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In the semiconductor industry, numerous potential occupational exposures exist as a result of the diversity of chemical and physical hazards unique to integrated circuit manufacturing. The hazards associated with maintenance tasks are challenging because the sporadic nature of the tasks make exposure monitoring difficult. In particular, vacuum pump maintenance is hazardous due to the close contact with chemical waste by-products. The purpose of this study was to characterize the chemical and physical occupational exposures associated with vacuum pump maintenance (VPM) in a semiconductor manufacturing environment. The study population consisted of 9 VPM technicians at a semiconductor manufacturing plant in Oregon. VPM tasks were observed and prioritized according to potential risk of exposure. For each task studied, an exposure monitoring strategy was developed to quantify both chemical and noise exposures. Personal and area air samples of potential waste gases were conducted during maintenance tasks. All air samples were below established governmental standards. Detectable levels were found for three tasks: 0.040 milligrams per cubic meter (mg/m^3) of hydrochloric acid, 0.014 mg/m^3 of chlorine, and 0.08 mg/m^3 of fluoride containing gases during tasks associated with the metal etch tool, polynitride etch tool, and tungsten deposition tool, respectively. Several bulk samples of waste residues collected during the tasks where corrosive having low pH levels. Representative noise sampling was conducted

during a 12 hour shift to characterize noise exposures. Noise samples revealed that 43 % of the samples were above the 80 dBA action limit thus requiring the VPM technicians to be involved in a hearing conservation program. Field observations revealed that there were many chemical hazards associated with waste gases and residues, therefore it is likely that occupational exposures occur even though they were not detected at significant levels in this study. In addition, there were several ergonomic risk factors associated with dismantling the pump during the maintenance activities. Specific improvements in personal protective equipment, general work practices, ergonomics, and engineering controls will help to reduce the potential for occupational exposures unique to VPM. Results from this study indicate the need to conduct in depth hazard evaluations of high risk populations such as the VPM technicians.

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Occupational Exposure Characterization of Vacuum Pump Maintenance Technicians

in a Semiconductor Manufacturing Environment

by

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Deborah Elaine Buser, Author

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DEDICATION

This thesis is dedicated to Edward, Diane and Shauna Buser , whose support and unconditional love as always guided me. Without their encouragement throughout my academic pursuits, I would not be where I am today. Thanks for giving me the freedom to choose my own path, even if you thought I was crazy at times! Also, I would like to dedicate this thesis to my dear friend, Marilyn Mader, who inspired me to pursue my graduate degree in Environmental Health and Safety.

Occupational Exposure Characterization of Vacuum Pump Maintenance Technicians in a Semiconductor Manufacturing Facility

INTRODUCTION

In the semiconductor industry, numerous potential occupational exposures exist as a result of the diversity of chemical and physical hazards unique to integrated circuit manufacturing. Over the past decade the semiconductor industry has grown to encompass a variety of sophisticated processes, many of which utilize chemicals that are toxic to humans (1). In this dynamic industry, such processes are continuously improved to accommodate the newest technological advancements. As a result of this fluctuating environment, workers are subject to a multitude of chemical exposures during the course of their work history. The continuous transformation of chemical processes makes challenging to conduct formal risk assessments that provide current information on hazard identification and potential occupational exposure. As the size of the semiconductor work force expands, the potential for adverse health effects related to occupational hazards ranging from transient irritant symptoms to reproductive effects and cancer will likely increase (1). Before effective control measures can be instituted, it is essential for the Environmental Health and Safety professional to characterize all hazards involved in the manufacturing process and to identify the group of workers at highest risk.

One of the high risk groups in the semiconductor industry is maintenance technicians. This group is at a higher risk for short-term occupational exposure because the nature of maintenance tasks involves closer contact with various process chemical by-products and residues. In one epidemiological study designed to investigate liver enzymes among a population of microelectronics equipment maintenance technicians, it was determined that abnormal liver enzymes were detected among equipment maintenance workers (odds ratio 16.4; $p < .008$) and electronic technicians (odds ratio 27; $p < .0005$) (2). Maintenance activities involve tasks such as work on interior process chambers, exhaust lines, and vacuum pump systems, each of which can be especially hazardous because of the tendency to concentrate high levels of toxic residues (3). While engineering controls have been designed to reduce occupational exposures, the emphasis is often on protection of the product from damaging particles rather than protection of the worker (1). Further, it is difficult to construct engineering controls to protect maintenance workers because, during many of their tasks, it is necessary to overstep safety interlocks in order to service the equipment. Despite the increased risk of exposure associated with maintenance technicians, they are typically not studied because their exposures are sporadic in nature making it difficult to conduct exposure monitoring (4). Consequently, the majority of hazard assessments characterizing exposures have focused on normal process operations (4). It is necessary for documentation of exposures to highly toxic materials during maintenance processes in order to provide guidance for establishing appropriate exposure control programs. Ultimately, maintenance related exposure data will benefit the overall industry by providing the necessary information to improve the protection of worker health.

In previous studies designed to characterize the exposure of preventive maintenance (PM) activities, several hazards were identified which were associated with a variety of semiconductor manufacturing process tools (5,6,7,9,10). In one process called the dry etch system, corrosive or oxidizing process gases are used in concert with radio frequency to produce a uniform pattern definition on the wafer (3). PM activities on dry etch systems involve opening, cleaning, and reassembling the reaction chambers and internal components of the tool (5). Opening the process chamber presents the potential for acute exposure to high concentrations of irritant gases such as complex mixtures of halogenated chemicals like chlorinated and fluorinated compounds (6). Such exposures are increased if the etch system is not adequately purged with an inert gas (i.e. nitrogen) before conducting preventive maintenance. Direct reading samples collected during a PM activity on a dry etch system, revealed exposure levels of greater than 9.0 parts per million (PPM) for hydrogen fluoride and hydrogen bromide, thus significantly exceeding the American Conference of Governmental Industrial Hygienists (ACGIH) ceiling concentration of 3 ppm within three minutes (5). In another study , Olson found high levels of acidic contaminants deposited in the pump oil and as residues on the inner surfaces of the dry etch tools (7). These findings stress the necessity to cool pump oil to room temperature before draining in order to reduce inhalation exposure due to off-gassing and to adequately protect the skin from contact with the hot contaminated oil.

Another semiconductor manufacturing process that involves potentially hazardous maintenance activities is the plasma enhanced chemical vapor deposition (PECVD) system. This process utilizes a combination of RF energy and desired deposition compounds to create a plasma which reacts to form a blanket layer of the desired film onto the surface of the wafer (3). Two common deposition techniques are the creation of oxide films using sources such as tetraethylorthosilicate (TEOS) and the creation of metallic films using tungsten hexafluoride (WF_6) (5). PM activities involve cleaning the interior chamber and components (5), changing of cylinders, and servicing associated vacuum pump systems (6). During these tasks, there is a risk of sporadic short-duration exposures to the combinations of toxic and corrosive reaction by-products.

A further hazardous process, called ion implantation, is a major safety concern for maintenance operations. Ion implantation is a process of introducing certain desired electrical properties into the silicon wafer using charged dopant ions (8). Typical process chemicals used as dopants are arsenic, arsine, phosphine, and boron trifluoride, each of which has potentially toxic effects to humans (9). Not only is there the risk from arsine and phosphine effects which are acute and immediately dangerous to life and health, but there also are long-term carcinogenic effects associated with arsenic (10). PM tasks generally consist of removing, decontaminating, and rebuilding components of the implanter, cleaning dopant residues from exposed surfaces within the implanter chambers and replacing contaminated pump oil (5, 9, 10). The primary safety concern during maintenance activities is exposure to dopant residues via the inhalation route during cleaning of the source housing (5). In a study designed to investigate the occupational exposure of ion implantation maintenance technicians, if was found that air samples for arsenic (0.8 mg/m^3) and phosphine (0.57 mg/m^3) exceeded the threshold limit value (TLV) of 0.05 mg/m^3 and 0.3 mg/m^3 respectively for an 8 hour time weighed average (TWA) (10). In a more recent study, First found significant surface contamination levels obtained from wipe samples that ranged form 0.02 to 268,000 ug/100 cm^2 (5). Although there are currently no exposure limits for surface contamination, these data reveal a significant risk of dermal exposure, as well as inhalation exposure, during maintenance activities.

While the above examples of hazardous maintenance activities associated with various semiconductor processes is not a comprehensive list, they highlight some of the ke maintenance problems unique to this industry. Typically, a maintenance team will be responsible only for one type of integrated circuit process tool thus creating a population of highly specialized technicians. Perhaps on of the most potentially hazardous maintenance activities are those encountered by vacuum pump maintenance (VPM) technicians. The majority of studies regarding maintenance workers have focused on activities as they relate to specific process equipment, and the known chemical and physical hazards associated with tool specific recipes. In these studies, the hazards are centered around the actual process, in which both the quantities of chemicals and the types of chemical reactions are well documented. In contrast, much less attention has been given to the acute and chronic health effects of exposures to unknown mixtures of chemical gases in the waste stream. In an animal study designed to investigate the subacute inhalation toxicity and genotoxicity of gaseous waste products from a plasma etch process, it was determined that exposed rats had increases in chromosomal aberrations and sister chromatid exchanges in bone marrow cells (11) These data indicate the potential human health risks associated with inhalation exposure to waste streams. One group of maintenance workers who are at risk of inhalation exposure to the waste streams are vacuum pump maintenance (VPM) technicians. VPM activities involve contact with unknown hazards associated with the waste stream of which chemical interactions are complex and in a constant state of flux. Vacuum pump oil and the internal surfaces of vacuum pump systems contain known and unknown and potentially hazardous by-products which may accumulate to levels of high concentrations (12). This study focuses specifically on the identification and characterization of occupational exposures associated with vacuum pump maintenance.

In every semiconductor manufacturing environment, the majority of process tools located within the fab or cleanroom require support equipment such as vacuum pump systems for process flow. With the increased use of cluster tools, one piece of equipment may require up to six separate vacuum pump systems which have unique maintenance requirements (13). The VPM technicians routinely perform preventive maintenance tasks such as the dismantling and decontamination of vacuum pump components and associated lines containing mixtures of chemical process waste. The major concern of such tasks is the potential for occupational exposure to process gases and reaction by-products formed in exhaust lines, pump oils, heat exchangers (coolers), and various other equipment parts (12). As a consequence of the dynamic interactions of chemicals within vacuum pump systems, workers performing maintenance activities are unsure of the characteristics of the hazardous by-products encountered and the adequate protection necessary to reduce exposures.

In addition to chemical hazards, there are several physical hazards which are of concern during VPM activities. For example, vibration and sound levels of the operating pump systems within the isolated pump rooms create a noisy environment which is likely to exceed the ACGIH TLV of 85 dBA for noise levels over an 8 hour time weighted average (TWA) (14). Noise exposure is compounded further by the fact that VPM technicians spend the majority of their work day in the vicinity of this equipment. Although there is general concern over VPM activities, there has been a paucity of published hazard assessments that characterize the chemical and physical exposures associated with these activities. Since VPM tasks are hard to define, as the process chemicals and pump systems vary widely within the semiconductor industry, it has been difficult to develop industry standards. The high potential for sporadic acute exposures to a range of chemical and physical hazards during VPM activities warrants an in-depth hazard evaluation and control strategy prioritization.

