazardous exposures. Exposure monitoring should be performed on an annual basis, or whenever changes in work processes or conditions are likely to lead to a change in exposures. Though not all workers have to be monitored, sufficient samples should be collected to characterize the exposures. Variations in work habits and production schedules, worker locations, and job functions should be considered when developing exposure monitoring protocols.

IX. REFERENCES

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X. AUTHORSHIP & ACKNOWLEDGMENTS

Report Prepared by:

David Orgel, MD, MS
Medical Officer
Medical Section
Surveillance Branch

Other Investigators:

Mary Newman, PhD
Industrial Hygienist
Industrial Hygiene Section

Christopher M. Reh
Industrial Hygienist
Industrial Hygiene Section

Originating Office:

Hazard Evaluations and Technical Assistance Branch
Division of Surveillance, Hazard Evaluations, and Field Studies

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Table 1

Air Sampling and Analysis Methodology

Parker Hannifin
Ravenna, Ohio
HETA 89-083

August 9, 1989

Substance	Collection Device	Flow Rate (liters per min.)	Analysis	References[1]
Acrolein/Formaldehyde chromatography	(solid sorbent tube) orbo-23 Tube	0.1	gas chromatography	OSHA 52
Acid gases (hydrochloric, hydrofluoric, nitric, sulfuric and phosphoric acid)	(solid sorbent tube) silica gel	0.5	ion chromatography	NIOSH 7903
Tetrahydrofuran	charcoal tubes	0.2	gas chromatography	NIOSH 1609
Isocyanates	impinger containing toluene	1.0	high performance liquid chromatography	NIOSH 5521
Cyclohexanone	charcoal tubes	0.1	gas chromatography	NIOSH 1300
Respirable dust (particulates)	tared PVC filter	1.7	gravimetric	---

[1] National Institute for Occupational Safety and Health (NIOSH) NIOSH Manual of Analytical Methods, Third Edition. Vol 1. Methods 7903, 2502, 1401, and 1501. DHHS Publication No. (NIOSH) 84-100. Cincinnati, OH: National Institute for Occupational Safety and Health, 1984

Table 2

Personal and Area Air Sampling Results for Acid Gases

Parker Hannifin
Ravenna, Ohio
HETA 89-083

August 9, 1989

Sampling Location	Sample Type	Sampling Time	Sample Volume (liters)	Hydro-Fluoric Acid (mg/m^3)	Hydro-Chloric Acid (mg/m^3)	Nitric Acid (mg/m^3)	Phosphoric Acid (mg/m^3)	Sulfuric Acid (mg/m^3)
Dept. 4915, line M1, 16" from nose and die, PVC extrusion	GA	11:06-16:07	151	ND	ND	trace	ND	trace
Dept. 4902, line 10, 5" from open gate while screen operator was "pulling the acres"	GA	12:08-15:57	115	0.33	22	trace	ND	trace
Dept. 4902, line 10, screw operator sampled while "pulling the screw"	PBZ	12:14-14:47	77	trace	trace	ND	ND	ND
Dept. 4902, line 10, screw operator sampled while "burning off" screw	PBZ	15:29-15:52	12	trace	ND	ND	ND	ND
Limit of Detection (ug/sample)				0.8	3	0.4	5	2.0
Limit of Quantitation (ug/sample)				2.5	7	1.3	16	3.9

GA = general area air sample; PBZ = personal breathing zone air sample
Trace indicates a concentration between the limit of detection and limit of quantitation
ND = non-detected (less than the limit of detection)
mg/m^3 = milligrams per cubic meter
ug/sample = micrograms per sample

Table 3

Area Air Sampling Results for Isocyanates

Parker Hannifin
Ravenna, Ohio
HETA 89-083

August 9, 1989

Sampling Location	Sampling Time	Sample Volume (liters)	2,4-TDI (mg/m^3)	2,6-TDI (mg/m^3)	MDI (mg/m^3)	PPI (mg/m^3)
Dept. 4902, line 9, 30" from nose and die, urethane extrusion	9:05-11:17	132	trace	ND	ND	0.053
Dept. 4904, 12" from the glue pot that had local exhaust ventilation	9:08-11:15	127	trace	ND	ND	0.039
Dept. 4904, 12" from the glue pot that did not have local exhaust ventilation	9:12-11:15	123	ND	ND	ND	0.049
Limit of Detection (ug/sample)			0.2	0.2	0.3	2.0
Limit of Quantitation (ug/sample)			0.6	0.5	0.9	4.0