STUDY DESCRIPTION

Purpose of the Study

The purpose of this study was to investigate the chemical and noise exposures associated with VPM technicians in a semiconductor manufacturing setting by conducting a comprehensive job hazard analysis (JHA). The JHA consisted of two main components: A qualitative assessment to identify potential hazards encountered during vacuum pump maintenance tasks and a quantitative occupational exposure assessment of the hazards. For the JHA, a series of observations and informational interviews were conducted to identify those tasks that placed the VPM technicians at highest risk for exposure. Based on the information obtained during the qualitative assessment, an exposure monitoring protocol was developed to quantify the chemical and noise hazards. The goals of the qualitative assessment consisted of two main categories:

A) Task Specific Information:

- a comprehensive job description of the VPM technicians.
- a detailed outline of the various tasks associated with the job.
- a description of the frequency and duration of each task.
- a summary of employee concerns for each task.

B) Tool Specific Information:

- a list of the process chemicals entering the system.
- a summary of the maintenance requirements for each vacuum pump associated with the specific process tool.
- a description of the process for each tool associated with the vacuum pump.

Study Objectives

- To conduct a comprehensive hazard assessment of the vacuum pump maintenance technicians.
- To complete a task analysis to identify the potential occupational exposures of each activity.
- To quantify occupational exposures through the collection of various samples.
- To make recommendations necessary to meet regulatory requirements and industry best safety practices.

Job Hazard Analysis

The study was conducted over a nine-month period at a semiconductor manufacturing facility in Oregon. Data for the qualitative component of the job hazard analysis occurred over a three-month period in order to identify a variety of tasks routinely performed by the VPM technicians. Initially, a series of walk-throughs were conducted to assess the work environment, to identify specific problem areas or high hazard locations, and to become familiarized with the general work area. Specific requirements for vacuum pump maintenance tasks were collected through individual interviews with the VPM technicians and through observations of tasks. Data for each specific task was then entered onto a detailed checklist form that was developed using various examples of job hazard analysis protocols from the literature (see appendix A) (3,15,16). In order to plan for future maintenance needs, theVPM technicians documented all past maintenance activities by entering each task into a data base. The past four years of data were reviewed to determine which activities were performed most frequently as these events would correspond to a higher potential for both acute and chronic exposures (figure 1).

The chemical recipes used in the manufacturing tools associated with the vacuum pumps were obtained by reviewing the hazard inventory data sheets for each process tool. From this list, process tools were grouped according to similar tool types and recipes and prioritized based on those tools which utilized the most hazardous chemicals. The prioritization of hazardous chemicals in the tool processes were determined by reviewing material safety data sheets (MSDS) and examining the ACGIH TLVs for each chemical. Once process tools were grouped, one representative tool from each category was chosen for the evaluation of a maintenance task with the associated vacuum pump. With the assistance of an industrial hygienist, a sampling protocol was developed by predicting the possible by-products that would result from the known chemical recipe. Process engineers also were consulted for their input on possible chemical by-products. Finally, by-product determination was completed by reviewing any previous data that characterized chemical components of the waste stream as well as reviewing the literature. The sampling protocol for exposure monitoring was based not only on the information of possible by-products, but also on the ability of the lab to analyze and detect the by-products. Some of the by-products contain exotic chemicals that are very difficult to collect and analyze. For this reason, a sampling strategy was chosen on the basis of the feasibility for monitoring procedures, lab analysis and financial resources. In summary, by combining the task and tool specific data, a series of specific tasks were isolated as those that would be monitored in this study. A detailed description of the sampling strategy will be discussed in the methods section. A list of the chemicals sampled in the study and the associated health effects, is given in table 1.

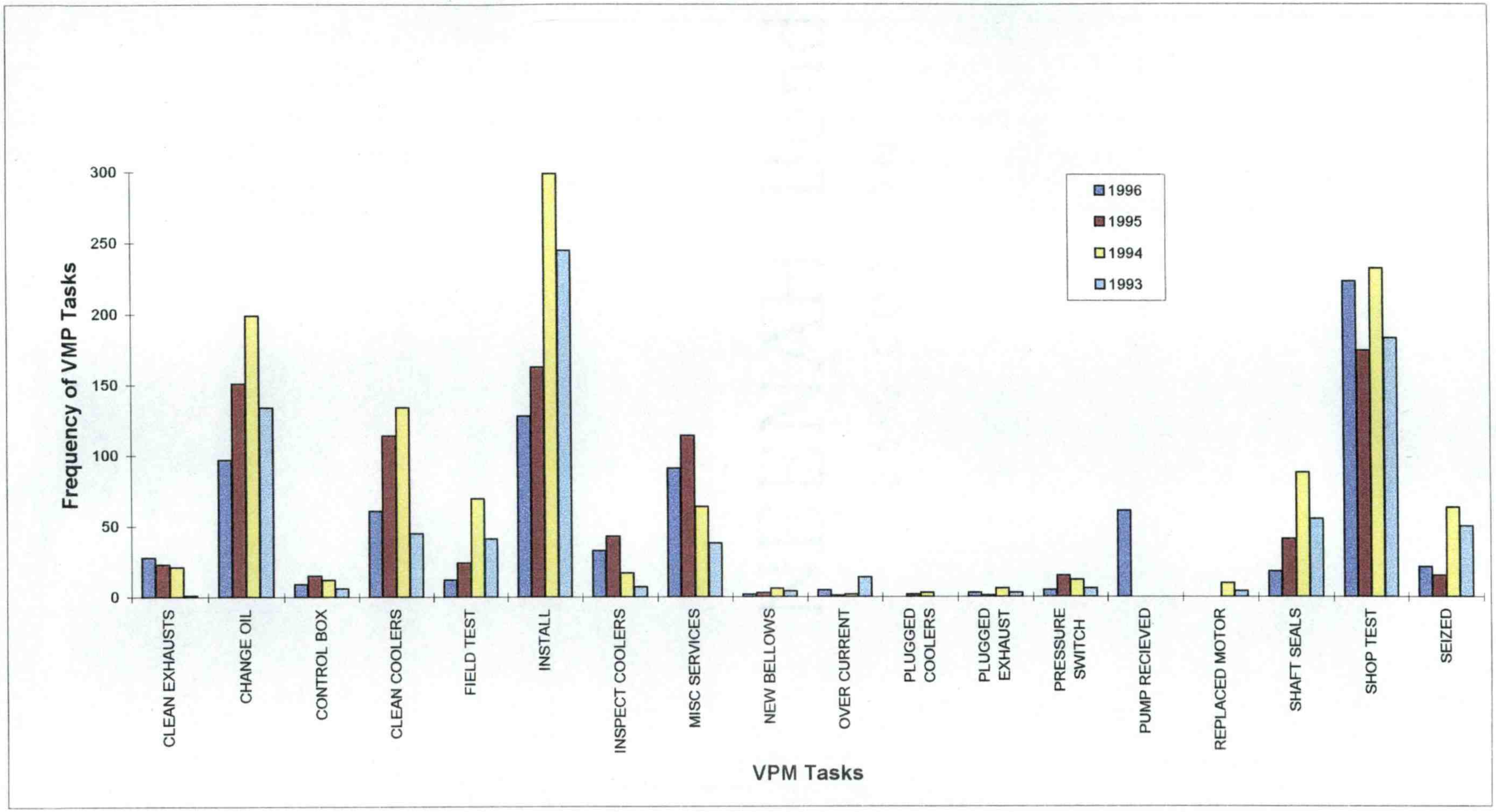

Figure 1 Summary of Yearly Vacuum Pump Maintenance Tasks

Table 1

Health Effects of the Chemicals Monitored During VPM Tasks

Chemical	Health Effects	Target Organ
Ammonia (NH_3)	Irritant causes inflammation, bronchial spasm, chest pain, bronchial edema; freezing of the skin, caustic burn	Eyes, skin, respiratory system
Chlorine (Cl_2)	Irritant, sneezing, copious salivation; restlessness and irritation; respiratory distress and violent coughing if high concentration	Eyes, skin, respiratory system
Hydrobromic acid (HBr)	Irritant to nose, throat, larynx, lung injury; ingestion causes burns of mouth and stomach; eye and skin contact causes severe irritation and burns	Eyes, skin, respiratory system
Hydrochloric acid (HCl)	Irritant to nose, throat, larynx; inhalation result in coughing and choking sensation; severe skin and eye irritant	Eyes, skin, respiratory system
Hydrofluoric acid (HF)	Severe skin irritant, causes second and third degree burns on short contact; very injurious to the eye; nausea, vomiting, diarrhea; metallic taste, garlic breath	Eyes, skin, respiratory system, bones
Nitric Acid (HNO_3)	Irritant to eyes, skin, mucous membranes; delayed pulmonary edema, pneumitis, bronchitis; dental erosion	Eyes, skin, respiratory system, teeth
Phosphine (PH_3)	Nausea, vomiting, abdominal pain, diarrhea, thirst; chest tightness, dyspnea (breathing difficulty); muscle pain, chills, stupor; pulmonary edema; burns or tissue damage due to frostbite	Respiratory system
Phosphoric acid (H_3PO_4)	Irritant to eyes, skin, upper respiratory system; high concentrations cause chemical burns to mucous membranes; long-term exposure causes erosion of teeth.	Eyes, skin, respiratory system
Tungsten (W)	Irritant; inflammation of respiratory system, diffuse pulmonary fibrosis; loss of appetite, nausea, cough, blood changes; CNS disturbances	Eyes, skin, respiratory system, CNS, GI tract, blood
Tetraethylortho-silicate ($(C_2H_5)SiO_4)$)	Irritant to eyes, nose; pulmonary edema; liver and kidney damage; anemia	Eyes, respiratory system

Study Population

The VPM technicians were chosen as the study population because they were isolated as a high risk group of employees for potential occupational exposures. The VPM team was a small group consisting of 9 male technicians. The range of age for this group was from 26 to 61 years. The range of experience in vacuum pump maintenance among this group was from 8 months to 14 years. It is important to point out that not all semiconductor manufacturing facilities have a team of maintenance workers that exclusively service vacuum pump systems. In some cases, it is the tool specific maintenance technicians that service the vacuum pumps associated with the manufacturing tools they are responsible for. At the facility where this study was conducted, the VPM team was responsible for servicing over three hundred vacuum pump systems. These systems are associated with a variety of different manufacturing tools that encompass the entire process for production of integrated circuits. Because the VPM technicians service such a wide range of vacuum pumps, they are subjected to a broader range of chemical exposures associated with the different process recipes of each manufacturing tool.

Work Environment

The general work environment was located in the subfab which is a floor level below the fab that houses support equipment such as vacuum pumps, chillers, radio frequency (RF) generators, and abatement systems. The majority of VPM activities took place within individual pump rooms located in the subfab (figure 2). The pump rooms vary in size and in the amount of vacuum pump systems that can be housed within an individual room. The largest pump room houses approximately 40 vacuum pumps, where as the smallest pump room houses approximately

5 pumps. Because space is at a shortage, the vacuum pumps are typically placed close together to conserve room. The close proximity creates a crowded environment in which it is difficult to access the vacuum pumps during maintenance operations.

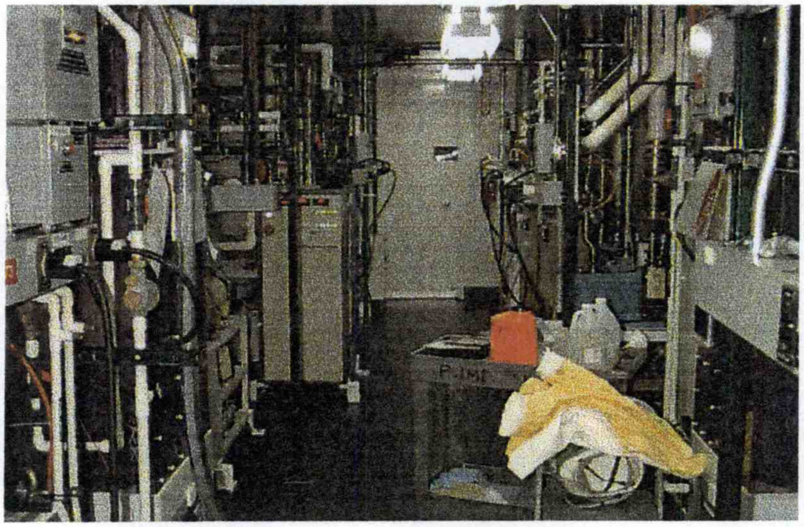

Figure 2 A Pump Room Located in the Subfab

Vacuum Pump Systems

While there is a wide variety of vacuum pump types that are used in the semiconductor industry, they can be divided into two main categories: wet and dry vacuum pumps. Wet pumps are oil sealed mechanical pumps. The pump is submerged in low vapor pressure oil which serves the purpose of lubricating the pump seals, cooling the pump, and sealing against atmospheric pressure (17). The major problem with wet pumps involves the direct interaction with process chemical waste and the oil. Contaminating chemicals can accumulate to high concentrations within the oil causing problems with corrosion of the vacuum pumps and health hazards from direct contact of the oil during maintenance tasks (12). In a study designed to investigate the levels of semiconductor process pump contamination in the oil, high levels of hazardous halogenated organic compounds were isolated thus indicating the need for precautionary measures to avoid airborne and dermal exposures (18). In another study vacuum pump oils were determined to be a primary safety concern (7). Contaminated oil from wet pumps presents a risk of exposure via the inhalation route due to off-gassing when oil is drained before cooling, and via the dermal route if direct skin contact occurs (18). Because of the high risk of exposure to contaminated oils, wet pumps are not optimal for processes that use hazardous chemicals.

Alternatively, dry vacuum pumps are oil free, thereby eliminating contact of process gases with lubricating oil (19). The reduction of contaminated oils making them well suited for use with processes that involve hazardous chemicals. Dry pumps are generally preferred because they require less maintenance (19). Dry pumps also provide the ability to purge the system with nitrogen to allow excess process gases and residues to be minimized before conducting maintenance tasks (19). Although the study facility utilizes both wet and dry pumps, wet pumps are currently being phased out and are therefore not associated with tools that use hazardous process chemicals. When possible, dry pumps should be used in conduction with hazardous processes because they utilize less oil. Alternatively to wet pumps, the oil in dry pumps do not come in direct contact with the process gases and by-products. For this reason, concentrated levels of hazardous chemicals will not build up in the pump which can cause pump failures. All tasks that were monitored in this study involved PM on dry vacuum pump systems. An example of one of the types of dry pumps used throughout the subfab is illustrated in figure 3.

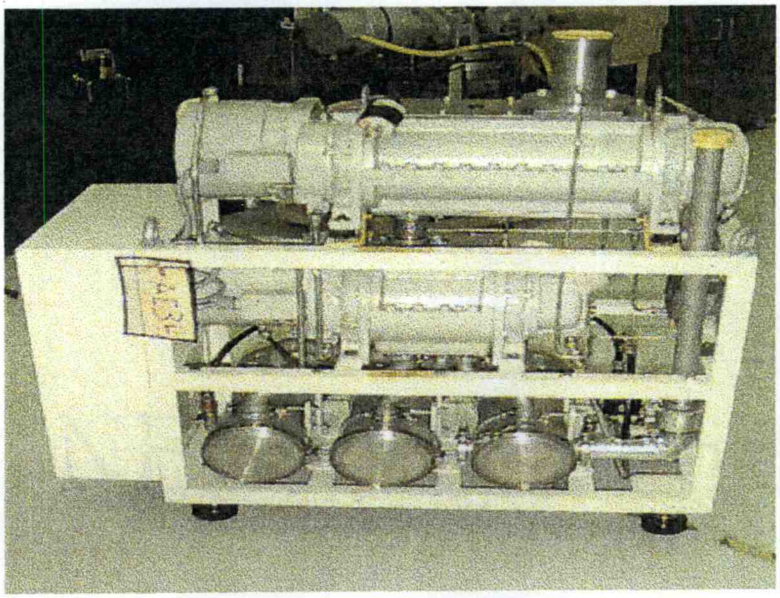

Figure 3 A Dry Pump System Associated with Vacuum Pump Maintenance Tasks

Task Description

Upon completion of the task assessment and the review of past maintenance data, specific tasks were chosen for occupational monitoring on the basis of the following criteria: tasks which were performed most frequently, tasks which were associated with the most hazardous process, and tasks which were expressed as a concern to the VPM technicians. It is important to note that while oil changes were initially isolated as a concern for occupational exposure during VPM, it was later determined that the hazard associated with this task were minimal. As mentioned earlier, dry pumps have replaced the wet pumps that were associated with hazardous process gases. Since dry pumps require far less oil and fewer changes, exposures are no longer a big problem. In addition, the VPM technicians use synthetic oil which does not have a tendency to build up process chemicals like hydrocarbon oils. Thus, for the reasons mentioned above, oil changes were not monitored in this study. For all tasks, the vacuum pump systems were required to be purged with nitrogen for approximately 1 hour. The VPM tasks that were selected for quantitative occupational exposure monitoring are described in the following subsections and summarized in table 2.

Heat Exchanger Inspections and Replacements

The heat exchangers (HE) are cooling systems that function to reduce the temperature of process gasses as they pass through the pump (figure 4).

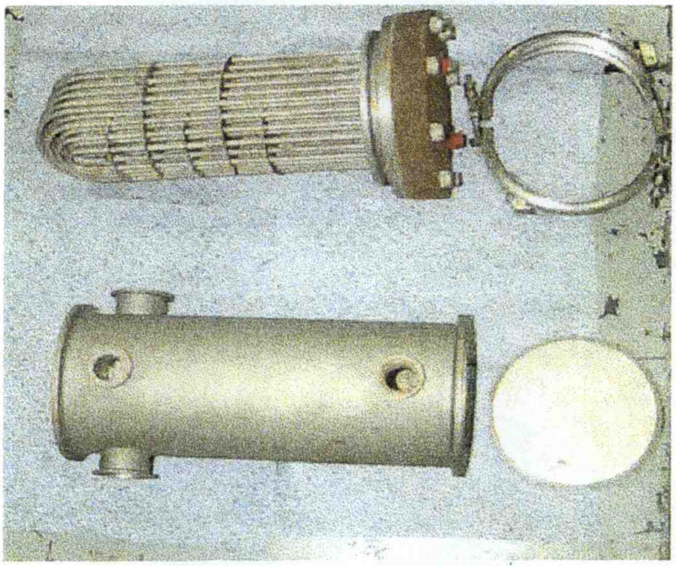

Figure 4 Cooling Coils and Encasement Unit of a Heat Exchanger

Spent gases within the pump undergo a series of compressions resulting in areas of high pressure followed by temperature drops as they pass through the HE. The drop in temperature causes chemicals to precipitate from the waste stream in areas of cool temperature such as the HE, resulting in the generation of very fine loose particles or deposits of unknown residues (20). These residues periodically concentrate in the HE units eventually causing a clog. At the facility where this study took place, the VPM technicians monitor the levels of residue buildup by conducting daily vacuum pump temperature and pressure readings. If a pump is operating at a temperature over 250°F or experiences an increase in the pressure reading, the HE is

Table 2

Summary of Vacuum Pump Maintenance Tasks and Associated Air Samples

Sample Event	Task	Date	Task Duration (min)	Chemicals Sampled	Tool Type	Tool Recipe
1	Heat exchanger clean and exhaust line inspection	1/22/97	140	Fluorides, Hydrofluoric ccid Tungsten	Tungsten Deposition	Tungsten hexafluoride, silane, freon 116, argon, oxygen.
2	Complete exhaust line clean	1/23/97	95	Ammonia Fluorides Hydrochloric acid Hydrofluoric acid Nitric acid Organics Phosphoric acid	Nitride Furnace	Ammonia, dichlorosilane, freon14, nitrogen
3	Heat exchanger and check valve clean	1/23/97	180	Chlorine Fluorides Hydrochloric acid	Metal Etch	Chlorine, boron trichloride, freon 14 and 23, nitrogen, oxygen.
4	Heat exchanger and exhaust line inspection	1/29/97	60	Ammonia Fluorides Hydrofluoric acid Nitric acid	Nitride Deposition	Nitrogen trifluoride, ammonia, silane, argon, freon 14, oxygen, nitrogen
5	Pump replacement	1/31/97	60	Fluorides Hydrobromic acid Hydrofluoric acid Phosphoric acid Phosphine	Ion Implanter	Silane tetrafluoride, phosphine, boron trifluoride,. argon
6	Heat exchanger and exhaust line inspection	2/5/97	105	Fluorides Organics Nitric acid Phosphine Phosphoric acid Tetraethylorthosilicate	Oxide Deposition	Tetraethylortho-silicate, phosphine, silane,nitrogen, oxygen, freon 116,trimethyl-borate, trimethyl-phosphite.

Table 2 (Continued)

Summary of Vacuum Pump Maintenance Tasks and Associated Air Samples

Sample Event	Task	Date	Duration (min)	Chemicals Sampled	Tool Type	Tool Recipe
7	Pump Replacement	3/21/97	50	Fluorides Hydrofluoric acid Nitric acid Tetraethylorthosilicate	Nitride Deposition	Tetraethylorthosilicate, nitrogen trifluoride, freon 14 and 116, argon, helium, oxygen, nitrogen, ozone
8	Pump Replacement	3/23/97	50	Fluorides Chlorine Hydrobromic acid Hydrochloric acid Hydrofluoric acid	Metal Etch	Chlorine, freon 23,14 and 116, hydogen bromide, sulfur hexafluoride, oxygen, nitrogen.
9	Heat exchanger and exhaust line inspection	3/23/97	50	Chlorine Fluorides Hydrochloric acid Hydrofluoric acid	Polynitride Etch	Chlorine, boron tricchloride, sulfur hexafluoride, argon, nitrogen, oxygen, helium, freon 14.

examined and replaced if necessary. Clogged heat exchangers were dismantled from the pump and placed in bags for transport to a ventilated acid bath for cleaning. The duration of this activity ranged from 1-2 hours.