2,4-TDI = 2,4-toluene diisocyanate
2,6-TDI = 2,6-toluene diisocyanate
MDI = 4,4-methylenediphenyl isocyanate
PPI = 2,6-diisopropylphenyl isocyanate
Trace indicates a concentration between the limit of detection and limit of quantitation
mg/m^3 = milligrams per cubic meter
ug/sample = micrograms per sample
ND = non-detected (less than the limit of detection)

Table 4

Evaluation Criteria and Health Effects Summary

Parker Hannifin
Ravenna, Ohio
HETA 89-083

August 9, 1989

Chemical (synonyms)	Evaluation Criteria (ppm)[1,2] OSHA PEL	NIOSH REL	ACGIH TLV	Health Effects
Acrolein	0.1 (8-hour)	--- ---	0.1 (8-hour)	Irritation of eyes, skin, and mucous membranes
	0.3 (STEL)	--- ---	0.3 (STEL)	
Caprolactam (vapor)	20 mg/m³ (8-hour)	--- ---	20 mg/m³ (8-hour)	Skin irritation
	40 mg/m³ (STEL)	--- ---	40 mg/m³ (8-hour)	
Carbon Monoxide	35 (8-hour)	35 (8-hour)	50 (8-hour)	Tissue hypoxin preventing the blood from carrying sufficient oxygen; headache; nausea
	200 (C)	200 (C)	400 (STEL)	
Cyclohexanone	25 Skin (8-hour)	25 (10-hour)	25 Skin (8-hour)	Irritation of the eyes and mucous membranes
Formaldehyde	1 (8-hour)	LFL Ca	0.3 ppm (ceiling)	Nasal cancer; irritation of the eyes, nose, and throat
	2 (STEL)	--- ---	2 Ca (STEL)	

Table 4 (continued, Page 2)

Evaluation Criteria and Health Effects Summary

Parker Hannifin
Ravenna, Ohio
HETA 89-083

August 9, 1989

Chemical (synonyms)	Evaluation Criteria (ppm)[1,2] OSHA PEL	NIOSH REL	ACGIH TLV	Health Effects
Hydrochloric Acid (hydrogen chloride)	7.5 mg/m³ (C)	--- (C)	7.5 mg/m³	Inflammation of the nose, throat, and larnyx
Hydrofluoric Acid (hydrogen fluoride)	2.6 mg/m³ (8-hour)	2.6 mg/m³ (10-hour)	2.6 mg/m³ (C)	Irritation of the eyes, nose, and throat
	5.2 mg/m³ (STEL)	5.2 mg/m³ (15 min C)	---	
Hydrogen Cyanade	4.7 Skin (STEL	4.7 Skin (10 min C)	10 Skin (C)	Metabolic asphyxiation
Nitric Acid	2 (8-hour)	2 (10-hour)	2 (8-hour)	Irritation of the eyes and mucous membranes; acute pulmonary edema; chronic obstruction pulmonary disease
	4 (STEL)		4 (STEL)	
Nitrogen Dioxide	3 (8-hour)	--- ---	3 (8-hour)	Irritation of the respiratory tract; pulmonary edema
	1 (STEL)	1 (15 min C)	5 (STEL)	

Table 4 (continued, Page 3)

Evaluation Criteria and Health Effects Summary

Parker Hannifin
Ravenna, Ohio
HETA 89-083

August 9, 1989

Chemical (synonyms)	Evaluation Criteria (ppm)[1,2] OSHA PEL	NIOSH REL	ACGIH TLV	Health Effects
Phosphoric Acid	1 mg/m³ (8-hour)	--- ---	1 mg/m³ (8-hour)	Irritation of the upper respiratory tract
	3 mg/m³ (STEL)	--- ---	3 mg/m³ (STEL)	
Respiratory Dust	10 (8-hour)		5 mg/m³ (8-hour)	
Sulfuric Acid	1 mg/m³ (8-hour)	1 mg/m³ (10-hour)	1 mg/m³ (8-hour)	Irritation of the eyes, nose, and throat
	--- ---	--- ---	3 mg/m³ (STEL)	
Sulfur Dioxide	2 (8-hour)	0.5 (10-hour)	2 (8-hour)	Irritation of the eyes, nose and throat
	5 (STEL)	--- ---	5 (STEL)	
Trichloroethylene	50 (8-hour)	25 Ca (10-hour)	50 (8-hour)	Potential for cancer in humans; has produced liver tumors in animals; central nervous system effects
	200 (STEL)	--- ---	200 (STEL)	