HE inspections and cleans were conducted on the vacuum pumps that were identified as the most problematic in terms of becoming clogged which also corresponded with a more hazardous chemical recipe.. The tools associated with the vacuum pumps that were studied for this task include: a nitride deposition tool, a oxide deposition tool, a tungsten deposition tool, and a metal etch tool.

Exhaust Line Inspections and Replacements

The vacuum pump exhaust line (EL) feeds from the heat exchanger unit and serves as a pathway for effluent gases en route to the main acid scrubber before being released into the environment. As part of a routine PM activity, the EL is examined to determine whether it is blocked with residues. During this procedure, a portion of the EL is dismantled and visually inspected for blockages. If there is a problem, the clogged EL is disconnected from the pump and is sealed in preparation for transport to a cleaning area. The contaminated EL is sprayed to remove excess residue and is placed in the acid sink for cleaning. A clean EL is then installed to replace the old unit. The duration of this activity ranges from 1-2 hours. EL inspections were conducted on vacuum pumps associated with the following process tools: a nitride deposition tool, a oxide deposition tool, and a tungsten deposition tool.

Complete exhaust line clean

In some situations, the process gases traveling through the pump system cause an excess of known and unknown chemical residues in the complete exhaust line system. In particular, there is a tendency for particles to become trapped at points where there is a bend in the piping . When a residue build-up occurs, the pump may go into critical failure until the entire exhaust line is disconnected and cleaned. The duration for a complete exhaust line clean can range from 3-6 hours to purge the system, and to dismantle, decontaminate, and replace the entire vacuum pump exhaust system. A complete exhaust line clean was conducted on a vacuum pump system associated with a nitride furnace.

Vacuum pump replacement and installment

When a pump reaches a level of maximum hours or a failure occurs, it is removed from the pump room and replaced with an alternate pump. Replacement of a pump requires a 1 hour nitrogen purge, followed by a disconnection of the foreline and exhaust line. In preparation for pump repairs, the oil is drained, the orifices of the pump are capped, and the unit is bagged and shipped to an outside vendor for servicing. A new pump is immediately installed and prepared for operation by connecting it to the foreline and exhaust line. The duration of this activity ranges from 1-2 hours. Pump replacements occurred for vacuum pumps associated with the following process tools: an ion implanter tool, a nitride deposition tool, a polynitride etch tool and a metal etch tool.

POTENTIAL HAZARDS OF VACUUM PUMP MAINTENANCE ACTIVITIES

The dynamics of vacuum pumps involve a series of compressions that cause temperature and pressure changes which differ significantly from the controlled environment of the process chamber. As a result, the partially-reacted chemicals exiting the process chambers can combine with newly created chemicals within the pump environment to form new unknown gases and residues (12). As chemicals are cooled during transportation through lengthy piping, materials may condense and form residues that can eventually clog the system. For instance, low-temperature and pressure silane/ oxygen reactions, which are widely employed to deposit thick oxide layers, are notoriously problematic due to dust formation downstream of the reactor (20). Chemicals traveling through the pump system are compressed and reheated forming new mixtures which can concentrate in pump oils, heat exchangers (coolers), pump valves, and associated lines (12). Consequently, there are numerous hazards associated with vacuum pumps as workers are potentially exposed to many of the hazardous process chemicals and to newly formed chemicals which may have synergistic health effects.

Inhalation Exposures

There is a risk of occupational exposure via the inhalation route which is primarily associated with off-gassing of the process gasses and by-products during maintenance activities. Inhalation exposures may occur during the dismantling of the exhaust line and forelines, during heat exchanger inspectors, and/or during oil changes.

Dermal Exposures

Traditionally, the majority of occupational exposures have been characterized through air monitoring techniques. Because of the complexity in sampling, monitoring for dermal exposures is not typically completed as a component of occupational hazard assessments. This is a problem area because occupational skin disease is one of the leading causes of time lost from work and needs to be examined more closely (21). Currently, there are limited data describing the ability of chemicals or combinations of chemicals to penetrate the skin. Workers who are in contact with multiple chemicals are at risk of using PPE that provide inadequate protection. In the semiconductor industry, proper selection of gloves for protection against dermal exposure is made difficult by the wide range of hazardous chemicals encountered in IC manufacturing (22). VPM technicians are exposed to numerous contaminants during PM of vacuum pump systems because they are responsible for a wide variety of pumps that service different process tools with miscellaneous process chemicals. The risk of dermal exposure is magnified by the frequent changes in process chemicals that result in contact with many unknown residues. The risk of skin contamination can occur from direct contact with process residues, from accidental spills, from vapor penetration of the skin, and from contact with contaminated surfaces. Each scenario is likely during the maintenance tasks performed by the VPM technicians. For this reason, it is crucial to monitor for dermal exposures as part of the overall hazard assessment to ensure appropriate personal protective equipment (PPE) is being used

Noise Exposures

The American Conference of Governmental Industrial Hygienist Threshold Limit Value (ACGIH TLV) for noise is 85 dBA as an 8 hour time weighted average (TWA). Many semiconductor companies have specified 80 dBA as an action limit for requiring employees to participate in a hearing conservation program (3). In the study facility, the VPM technicians work a 12 hour shift therefore they are at potentially higher risk for noise related health problems because of the longer duration of exposure. During the course of a work shift, the VPM technicians are subject to working in noisy environments. The majority of vacuum systems within the subfab are located in small isolated pump rooms. The VPM technicians spend a significant amount of their shifts in the subfab during activities such as routine walk through to monitor the pumps, scheduled maintenance on individual pumps, and problem-solving investigations on pumps that have failed or are in critical mode. The accumulation of many vacuum systems in these closed in pump rooms creates a noisy environment. This noise level is exacerbated by the loud environment of the subfab which houses chillers, boilers, and furnaces. If adequate noise protection is not used while working in the subfab and pump rooms, the VPM technicians are likely to be exposed to levels above the 80 dBA action limit.

Ergonomic Risk Factors

The VPM technicians often work in awkward positions when servicing the vacuum pumps. Because many of the pump units are located at floor level, the VPM technicians work primarily on their hands and knees, and occasionally while lying on their backs to disconnect components of the pump. Additionally, the tasks are physically demanding and have a high risk for ergonomic problems such as strains, back problems and repetitive motion injuries. Alterations of the work environment are needed to reduce the ergonomic risks associated with VPM tasks

SAMPLING AND ANALYTICAL METHODS

Exposure monitoring for the specified VPM tasks occurred over a three month period, from January 20th, 1997 to March 23rd, 1997. In total, nine sampling events were monitored on nine separate tool types, as discussed in the task description section.. For each event a series of different industrial hygiene exposure monitoring samples were taken. A quantitative assessment data sheet was used to enter relevant data such as task observations and exposure monitoring data (see appendix B). The types of samples and methods for each, are described in the following subsections:

Air Samples

The air sampling strategy was developed by choosing those tools that utilized the most hazardous chemicals in their process recipes and determining the possible by-products that could be characterized. Another consideration for monitoring involved the capabilities of sampling methods. For example, the waste effluent within the pump includes complex mixtures of fluoride-containing gases. Because it would be very difficult to sample for each individual type of fluoride compound, a strategy was used to screen for total fluorides rather than to characterize each component separately. For tasks involving the monitoring of fluorides, fritted bubblers were used with a bicarbonate solution as media to collect area samples. The bubblers are designed to detect low concentrations by allowing a high degree of air-liquid mixing (23). Simultaneous personal samples for fluoride screening were not taken due to the substantial potential for spillage of the liquid media and damage to the sampling pump.

All air samples were collected and analyzed using National Institute of Occupational Safety and Health (NIOSH) and Occupational Safety and Health (OSHA) industrial hygiene methods. To evaluate a technician's occupational exposure during each maintenance task, personal samples were collected by placing the sampling media near the technician's breathing zone. While the tasks were carried out, concurrent area samples were placed strategically at fixed locations to pinpoint potentially high exposure regions. Area samples involving the collection of unknown organics were analyzed by gas chromatography and mass spectrometry to identify the five most predominant peaks. For all integrated air samples, dual-range pumps were used at specified flow rates according to the NIOSH method. Each pump was calibrated with a primary standard bubble meter both before and after sampling events to determine the overall average flow rate. All samples were analyzed by an American Industrial Hygiene Association (AIHA) approved laboratory. For a summary of the air sample protocol and analytical methods used, refer to table 3.

Direct reading samples for phosphine were collected using colormetric detector tubes. The amount of air drawn through the hand pump was determined according to the manufacturer's instructions; the concentration was determined by the level of color change which corresponded to the calibration scales marked on the indicator tubes.

Dermal Samples

For each task studied, dermal exposures were measured using adhesive Permea-Tec™ breakthrough colormetric indicator pads. Indicator pads are advantageous because they are simple to perform, are less expensive to analyze, and provide an easy method to locate areas of high exposure. The results are readily available thus can provide an immediate evaluation of

Table 3

Summary of Sampling Protocol and Analytical Methods for Vacuum Pump Maintenance Tasks

Sample Event	Task	Tool Type	Sample	Type	Flow rate (L/min)	Time (min)	Volume (L)	Analytical Method**	Detection Method
1	Heat exchanger clean and exhaust line clean	Tungsten Deposition	Fluorides	Area	1.50	115	173	7903	IC*
			Hydrofluoric acid	Personal	0.43	140	60	7903	IC*
			Hydrofluoric acid	Area	0.41	110	45	7903	IC*
			Tugsten	Personal	2.00	140	283	7300	ICP-AES*
			Tungsten	Area	2.00	120	240	7300	ICP-AES*
2	Complete exhaust line clean	Nitride Furnace	Ammonia	Personal	0.22	75	17	OSHA 188	ISE*
			Ammonia	Area	0.22	95	21	OSHA 188	ISE*
			Fluorides	Area	1.50	95	143	7903	IC*
			Hydrochloric acid	Personal	0.42	75	31	7903	IC*
			Hydrochloric acid	Area	0.40	95	38	7903	IC*
			Hydrofluoric acid	Personal	0.42	75	31	7903	IC*
			Hydrofluoric acid	Area	0.40	95	38	7903	IC*
			Nitric acid	Personal	0.42	75	31	7903	IC*
			Nitric acid	Area	0.40	95	38	7903	IC*
			Phosphoric acid	Personal	0.42	75	31	7903	IC*
			Phosphoric acid	Area	0.40	95	38	7903	IC*
			Organics	Area	0.20	95	19	1500,1501,1003	GC,FID*
3	Heat exchanger and check valve clean	Metal Etch	Chlorine	Personal	0.73	120	88	8011	IC*
			Chlorine	Area	0.73	120	88	8011	IC*
			Fluorides	Area	1.50	150	228	7903	IC*
			Hydrochloric acid	Personal	0.42	180	76	7903	IC*
			Hydrochloric acid	Area	0.40	150	60	7903	IC*
4	Heat exchanger and exhaust line inspection	Nitride Deposition	Ammonia	Personal	0.40	55	23	OSHA 188	ISE*
			Ammonia	Area	0.42	60	25	OSHA 188	ISE*
			Fluorides	Area	1.50	55	82	7903	IC*
			Hydrofluoric acid	Personal	0.41	60	25	7903	IC*
			Hydrofluoric acid	Area	0.41	50	21	7903	IC*
			Nitric acid	Personal	0.41	60	25	7903	IC*
			Nitric acid	Area	0.41	50	21	7903	IC*

Table 3 (Continued)

Summary of Sampling Protocol and Analytical Methods for Vacuum Pump Maintenance Tasks

Sample Event	Task	Tool Type	Sample	Type	Flow rate (L/min)	Time (min)	Volume (L)	Analytical Method**	Detection Method
5	Pump replacement	Ion Implanter	Fluorides	Area	1.50	60	90	7903	IC*
			Hydrobromic acid	Personal	0.42	50	21	7903	IC*
			Hydrobromic acid	Area	0.40	60	24	7903	IC*
			Hydrofluoric acid	Personal	0.42	50	21	7903	IC*
			Hydrofluoric acid	Area	0.40	60	24	7903	IC*
			Phosphoric acid	Personal	0.42	50	21	7903	IC*
			Phosphoric acid	Area	0.40	60	24	7903	IC*
			Phosphine	Grab	-	-	-	D/R**	-
6	Heat exchanger and exhaust line inspection	Oxide Deposition	Fluorides	Area	1.50	90	13	7903	IC*
			Organics	Area	0.20	85	17	1500,1501,1003	GC,FID*
			Phosphine	Grab	-	-	-	D/R**	-
			Phosphoric acid	Personal	0.42	110	46	7903	IC*
			Phosphoric acid	Area	0.41	100	41	7903	IC*
			Nitric acid	Personal	0.42	110	46	7903	IC*
			Nitric acid	Area	0.41	100	41	7903	IC*
			TEOS*	Personal	0.13	110	14	3(S264)	GC,FID*
			TEOS*	Area	0.12	90	11	3(S264)	GC,FID*
7	Pump replacement	Nitride Deposition	Fluorides	Area	1.50	45	68	7903	IC*
			Hydrofluoric acid	Personal	0.42	45	19	7903	IC*
			Hydrofluoric acid	Area	0.43	45	19	7903	IC*
			Nitric acid	Personal	0.42	45	19	7903	IC*
			Nitric acid	Area	0.43	45	19	7903	IC*
			TEOS*	Personal	0.11	50	5.5	3(S264)	GC,FID*
			TEOS*	Area	0.11	50	5.5	3(S264)	GC,FID*

Table 3 (Continued)

Summary of Sampling Protocol and Analytical Methods for Vacuum Pump Maintenance Tasks

Sample Event	Task	Tool Type	Sample	Type	Flow rate (L/min)	Time (min)	Volume (L)	Analytical Method**	Detection Method
8	Pump replacement	Metal Etch	Fluorides	Area	1.50	40	60	7903	IC*
			Chlorine	Personal	1.00	40	40	8011	IC*
			Chlorine	Area	1.00	40	40	8011	IC*
			Hydrobromic acid	Personal	0.50	40	20	7903	IC*
			Hydrobromic acid	Area	0.50	40	20	7903	IC*
			Hydrochloric acid	Personal	0.50	40	20	7903	IC*
			Hydrochloric acid	Area	0.50	40	20	7903	IC*
			Hydrofluoric acid	Personal	0.10	50	5	7903	IC*
			Hydrofluoric acid	Area	0.12	50	6	7903	IC*
9	Heat exchanger and exhaust line inspection	Polynitride Etch	Chlorine	Personal	1.05	55	58	8011	IC*
			Chlorine	Area	1.06	60	64	8011	IC*
			Fluorides	Area	1.50	60	90	7903	IC*
			Hydrochloric acid	Personal	0.50	55	14	7903	IC*
			Hydrochloric acid	Area	0.50	60	30	7903	IC*
			Hydrofluoric acid	Personal	0.50	55	28	7903	IC*
			Hydrofluoric acid	Area	0.50	60	30	7903	IC*

*D/R= Direct Reading
* TEOS= Tetraethylorthosilicate
*IC= Ion Chromatography
*ICP-AES= Inductively Coupled Plasma, Atomic Emission Spectroscopy
*ISE= Ion Specific Electrode
*GC.FID= Gas Chromatograhy, Flame Ion Detection

**Analytical Method: NIOSH methods were used for all samples unless otherwise specified the protective gloves used during various tasks. The indicator pads contain an absorbent pad that contains color change media. This media will react when contacted with the specified contaminant. Two types of indicator pads were used in this study: pads for acid/base contaminants and pads for solvent contaminants. The solvent pads provide a color change by utilizing a highly absorbent charcoal pad to trap the contaminant(24). A gray color indicates a positive result and a white color indicates a negative result. The acid pads are capable of detecting acid compounds such as hydrochloric, sulfuric, hydrofluoric, phosphoric, nitric and acetic acids and basic compounds such as ammonia, sodium hydroxide, triethylamine, and 1-amino-2-propanol. A negative result is indicated by an orange color while a positive result is indicated by a violet color at pH 1 and a blue color at pH 9.5 (24).

Positive controls and color references were determined by testing one pad from each package with 1 drop of a representative chemical under study. To determine whether the gloves under investigation provided dermal protection, acid pads were placed on the right thumb, middle finger, and forearm, while solvent pads were placed simultaneously on the left thumb, middle finger and forearm. The subjects applied one pair of gloves before the indicator pads were positioned. The pads were positioned over the glove and then overlaid by a second pair of gloves. This precaution helped to prevent accidental contamination of the pads during removal of the gloves. Indicator pads placed on the forearms served to indicate dermal exposure to exposed skin because the majority of subjects worked in t-shirts.

Bulk Samples

When the VPM technicians encountered residual waste material during the tasks which were monitored, the residue was collected from various locations within the pump system. Bulk samples were collected in 250 ml screw top glass jars and stored in the refrigerator. Samples were analyzed for pH values to determine the correct handling procedures and personal protective equipment (PPE) usage.

Noise Samples

Personal noise exposures were measured using a digital audio dosimeter. Dosimeter microphones were secured to the shoulder of the VPM technicians slightly below the ear level. The dosimeters were calibrated before and after each sampling event. Dosimeters were worn for a time period ranging from 5.5 to 8.5 hours during the 12 hour shift. Representative samples were taken from each shift to characterize the overall noise exposure experienced by this population of workers. Upon completion of the noise sampling period, data from the noise dosimeters was entered onto a noise monitoring data sheet (see appendix C). The study subject being monitored for noise exposure was instructed to keep a log documenting all activities completed during the sampling period. This information was entered onto a noise monitoring work sheet (see appendix D). This information was necessary to establish a pattern in relationship with the noise level reading obtained from the noise dosimeter. Thus, if a noise spike occurred in the data, it would be possible to identify which activity was associated with the elevated noise level.

RESULTS

Air Samples

No significant occupational exposures were detected for any of the tasks monitored (table 4). All results were calculated as an average over the sampling period and the results were compared to the ACGIH TLV for an 8 hour TWA. Detectable levels were measured during the vacuum pump maintenance tasks associated with sample events 1, 3, and 9 which corresponded to the tungsten deposition tool, the metal etch tool, and the polynitride etch tool, respectively. During the heat exchanger clean of the pump associated with the tungsten deposition tool, levels of fluorides were detected at 0.08mg/m^3 for the area sample using the fritted bubbler to capture fluoride levels. . The percentage of the ACGIH TLV experienced during this task was 3.2%. During the heat exchange change and exhaust line clean of the pump associated with the metal etcher, average levels of hydrochloric acid were detected at 0.040 mg/m^3 for the personal sample and 0.035 mg/m^3 for the area sample. The percentage of the ACGIH TLV experienced during this task were 0.57% and 0.50% respectively. Finally, during the heat exchanger and exhaust line inspection associated with the polynitride etch tool, levels of chlorine were detected at 0.014 mg/m^3 for the personal sample. The percentage of the ACGIH TLV experienced during this task was 0.93%.

It was interesting to note that the events for which detectable levels were measured correspond with events that had the greatest amount of chemical residue located in the heat exchangers and exhaust lines. The VPM technicians involved in those tasks revealed that these particular pump systems are notorious for accumulating residues in greater amounts than were observed during exposure monitoring.

Table 4

Summary of Air Sample Results for the Vacuum Pump Maintenance Tasks

Sample Event	**Tool Type/ Vacuum Pump**	**VPM Task**	**Chemicals Sampled**	**Personal Sample Results (mg/m^3)**	**Area Sample Results(mg/m^3)**	**ACGIH TLV 8hr TWA**
1	Tungsten Deposition	Heat exchange clean and exhaust line inspection	Fluorides	N/C	**0.080**	2.5
			Hydrofluoric acid	N/D, <0.035	N/D, <0.047	2.5
			Tungsten	N/D, <1.767	N/D, <2.083	5.0
2	Nitride Furnace	Complete exhaust line clean	Ammonia	N/D,	N/D	17.0
			Fluorides	N/C	N/D, < 0.030	2.5
			Hydrochloric acid	N/D, <0.066	N/D, <0.054	7.0
			Hydrofluoric acid	N/D, <0.068	N/D, <0.055	2.5
			Nitric acid	N/D, <0.164	N/D, <0.134	5.0
			Phosphoric acid	N/D, <0.166	N/D, <0.136	1.8
			Organics	N/C	N/D, <1.030	N/A
3	Metal Etch	Heat exchanger and check valve clean	Chlorine	N/D, <0.027	N/D, <0.034	1.5
			Fluorides	N/C	N/D, < 0.020	2.5
			Hydrochloric acid	**0.040**	**0.035**	7.0
4	Nitride Deposition	Heat exchanger and exhaust line inspection	Ammonia	N/D, <0.417	N/D,<0.417	17.0
			Fluorides	N/C	N/D, < 0.05	2.5
			Hydrofluoric acid	N/D, <0.085	N/D, <0.102	2.5
			Nitric acid	N/D,<0.164	N/D,<0.164	5.0
5	Ion Implanter	Pump Replacement	Fluorides	N/C	N/D, < 0.040	2.5
			Hydrobromic acid	N/D,<0.07o	N/D, <0.060	7.0
			Hydrofluoric acid	N/D,<0.101	N/D,<0.087	2.5
			Phosphoric acid	N/D,<0.248	N/D,<0.213	1.8
			Phosphine	N/C	N/D,<0.050	0.4
6	Oxide Deposition	Heat exchange and exhaust line inspection	Fluorides	N/C	N/D, <0.030	2.5
			Nitric acid	N/D,<0.112	N/D,<0.125	5.0
			Organics	N/C	N/D,<1.160	N/A
			Phosphoric acid	N/D,<0.133	N/D,<0.126	1.8
			Phosphine	N/D	N/D,<0.050	0.4
			Tetraethylorthosilicate	N/D,<0.220	N/D,<0.180	10.0

Table 4 (Continued)