Table 4 (continued, Page 4)

Evaluation Criteria and Health Effects Summary

Parker Hannifin
Ravenna, Ohio
HETA 89-083

August 9, 1989

Chemical (synonyms)	Evaluation Criteria (ppm)[1,2] OSHA PEL	NIOSH REL	ACGIH TLV	Health Effects
1,1,1-trichloroethane (methyl chloroform)	350 (8-hour)	200 (10-hour)	350 (8-hour)	Central nervous system, liver and cardiovascular effects
	450 (STEL)	350 (15 min C)	450 (STEL)	

[1] = exposure limits defined as 8- or 10-hour time-weighted averages, as noted.
[2] = expressed as ppm unless otherwise noted.
OSHA = Occupational Safety and Health Administration
PEL = Permissible Exposure Limits
NIOSH = National Institute for Occupational Safety and Health
REL = Recommended Exposure Limits
ACGIH = American Conference of Governmental Industrial Hygienists
TLV = Threshold Limit Values
STEL = short-term exposure limit
C = ceiling limit
min = minutes
ppm = parts per million
mg/m^3 = milligrams per cubic meter
- = no evaluation criteria
LFL = lowest feasible limit
Ca = The substance should be treated as a potential human carcinogen.
Skin = Potential contribution to overall exposure by the cutaneous route including mucous membranes and eyes.

Table 5

Respiratory Symptoms by Department

Parker Hannifin
Ravenna, Ohio
HETA 89-083

March 8-9, 1989

Symptom	Warehouse	Extrusion	Multitube Taping Armoring	Cabling/ Braiders # (%)	Large/Small Respool # (%)	Finishing # (%)	Inspection # (%)	Maintenance
Shortness of breath	14 (29)	12 (25)	1 (20)	2 (25)	8 (36)	3 (14)	3 (43)	2 (25)
Chest pain or tightness	10 (21)	8 (17)	1 (20)	1 (13)	6 (27)	1 (5)	3 (43)	2 (25)
Wheezing	10 (21)	7 (15)	1 (20)	0	5 (23)	2 (10)	3 (43)	2 (25)
ALL THREE	8 (17)	5 (10)	1 (20)	0	5 (23)	1 (5)	3 (43)	1 (13)

Table 6

Demographics of 52 Medical Evaluation Participants

Parker Hannifin
Ravenna, Ohio
Heta 89-083

February/March, 1990

Characteristic	
Mean Age	42 years
Sex	
Male	26 (50%)
Female	26 (50%)
Race	
White	45 (87%)
Black/Hispanic	7 (13%)
Years employed	
Average	10 (range 1-21 years)
Median	13
Job location	
Warehouse	20
Extrusion	11
Multitube	3
Braiding	6
Finishing/Respool	3
Inspection	4
Maintenance	4
Other	1

Table 7

Respiratory Symptoms among 52 Medical Evaluation Participants

Parker Hannifin
Ravenna, Ohio
HETA 89-083

February/March, 1990

Symptoms	# (% of all participants)
Wheezing	28 (54)
Onset after employment	27 (52)
Lasts > one hour	19 (37)
Shortness of Breath	28 (54)
Onset after employment	28 (54)
Lasts > one hour	17 (33)
Chest Tightness	32 (62)
Onset after employment	31 (60)
Lasts > one hour	19 (37)

Table 8

Parker Hannifin
Ravenna, Ohio
HETA 89-083

February/March, 1990

Current Symptoms and Reported Medical Conditions

	+ *	- **	Total	Prevalence	RR (95% CI)
A. ASTHMA					
Yes	12	2	14	86	
No	21	17	38	55	1.6 (1.1-2.2)
Total	33	19	52		
B. SINUS PROBLEM					
Yes	20	4	24	83	
No	13	15	28	46	1.8 (1.2-2.8)
Total	33	19	52		
C. ECZEMA					
Yes	2	0	2	100	
No	31	19	50	62	1.6 (1.3-2.0)
Total	33	19	52		