Summary of Air Sample Results for the Vacuum Pump Maintenance Tasks

Sample Event	Tool Type/ Vacuum Pump	VPM Task	Chemicals Sampled	Personal Sample Results (mg/m^3)	Area Sample Results (mg/m^3)	ACGIH TLV/ 8 hr TWA (mg/m^3)
7	Nitride Deposition	Pump replacement	Fluorides	N/C	N/D, < 0.070	2.5
			Hydrofluoric acid	N/D,<0.111	N/D,<0.111	2.5
			Nitric acid	N/D,<0.270	N/D,<0.270	5.0
			Tetraethylorthosilicate	N/D,<0.220	N/D,<0.220	10.0
8	Metal Etch	Heat exchange clean and exhaust line inspection	Fluorides	N/D	N/D, < 0.07	2.5
			Hydrochloric acid	N/D,<0.103	N/D,<0.103	7.0
			Hydrobromic acid	N/D,<0.08	N/D,<0.08	10.0
			Hydrofluoric acid	N/D,<0.105	N/D,<0.105	2.5
			Chlorine	N/D,<0.017	N/D,<0.017	1.5
9	Polynitirde Etch	Pump replacement	Fluorides	N/C	N/D, < 0.037	2.5
			Hydrochloric acid	N/D,<0.082	N/D,<0.082	7.0
			Hydrofluoric acid	N/D,<0.084	N/D,<0.084	2.5
			Chlorine	**0.014**	N/D,<0.0136	1.5

N/A= Not applicable
N/C= Not collected
N/D= None detected
D/R= Direct reading

Dermal Samples

There were no observable dermal exposures detected on the acid/base or solvent Permea-Tec™ indicator pads, although work practices suggest that the VPM technicians are at risk for dermal exposures. For each task, the VPM technicians used latex gloves rather than acid gloves because the latex gloves provide better manual dexterity. The acid gloves supplied at this facility are comprised of a triple polymer blend of neoprene, nitride, and natural rubber. Failure to use acid gloves is a concern, because many of the process gasses entering the pump system contain strong acids. Thus the chemical waste by-products such as residues also are likely to have very low pH levels. In addition, many contaminated parts are cleaned in a solution that contains 49% hydrofluoric acid. It was observed that one gallon bottles of 49% hydrofluoric acid were poured into the sink using latex gloves rather than using the required acid gloves. Chemical breakthrough of the latex gloves may not have been observed due to the short task duration, ranging from 1- 1.5 hours. This period of time may not be long enough for breakthrough to be detected. Another possible reason why chemical breakthrough was not detected was that the VPM technicians frequently change their gloves in between each task. If the latex gloves were worn for longer than the duration tested in this study, detectable break through levels may have been observed.

Bulk Samples

Although no significant airborne chemical exposures were detected, the VPM technicians were in close contact with many residues which caused significant blockages in the exhaust lines and heat exchangers. Bulk samples were collected from each task, and were submitted for analysis to characterize the pH level. A description of each sample, of the location within the specific pump system, and of the task during which residues were encountered are indicated in table 5. The samples with low pH are corrosive in nature and are known to cause irritation if dermal exposures occur. The fact that residues are corrosive also raises a serious concern as to how they are handled by the VPM technicians. During observations of each task, there were several events where excess residues caused contamination of the floor and surrounding work surfaces:

- During the heat exchanger clean associated with the tungsten deposition tool, liquid residue escaped from the unit while it was being dismantled from the pump. The spilled residue was wiped up using an absorbent pad. Once the residue was removed, the VPM technician resumed working on his hands and knees in the area.
- During the heat exchanger clean/ exhaust line inspection associated with the metal etch tool, a solid brown residue lined the surfaces of the exhaust line, check valve, and heat exchanger. When these items were taken to the sink, they were removed from their bags outside of the ventilated hood. This activity generated a sharp pungent odor in the surrounding area.
- During the foreline and exhaust line inspection associated with the nitride deposition tool, fine white powder escaped from the foreline bellow and was suspended in the surrounding air. Residues from contaminated surfaces were removed using a dry vacuum.
- During the exhaust line clean associated with the oxide deposition tool, two types of residues were located in different heat exchangers. The first residue was a fine white powder that was cleaned out using a dry vacuum. Once again, fine white powder escaped

Table 5

Summary of Bulk Samples Collected During Vacuum Pump Maintenance Tasks

Process Associated with Vacuum Pump	**Location Where Sample was Collected**	**Description of Sample**	**pH of Sample**	**Chemicals in the Process**
Tungsten Deposition	Residue from interior of heat exchanger	Green-yellow particulate suspended in clear liquid	1	Tungsten, Silane, Freon 116, Argon, Oxygen.
Metal Etch	Residue coating the interior of the heat exchanger and check valve	Brown solid particulate matter, gravel-like in appearance	1	Chlorine, Boron trichloride, Nitrogen, Oxygen, Freon 14 and 23.
Nitride Deposition	Residue from the foreline bellows	Fine, chalky white particulate	6-7	Nitrogen trifluoride, Ammonia, Silane, Freon 14, Nitrous oxide,Ethylene glycol, Oxygen, Nitrogen.
Oxide Deposition	Residue from the interior of heat exchanger #1	Fine, chalky white particulate	6-7	Tetraethylorthosilicate, Phosphine, Silane, Nitrous oxide,0xygen, Nitrogen, Trimethyl phosphite, Trimethly borate
Oxide Deposition	Residue from the interior of heat exchanger #3	Black-green viscous matter, tar-like appearance	1	Tetraethylorthosilicate, Phosphine, Silane, Nitrous oxide,0xygen, Nitrogen, Trimethyl phosphite, Trimethly borate

into the surrounding area and onto the floor. The second residue was a thick black tar that contaminated a small portion of the surrounding floor space.

Noise Samples

The ACGIH has set 85 dBA as a TLV and 80 dBA as the action level for an 8 hour TWA. All noise samples were compared to the 80 dBA action level because this level was used at the study facility to determine if employees need to be included in a hearing conservation program. Noise monitoring results indicated that 43% of the VPM group were exposed to noise levels above the action limit of 80 dBA (see table 6). The samples were representative of the noise levels that were experienced during a full 12 hour work shift. The duration of the noise sampling ranged from 5.5 to 8.5 hours. In all seven sampling events, none of the peak noise levels exceeded the ACGIH TLV ceiling level of 115 dBA. The peak noise levels experienced during the 12 hour shifts ranged from 102-109 dBA. The average noise exposure was calculated at 78 dBA. Since the majority of noise exposures were in the range of 80 dBA, these data indicate that the VPM technicians should be included in the hearing conservation program.

Table 6

Summary of Noise Sample Results Collected During Vacuum Pump Maintenance Tasks

Noise Sample	Time (hours)	Peak dBA	Average at 80 dBA Cutoff
1	8.5	107	80
2	6.5	106	82
3	7.0	109	88
4	8.0	102	76
5	7.0	102	74
6	5.5	105	77
7	6.0	103	70

WORK PRACTICES AND FIELD OBSERVATIONS

The VPM technicians were conscientious in isolating the work area and placing warning signs to prevent other workers from entering an unsafe area. Observations of VPM tasks during this qualitative assessment however, revealed that certain work practices need improvement in order to protect the VPM technicians from occupational exposures. Training for VPM tasks involves a "hands on approach". Due to the "non-routine" nature of their work, there is limited documentation on the proper procedure to complete a specific task, the hazards involved, and the PPE required. Although all employees within this facility receive basic hazard communication, it is not thorough enough to describe the unique and complex chemical hazards experienced by maintenance populations such as the VPM technicians. The shortcomings in VPM training presents a significant problem to this group. Upon completion of the task assessments, the following observations were made:

- In preparation for maintenance, the pumps are supposed to be purged with nitrogen for a minimum of 1 hour to clear the system of process gases. In several instances, the pumps were not purged for this duration of time thus increasing the likelihood of off-gassing higher concentrations of chemical gases.
- While completing VPM tasks, hand tools were repeatedly used with contaminated gloves. The tools were then placed back in the tool box to be used at a later time. Currently, there is no protocol for decontaminating the tools after use or on a weekly basis. The contaminated tools provide a risk for dermal exposures.
- During many of the VPM activities, residues from contaminated heat exchangers, forelines and exhaust lines were spilled onto the floor and surrounding surfaces during the dismantling

process. The chemical spills were cleaned with absorbent pads which is not a sufficient method to decontaminate the area. Once the area was wiped, the technicians resumed work in the area. Chemical spills present a significant problem because workers are on their hands and knees during the maintenance tasks. Some tasks require workers to lie on the floor to reach under the pump. Because the technicians do not wear protective suits, there is a risk of dermal exposures to corrosive chemical residues.

- The technicians work in an extremely crowded environment, making it difficult to complete required tasks. There are a multitude of ergonomic problems that result from the placement of vacuum pumps in close proximity to one another. In addition, the support structures that house the pumps often block crucial components of the pump thus making it difficult to use the necessary tools required for maintenance (figure 5).

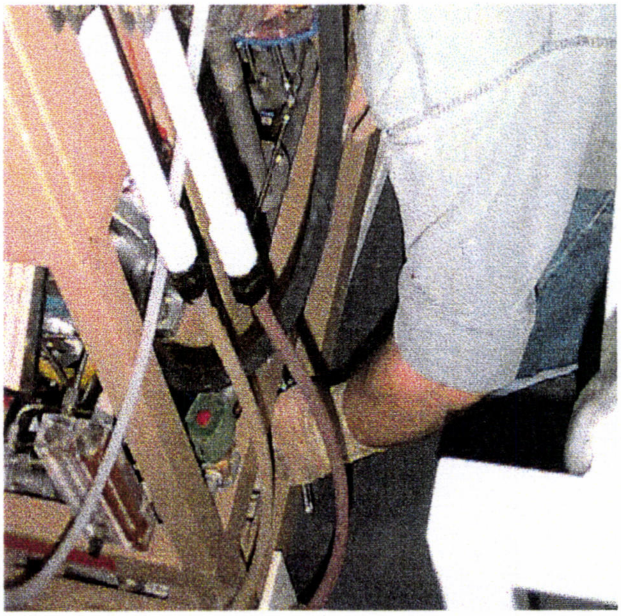

FIGURE 5: Ergonomic Problems Associated with Dismantling Vacuum Pump Components

In general, the VPM technicians follow the written PPE standards for general entry into the subfab which includes: chemical spill jackets, shoe covers, hard hat with face shield, safety glasses and ear plugs. While engaged in vacuum pump maintenance within the individual pump rooms of the subfab, the VPM technicians wore the required PPE which included a full-face airline respirator, latex gloves, and ear plugs. Although the VPM technicians were conscientious about wearing the required PPE, it was in the manner that it was used which signified a safety concern. Currently, there are limited written guidelines that clearly describe the best safety practices for each task performed by the VPM Technicians. Instead, safety practices have been developed verbally and are delivered to new employees through examples and word of mouth. As a result, there is variation in practicing safe methods during maintenance activities. The following observations were made on the usage of PPE:

Respiratory Protection

The use of full-face supplied air respirators provide a barrier to communication during maintenance tasks. This barrier presents a significant problem because communication among technicians is crucial to completing the task. The inability to communicate was a substantial problem during tasks that involve trouble-shooting and problem-solving to isolate the problem. Consequently, the technicians have adopted the practice of lifting up their face masks to talk to one another in the middle of a task. In one case, the face mask was removed completely during a task because it was hindering the work of a technician. Frequently, the masks were removed in the contaminated pump room before exiting for a break or to collect spare parts and tools. Because individual pump rooms have their own exhaust systems and monitoring devices for specific hazardous chemicals, the technicians appear to rely heavily on these devices to protect them from hazardous gases. However, there is a high probability for concentrations of gases to be located near the serviced pump from off gassing of waste vapors, from volatile residue constituents located in drip pans, and from contaminated surfaces. There also is a high potential to contaminate the inside of the respirator because it is removed with contaminated gloves that often come in contact with the internal surface of the respirator.

Hearing Protection

The use of hearing protection is required by the VPM technicians however, the use of ear plugs appears to be loosely followed. In several observations, the technicians completed maintenance tasks without hearing protection. Similar to respirators, ear plugs provide a barrier to communication during maintenance activities making it hard to complete the job. It appears that the short duration of activities provides a false safety factor for worker noise exposure because they view there exposure as being minimal. Consequently, the technicians often will carry out a task without hearing protection because the task may not take very long to complete. Noise levels in the pump rooms range from 85-95 dBA. Because the VPM technicians frequently visit these rooms, they are being exposed to multiple short-term exposures within a given shift. It has been noted that some workers often do not wear hearing protection when using the bead blaster which is used to remove stubborn residues from tool parts before cleaning. Under usage of ear protection is a concern because the bead blaster is known to have a loud impact noise when it is initiated. One possible reason why workers have not been wearing ear plugs during this task is because they are not readily available in that specific area.

Hand and Arm Protection

Latex gloves are used for all VPM activities because they provide the technicians with the greatest degree of manual dexterity. However, many of the residues are strong acids and may be able to penetrate the latex gloves. Although no dermal exposures were observed using indicator pads, there were many observations that indicated a great potential for dermal exposure. In only one task did a VPM technician used chemical resistant sleeves to prevent dermal exposure of the forearms. In all other cases, the technicians wore short sleeve t-shirts that expose their bare arms. If a chemical spill occurred, which is a frequent occurrence when servicing the pumps, there would be a high risk for dermal exposures from direct contact with contaminated surfaces.

CONCLUSIONS

A comprehensive risk assessment to evaluate occupational hazards involves identifying high risk groups, identifying all possible potential hazards and attempting to measure the identified hazards using industrial hygiene exposure monitoring techniques. In a risk assessment, both the qualitative component (hazard identification), and the quantitative component (exposure monitoring), are equally important in isolating and controlling for occupational hazards. For this reason, the field observations, the data obtained from exposure monitoring, and the bulk sample results played an equal role in the characterization of exposures for the VPM tasks. The information obtained in the risk assessment is then used to determine methods to reduce the potential for occupational exposure. Thus, although all integrated personal and area samples as well as direct reading samples were below ACGIH TLVs, the potential for exposure still exists and must be minimized.

This study examined tasks, associated with nine vacuum pumps which were representative of the groups of hazardous process tools used at this facility. However, the VPM technicians are responsible for servicing over 300 vacuum pump systems and conduct similar maintenance tasks frequently, thereby increasing the probability of becoming exposed to chemical hazards. In particular, the likely hood of occupational exposures increases during unscheduled maintenance tasks such as pump failures. In these cases, the pump and/or associated lines may become clogged with excess chemical residues causing the pump to seize. All tasks sampled in this study were scheduled maintenance tasks and chemical buidlups within the vacuum pump systems were not at critical levels. Thus, although no significant levels were detected in this study, it is imperative that the proper PPE and work practices be followed to reduce the potential for exposures.

Results from the bulk sample analysis reveal that several of the residues were found to be corrosive in nature indicating the potential for acute irritations if adequate dermal and inhalation protection is not used. Currently, the VPM technicians are using exam weight latex gloves (define this) which do not provide adequate protection against corrosive substances. Although no chemical breakthroughs were detected in this study, the use of latex gloves is not the most effective type of PPE that should be used during the VPM tasks. Alternatives for PPE will be discussed in the recommendations section.

Results from the noise samples revealed that it is likely for the VPM technicians to exceed the 80 dBA action limit during the course of their work shift. Therefore, the all individuals within the VPM group should be placed on the hearing conservation program. The use of hearing protection should be practiced more consistently to reduce the risk of hearing loss over time. Recommendations to improve the current use of hearing protection will also be discussed in the recommendations section.

Overall, the VPM environment is relatively unpredictable due to the frequency with process recipes adjustments and changes. This fact emphasis the need for more frequent exposure monitoring to characterize the hazards. Monitoring for maintenance activities are a substantial problem for Environmental Health and Safety (EHS) Professionals because often the worst case scenarios are ones that occur sporadically; thus there is little to no opportunity to prepare for exposure monitoring. As a result, many of the suspected worst-case exposures go unrecorded. To accurately characterize the occupational chemical, dermal, and inhalation exposures a more comprehensive assessment should be conducted over a longer period of time. A more extensive investigation would allow for some of the more critical maintenance activities to be monitored that occur over longer duration of time.

The benefit of this study was that many occupational hazards of the job were identified through field observations. Field observations provide a valuable tool for assessing hazards and making recommendations without the need to conduct exposure monitoring. This study outlines the importance of characterizing hazards through qualitative assessments such as field observations. In general, there is a higher potential for occupational exposures during maintenance tasks than in normal operating conditions, thus special attention should be given to minimize the potential for unexpected releases of toxic materials. The use of engineering controls to reduce or eliminate chemical and physical hazards, comprehensive training, and good work practices are critical to the protection of employees conducting maintenance tasks on vacuum pump systems.

There were several limitations in this study which made conducting a comprehensive hazard assessment challenging. One limitation to the sampling strategy was the relatively low number of sampling events that were monitored. It is important to remember that these exposure monitoring data provide only a "snapshot" of actual exposures. Repetitive sampling of these tasks over a longer duration of time would result in more statistically significant occupational exposure data. Another limitation in characterizing occupational exposures of VPM tasks was inherent in the day to day variation of their jobs. Unlike process operators whose work day is more predictable, maintenance workers are responsible for a diversity of tasks. Therefore, on a weekly basis, they are likely to experience a wider variety of hazards. It is difficult to conduct "representative sampling" for such a population because the tasks, tools, and processes vary substantially in vacuum pump maintenance. Another limitation in the sampling strategy was the short duration of tasks which made it difficult, at times, to obtain the minimal volumes required for the NIOSH sampling protocol. In addition, the short time frame of this study made it difficult to observe some of the less frequent tasks which consequently may have a higher potential for exposures in some cases. As a result, tasks that were sampled did not necessarily represent the worst case scenario. Finally, there is a possibility that the VPM engaged in more appropriate safety behaviors than normally because they were being observed. As a result, it is possible that some of the poorer safety practices which may occur on a more regular basis were missed.

A logical extension of this study would be to use a the job hazard assessment strategy developed in this study to characterize the occupational exposures to other maintenance groups in the semiconductor industry. In order to develop industry wide best safety practices, it would be helpful to gain data from other facilities that identifies the problems associated with vacuum pump maintenance. In summary, an effective job hazard assessment that utilized both a solid qualitative and quantitative assessment can be used to systematically characterize the hazards associated with a variety of tasks in any industrial setting. It is important to identify all high risk groups in an industrial setting and conduct a thorough hazard assessment to assure that the employees are working under safe conditions.

RECOMMENDATIONS

Personal Protective Equipment (PPE)

Respiratory Protection

Air line respirators with battery powered speaking diaphragms should replace the respirators that are currently in use. Because of the communication problems experienced while using the full-face supplied air respirators, the VPM technicians have adopted the practice of lifting their masks up in the middle of a task to consult with each other. Implementation of the new respirators should help solve this problem.

Gloves and Arm Protection

Long cuff acid gloves with a triple polymer blend of natural rubber, neoprene, and nitrile should be used instead of latex gloves. Acid gloves will be more effective in hand and forearm protection against potential dermal exposure while working with chemical wastes. After reviewing the chemical recipes of the tools associated with the pump systems serviced in this study, it was determined that many strong acids and bases were used. Latex gloves do not provide adequate protection against the chemicals encountered by the VPM technicians. A common complaint with acid gloves was that they did not provide optimal manual dexterity which is needed during maintenance tasks. To overcome this problem, a field trial study should be conducted using a number of different sizes and manufacture types in order to find the best gloves for the job. If long cuff gloves are not preferred, chemical sleeves should be worn in addition to acid gloves when performing the tasks.

Hearing protection

Hearing protection requirements must be clarified and enforced more strictly. The monitoring data for noise levels revealed that the VPM technicians should be included in the hearing conservation program. Although hearing protection was used, it was observed that they were often removed at some point during the tasks. In some cases, workers did not wear any hearing protection during the tasks. In one case, a worker revealed that the reason for not wearing ear plugs was because they were not located close to his work area. More stations that supply hearing protection need to be installed to increase the availability so that they will be used more widely.

Protective Clothing

Currently, the VPM technicians wear personal clothing such as t-shirts and jeans to work. Because the majority of tasks require the technicians to work on their hands and knees, and in some cases, while lying on the ground, there is a risk of contaminating their clothes. Personal clothing does not provide adequate dermal protection. Further, contaminated clothing should not be worn at home as it increases the risk of transferring contaminants to family members. The use of chemical resistant jackets are not practical because many of the pump rooms have elevated temperatures which increase the risk of heat stress. Disposable coveralls could be used in association with a work rest cycle to prevent heat stress. Alternatively, a disposable tarp could be placed on the surrounding floor space to protect the worker from surface contamination.

Work Practices

Chemical Spills

Proper decontamination procedures need to be followed when chemical spills occur. Wiping the surface with absorbent wipes is an insufficient method as it does not decontaminate the area. The VPM technicians should undergo training to become certified in spill containment and the group should be required to take a spill kit with them to all VPM tasks. The spill kits should contain litmus paper for determining the pH of the spill as well as acidic and basic solutions which could be used to neutralize the spill before cleaning the surface with an absorbent pad. However, the spill kits should only be used to decontaminated small chemical spills. If the spill is large, the VPM technicians should still activate the facility emergency response team.

Cleaning Decontaminated Parts and Surfaces

When preparing contaminated parts for cleaning in the acid bath, the VPM technicians should dismantle the parts within the ventilated sink rather than on the tool cart. During the process of cleaning parts, the VPM should wear acid gloves, chemical protective barrier clothing, face shields, and safety glasses. In many cases, chemical pours were observed without the use of these PPE requirements thus placing the technicians at high risk for exposure. When cleaning contaminated surfaces, a wet process could be used by spraying the fine particulate residues to reduce airborne concentrations. This process should not be implemented until the bulk samples are analyzed because introducing water may cause unfavorable results.

Hand Tool Decontamination

During each task, the technicians gloves became contaminated with chemical waste while using hand tools. After each task, the tools were placed back into the tool kit for use at a later date. It is possible that contaminated tools are handled without gloves during other types of tasks than those described in the study. It is not practical to decontaminate the tools after each task however, a weekly cleaning schedule could be enforced to reduce the levels of contamination and possible dermal exposures.