Employment and Reported Medical Conditions

	+	-	Total	Prevalence	RR (95% CI)
D. HAY FEVER					
Yes	5	1	6	83	
No	28	18	46	61	1.4 (0.9-2.1)
Total	33	19	52		
E. ALLERGIES					
Yes	9	0	9	100	
No	24	19	43	56	1.8 (1.4-2.3)
Total	33	19	52		
F. SMOKING HISTORY					
Yes	21	17	33	64	
No	12	7	19	64	1.0 (0.7-1.6)
Total	33	19	52		
G. UNDER CARE OF PHYSICIAN					
Yes	17	8	25	68	
No	16	11	27	59	1.2 (0.8-1.7)
Total	33	19	52		
H. USING MEDICATIONS					
Yes	17	9	26	65	
No	16	10	26	62	1.1 (0.7-1.6)
Total	33	19	52		

* - (+) individual with work-related symptoms
** - (-) individual without work-related symptoms

Table 9

Occupation and Peak Flow Testing

Parker Hannifin
Ravenna, Ohio
HETA 89-083

February/March, 1990

	Warehouse	Extrusion	Braiders	Other	Total
A. Occupation and Peak Flow					
Normal	11	4	2	10	27
Abn/Borderline	9	7	4	5	25
Total	20	11	6	15	52
B. Occupation and Symptoms					
Wheezing					
Yes	8	4	5	11	28
No	12	7	1	4	24
Total	20	11	6	15	52
Shortness of Breath					
Yes	11	3	6	8	28
No	9	8	0	7	24
Total	20	11	6	15	52
Chest Tightness					
Yes	9	6	6	11	32
No	11	5	0	4	20
Total	20	11	6	15	52

Table 10

Results of Immunologic Testing

Parker Hannifin
Ravenna, Ohio
HETA 89-083

May 9-10, 1990

	Range	# Positive (%)	# Borderline
PPI			
IgE	0.0-0.8	1 (3)	0
IgG4	0.0-0.0	0	0
IgG	0.08-0.80	15 (43)	7 (20)
TDI			
IgE	0.0-0.1	0	0
IgG4	0.0-0.19	2 (6)	0
IgG	0.04-0.84	6 (17)	5 (14)

Table 11

Peak Flow Results and Antibodies to PPI/TDI

Parker Hannifin
Ravenna, Ohio
HETA 89-083

May 9-10, 1990

	IgG PPI				
PEAK FLOW	**Normal**	**Abnormal**	**Total**	**Prevalence (%)**	**RR (95% CI)**
Normal	9	5	14	36	
Abnormal	15	6	21	29	0.8 (0.3-2.1)
Total	24	11	35		
	IgG TDI				
PEAK FLOW	**Normal**	**Abnormal**	**Total**	**Prevalence (%)**	**RR (95% CI)**
Normal	9	5	14	36	
Abnormal	16	5	21	23	0.7 (0.2-1.9)
Total	25	10	35		

Table 12

Job Classification and Antibodies to PPI/TDI

Parker Hannifin
Ravenna, Ohio
HETA 89-083

May 9-10, 1990

JOB	IgG PPI Normal	Abnormal	Total	Prevalence (%)	RR (95% CI)
Extr or Whse	7	14	21	67	
Other	6	8	14	57	1.2 (0.7-2.0)
Total	13	22	35		
JOB	**IgG TDI Normal**	**Abnormal**	**Total**	**Prevalence (%)**	**RR (95% CI)**
Extr or Whse	14	7	21	33	
Other	11	3	14	21	1.6 (0.5-5.0)
Total	35	10	35		

Table 13

History of Asthma and Antibodies to PPI/TDI

Parker Hannifin
Ravenna, Ohio
HETA 89-083

May 9-10, 1990

	IgG PPI				
H/O ASTHMA	**Normal**	**Abnormal**	**Total**	**Prevalence (%)**	**RR (95% CI)**
Yes	7	16	23	70	
No	6	6	12	50	0.7 (0.4-1.4)
Total	13	22	35		
	IgG TDI				
H/O ASTHMA	**Normal**	**Abnormal**	**Total**	**Prevalence (%)**	**RR (95% CI)**
Yes	16	7	23	30	
No	9	3	12	25	0.8 (0.3-2.6)
Total	25	10	35		