Unscheduled Maintenance

The VPM groups should strive to prevent unscheduled maintenance events such as pump failures because these produce the greatest risk for exposures. Certain vacuum pumps are more problematic than others therefore, they should be placed on a more stringent PM schedule to avoid crisis situations. Not only will a well defined PM schedule reduce the amount of critical pump failures and increased risk of exposure levels, it will also reduce process tool downtime which negatively effects manufacturing (25). For an effective PM program, it is recommended that all pumps be carefully monitored for performance characteristics such as base pressure, rate of pressure rise, fluid/oil level, and temperature (25,26). Perhaps the most effective monitoring strategy is the use of a central monitoring system which can be extended to include automation using a computer (27). This monitoring system gives early warnings of possible defects, and indicates what service work must be done. Thus maintenance work can be effected at a more suitable time, production is not affected, and the operation reliability of the pump system is increased (27).

Ergonomic Improvements

Proximity of Vacuum Pumps

The vacuum pumps currently are placed in close proximity to one another making it extremely difficult to perform maintenance activities. Consultation with the VPM technicians could help in the determination of a standard measurement for the length and width of a maintenance chase around the pump. Installations of new pumps should be required to be placed at a set distance from one another to improve the efficiency of maintenance work. Currently, tasks are taking substantially longer than needed because of the difficult set up. Consequently, manufacturing suffers because maintenance tasks take longer to complete thus slowing production. This recommendation will be a challenge because space is a commodity within this type of industry due to the constant addition of new process tools.

Vacuum Pump Support Frames

As previously described, the support frames that house the pumps often block crucial components of the pump thus making it difficult to use the necessary tools required for maintenance (see figure 5). To improve this situation, the VPM technicians should be consulted on the design of these support structures in order to assure that important areas of the pump are readily assessable.

Ergonomic Hand Tools

The VPM technicians spend the majority of their time working with various tools. Many of the hand tools are not efficient for the hard to reach positions encountered by the technicians. In order to reduce the use of non-neutral postures during the tasks, some of the critical tools could be replaced with power tools such as powered screwdrivers and socket wrenches. A trial period for new tools should be implemented in order to find the best solution for reaching the complicated positions experienced when dismantling components of pump.

Engineering Controls

Abatement Systems

Abatement systems should be investigated for potential installation upstream from the pump systems to reduce the amount of waste build up in the vacuum pump system. An effective abatement system is positioned as close to the source as possible. For example, when chemical waste is conditioned directly at the process equipment, it is possible to greatly reduce and/or eliminate the accumulation of particulate and pump oil vapors in the exhaust ducting (28). There are a number of scrubbing systems that provide effective and versatile methods for reducing the toxic hazards of process tool effluents (28). For example, in one study, a plasma reactor system was installed upstream from a dry vacuum pump and served to prevent hazardous gas effluents form reaching the pump (29). As a result, the amount of particle by-products within the dry pump was dramatically reduced which subsequently caused a decreased in the amount of pump failures (29). Another effective alternative would be to install multiple-step trapping systems to trap nongaseous effluents which will help keep the vacuum system free from residues, thus reducing pump failures and clogged lines (30)

Choosing the Best Vacuum Pump System

The selection of a pump is of primary importance since it can affect the downtime of the production equipment and the level of maintenance required (31). Users of pump systems need to demand specific characteristics of the vacuum systems that will best suit the chemical make-up of waste flowing through the system. Criteria to consider when purchasing a vacuum pump system include: the ability to handle process gases and dissociated gases which can be corrosive to the pump internals, the ability to handle particulate matter, the ability to have a long lifetime in this environment, and the benefit of requiring minimum maintenance (31,32).

Documentation and Training

Currently, the VPM tasks are not well documented thus making it difficult to train new VPM technicians. Currently, a hands on approach is used to train new employees on all VPM tasks. This approach is problematic because poor safety practices are adopted by the new workers during the training process. In addition, the VPM group should have more detailed training classes in hazard communication. Currently, the technicians are required to take a basic hazard communication class that is offered to all new employees. This is not sufficient training for jobs that are more chemically intensive such as vacuum pump maintenance.

Exposure Monitoring

Maintenance activities should be monitored on a more frequent basis in order to capture occupational exposures. Although exposure monitoring of maintenance tasks is challenging, EHS professionals should conduct hazard assessments and identify those activities that place the maintenance workers at higher risk for occupational exposures. In addition, the characterization of occupational exposure to the VPM technicians should take place over a longer period of time in order to capture some of the worst case scenario activities.

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APPENDICES

Appendix A

QUALITATIVE ASSESSMENT: JOB HAZARD ANALYSIS

I. General Information

1. Date: 2. Time: 3. Shift: A B C D

4. Name of Technician:

5. Name of maintenance task: 6. Location of task:

7. Equipment/Tool (Mnfr, Model#,ID#):

8. Description of task:

____
____
____
____
____
____
____
____
____
____

9. Number of persons performing task:

10. Frequency of Activity: ______per day _____per week ____per month

11. Duration of Activity:

II. Potential Hazards:

[ ] 1.Chemical (obtain MSDS sheets if possible)

a) Hazardous chemicals involved in process(list):

b) Hazard chemicals involved in maintenance activities (solvents, etc.):

c) Estimated amount of hazardous chemicals

Potential routes of chemical exposure: Inhalation Ingestion Skin Contact

[ ] 2. Radiation:

a) Ionizing

b) Non-ionizing

[ ] 3. Noise (identify source):

[ ] 4. Ergonomic (describe):

[ ] 5. Electrical:

a) Voltage
b) Current
c) Stored energy (batteries, capacitors, etc.)

[ ] 6. Physical Hazards

a) Capable of crushing, pinching, cutting, snagging, striking.

b) Fall or slip hazard.

<u>III Safety Controls</u>

1. Engineering controls

2. Administrative controls

3. Personal Protective Equipment required for task:

4. Safety certifications for activity:

IV. Additional Information:

1. Employee comments/concerns:

2. General Observations (good housekeeping, work practices, etc.):

3. What potential occupational exposure sampling is needed for this task:

4. Has their been previous occupational exposure sampling for this task?

Appendix B

Quantitative Assessment Data Sheet

<u>General Information</u>:

Date: Time: Shift: A B C D Employee code
a) ______________________
b) ______________________

<u>Task Specific Information:</u>

Task: Task (Event)Code: Pump room: Pump location code:

Vacuum Pump/Tool name: Vacuum Pump type: Duration of Task:
Wet Start:
Dry Finish:

Temperature: Altitude: Rel. Humidity:

<u>Sample Data:</u>
A) Dermal Samples:
Acid/ Base Indicator Pads

Sample Number	1	2	3	4	5	6
Sample Type *						
Employee Code						
Location code *						
Start time						
Finish time						
Results						

*Location Code: 1= Right thumb 2= Right index/middle 3= Right palm
4= Left thumb 5= Left index/middle 6= Left palm

Solvent Indicator Pads

Sample Number	1	2	3	4	5	6
Sample Type						
Employee Code						
Location code *						
Start time						
Finish time						
Results						

** Location Code: 1= Right thumb 2= Right index/middle 3= Right palm
4= Left thumb 5= Left index/middle 6= Left palm

B)Direct Reading Samples

Indicate whether sample is direct reading or a wipe

Sample #	1	2	3	4	5	6	7	8
Sample Code								
Location *								
Instrument								
Media								
Chemical sampled								
Time								
Reading (units)								

* Location:
Diagram where direct reading samples were taken indicating sample points

Comments:

C)Integrated Air Monitoring Record

Sampling Pump Calibration

Pump Code	Pump make/serial #	Pre-sample flow rate	Avg flow rate	Post-sample flow rate	Avg flow rate	Overall average flow rate
		1) 2) 3)		1) 2) … 3)		
		1) 2) 3)		1) 2) 3)		
		1) 2) 3)		1) 2) 3)		
		1) 2) 3)		1) 2) 3)		
		1) 2) 3)		1) 2) 3)		

Employee Information

Sample Number	Sample Code	Employee Code	Shift
1			
2			
3			
4			
5			
6			
7			
8			

Data Collected

Sample Number	Sample Code	Pump Code	Sample Type (area/personal)	Chemical Sampled	Start Time	Stop Time	Total (min)	Total Volume Sampled (Avg rate x Time)
1								
2								
3								
4								
5								
6								
7								
8								

Comments:

D) Bulk Samples

Sample #	Sample Code	Time	From where was sample collected?	Sample Description (color,solid,liquid, etc)	Disposal route

Comments:

Field Notes and Diagram:
(include location of all area samples)

Analysis

Sample Number	Sample Code	Chemical Sampled	Analytical Lab Number	Result	Current Standard
1					
2					
3					
4					
5					
6					
7					
8					

Task Description Form

1)Personal Protective Equipment Used:

Protective Clothing:

Respirator:

Gloves:

Footwear:

Eye/Face Protection:

Ear Protection:

Condition of PPE:

Is any PPE being reused?

2)Engineering/Administrative controls:

3)Task Description:

Describe work procedure:

Work environment/conditions:

Recommendations/Additional Surveillance or Controls:

Work Schedule Description

Day Shift (A and B)

6:00-7:00 am	
7:00-8:00 am	
8:00-9:00 am	
9:00-10:00 am	
10:00-11:00am	
11:00 am- 12:00 pm	
12:00-1:00 pm	
1:00-2:00 pm	
2:00-3:00 pm	
3:00-4:00 pm	
4:00-5:00 pm	
5:00-6:00 pm	

Work Schedule Description

Night Shift (C and D)

6:00-7:00 pm	
7:00-8:00 pm	
8:00-9:00 pm	
9:00-10:00 pm	
10:00-11:00 pm	
11:00pm- 12:00 am	
12:00-1:00 am	
1:00-2:00 am	
2:00-3:00 am	
3:00-4:00 am	
4:00-5:00 am	
5:00-6:00 am	

Appendix C

NOISE MONITORING DATA SHEET

General Information:

Sample Date:
Shift: A B C D
Employee Code:
Currently on Hearing Conservation Program: Yes No
Correspondence with which task code (if applicable):

Monitoring Equipment Information:

Microphone location:
SLM/ Dosimeter:
Calibration: Pre: Post:

Results:

Start time:
Stop time:

Noise Dosimeter Categories	Reading 1	Reading 2	Reading 3	Reading 4
Time of recording				
Dose % @ 80 dBA				
Ave. @ 80 dBA				
Dose % @ 90 dBA				
Ave. @ 90 dBA				
Max sound				
Time of max. sound				
Projected 8 hr dose				
< 115 dB (time)				

Comments:

Appendix D

NOISE MONITOIRNG WORK SHEET

Description of Work Day Activities

The following work sheet is to be filled out as you work through your day. These data will be used to establish a work pattern in relationship with the reading obtained from the noise dosimeter. Please fill the form out as you rotate through the various tasks associated with your job. The accuracy of this form is critical to the noise sampling that is being completed.

Type of Task and Associated Equipment	Time Spend on Task
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	
11.	
12.	

Time of lunch break:

Time of all breaks (list):